IIASA Conference '76

VOLUME 1
10-13 MAY 1976

IIASA CONFERENCE '76

10 – 13 May, 1976

Volume 1

"...Convinced that science and technology, if wisely directed, can benefit all mankind,

Believing that international co-operation between national institutions promotes co-operation between nations and so the economic and social progress of peoples..."

Preamble to the Charter
of the International Institute
for Applied Systems Analysis

PREFACE

The IIASA Conference '76 was the first General Conference of the International Institute for Applied Systems Analysis. It provided a major forum for review of the creation, development, research, and future role of IIASA. Thus, these proceedings provide a comprehensive report on the first three years of the Institute.

The proceedings appear in two volumes. Volume 1 contains presentations, comments, and discussions on the concept of IIASA, its creation and research strategy, its studies of global issues (including energy, food, and global development), its work on regional issues, the relationship between analysis and policy-making, and the role of policy analysis in an international setting. The invited comments of the National Member Organizations on the development of the Institute and on the Conference also appear in Volume 1. A list of participants and the table of contents for Volume 2 are appended.

Volume 2 contains presentations, comments, and discussions of the research areas: Resources and Environment, Human Settlements and Services, Management and Technology, and System and Decision Sciences. The table of contents of Volume 1 is appended.

Each volume contains brief biographies of the authors of presentations in that volume.

Recognition is due to the Council of the Institute and the Austrian Government for their significant contribution to the development of the Institute; to the participants of the Conference for their support and guidance; and to the IIASA staff for the spirit and effort devoted to the Conference and the preparation of the proceedings.

Table of Contents

Dr. Bruno Kreisky
Welcoming Address 1

Message from the Council of Ministers of the USSR 5

Message from the US Secretary of State 7

INTRODUCTION TO THE INSTITUTE

J. Gvishiani
The Concept of IIASA 11

H. Raiffa
Creating an International Research Institute 19

R.E. Levien
Applying Systems Analysis in an International Setting 29

McGeorge Bundy
Dinner Address 49

GLOBAL PERSPECTIVES

R.E. Levien
Introduction 55

W. Häfele
Energy Systems: Global Options and Strategies 57

F. Rabar
Food and Agriculture: Global Aspects of Supply and Demand 93

Panel Discussion

GLOBAL ENERGY SYSTEMS

G.B. Dantzig 111
M. Styrikovich 112
Discussion (*W. Sassin, Rapporteur*) 114

GLOBAL RESOURCES

Z. Kaczmarek 114
H. Mottek 119
Discussion (*E.F. Wood, Rapporteur*) 122

Panel Discussion (cont'd.)

GLOBAL DEVELOPMENT

G. Bruckmann 123
E. Pestel 126

GENERAL DISCUSSION
(K. Parikh and W. Sassin, Rapporteurs) 128

P. Handler
Invited Comment 131

UNIVERSAL PERSPECTIVES

H. Raiffa
Introduction 137

C.S. Holling, D.D. Jones, and W.C. Clark
Ecological Policy Design: A Case Study of Forest and Pest Management 139

W.K. Foell
Management of Regional Energy/Environment Systems 159

H. Knop
Large-Scale Planning Projects: the Tennessee Valley Authority and the Bratsk-Ilimsk Complex 187

A. Aganbegyan
Future Research Directions 203

Discussion
(W.A. Buehring and A.B. Demb, Rapporteurs) 209

SYSTEMS ANALYSIS AND POLICY-MAKING

T.C. Koopmans
Analytical Aspects of Policy Studies 213

L. Kantorovich
Theoretical Aspects of Policy Studies 233

H. Koziolek
The Systems Approach to Solving National Economic Problems 237

J. Lesourne
Systems Analysis and International Organizations 255

CLOSING SESSION

Invited Comments of the
National Member Organizations

The Polish Academy of Sciences 267

The Max Planck Society for the Advancement of Sciences, Federal Republic of Germany 270

The Hungarian Committee for Applied Systems Analysis 271

The National Academy of Sciences, United States of America 272

The Academy of Sciences of the Union of Soviet Socialist Republics 274

The Austrian Academy of Sciences 277

The Academy of Sciences of the German Democratic Republic 279

The Japan Committee for the International Institute for Applied Systems Analysis 281

The National Centre for Cybernetics and Computer Techniques, People's Republic of Bulgaria 281

The Royal Society, United Kingdom 283

J. Gvishiani
Closing Remarks 285

APPENDIXES

Appendix 1: About the Authors 291

Appendix 2: Conference Participants 295

Appendix 3: Table of Contents of Volume 2 321

Welcoming Address†

Dr. Bruno Kreisky

Federal Chancellor of The Republic of Austria

Ladies and Gentlemen, I do not intend to explain to you here today, in my opening address, the significance of the International Institute for Applied Systems Analysis. To use a Viennese formula, that would be carrying water to the Danube: you know more than I about the importance and the tasks of your Institute. I am greatly interested in all these questions, but very much of a layman. So it seems to me more sensible to turn very briefly to questions that, so some believe, I know more about.

Your Institute is a magnificent institution also from a political point of view; and while I know of the tendency of science to expand frontiers, the fact that scientists of the highest standing have found here new ways of cooperation is by no means a matter of course. Though not everyone may have been fully aware of it, the political preconditions for this had to exist first; and as it was possible to create them, the founding of your Institute in October 1972 was a great event, and one of political significance.

Let us recall here Ambassador Walter Wodak, who contributed so much to the realization of this project, and thanks to whose efforts the Institute is located in Vienna and Laxenburg.

The time is long past, I think, when one felt safe if scientific activity was shrouded in secrecy, when one believed that a higher degree of safety could be achieved by greater secrecy. On the contrary, I believe that precisely because we can show how much scientific potential we have at our disposal, inconceivably perilous errors can be avoided.

It is my claim that in world politics the important thing is not ignorance of what the others know, of what they can do, and of what they have; the important thing is knowledge. Only thus can reality-oriented illusion-free politics be pursued, and only thus can we act with the full measure of responsibility that is needed for solving the great and complex problems of world politics.

---

†Translated from the German.

I remember very well the surprise throughout the world--including scientific circles in the West--when the first Sputnik was successfully launched. This finally stamped as myth the allegation that a great State depended for its scientific development on prisoner-of-war scientists. This erroneous assumption was of great political significance. The conviction of one's own outstanding technological abilities and the backwardness of the other side not infrequently led to false judgments by political commentators and in foreign ministries.

At the time of Sputnik, I was asked when making a speech--I believe it was at the Council on Foreign Relations in New York--how I explained all this, particularly the fact that the United States did not have this scientific achievement. At that time I thought I should answer the question, from my point of view, in a very trivial way: if there had been a market for Sputnik, the United States would have had it too. And thus I have also made the other point I want to make: that as a rule scientific developments take place most rapidly--as you yourselves know best--when a pronounced social or political need exists or can be created.

Your program includes a topic with the title "Systems Analysis and Policy Making". This shows that you are aware of correlations between those fields and think it worth stressing. Again and again the policy-making aspect appears in your papers, simply because this concept is indispensable.

I should like to say a few more words. I began by stating my view that a certain degree of maturity in the policy of détente had to be reached before this fascinating collaboration of so many scholars and so many eminent academies and institutes was possible. And I understand that one may ask: was there really a crisis in the policy of détente, or was Helsinki merely chimeric?

A few days ago, speaking before the delegates of the European Parliament in Strasbourg, I expressed my conviction--and tried to prove it--that the policy of détente has produced real results.

Ladies and Gentlemen, you have come together in a city that 25 years ago was a pile of rubble, in a country that in the eyes of many had no chance. Today, neutral Austria--on the border between the big blocs, right in the center of Europe--is a true zone of détente. This is the result of the State treaty concluded 20 years ago, the first decisive, real, and evident act of détente; and Austria is only one example. The policy of détente had other, less spectacular successes; but there were also setbacks, and some believed that these lasted too long.

It is our task not to remain idle, to pursue a genuine policy of détente on all sides--even if this policy is necessarily sometimes controversial.

And I should like to close with this plea: the power you have is greater than most of you probably believe. With what you know and what you can do, you can exercise great political influence. You must make use of this capability, in the interest of détente.

I don't like to use the word peace, realizing that in a polarized world, as I once remarked, coexistence constitutes that measure of peace that can be achieved at present; but détente, even if less than peace, is still better than war.

I adhere to the conviction that quantitative developments ultimately become qualitative. Institutions such as yours, and an ever increasing degree of cooperation, will change the international situation. In your work you certainly serve science, the economy, and perhaps also the striving for contacts at a high level. But believe me: above all you serve peace.

And this is why we are particularly pleased that you have raised your tents here among us.

Message from the Council of Ministers of the USSR†

The Council of Ministers of the USSR conveys its greetings to the participants of the first Conference of the International Institute for Applied Systems Analysis.

Over the short time span that has elapsed since the day of its foundation, the Institute has succeeded both in completing the initial stage of its establishment and in making a valuable contribution to the shaping of a rapidly developing discipline: the branch of science dealing with large-scale complex problems that have been put on our agenda by the scientific and technological revolution.

The organizational principles of the Institute, where a scientific staff from countries with different economic, political, and social systems jointly tackles the topical problems of our times, have proved valid. The establishment of the Institute was possible due to détente, and above all to changes for the better in relations on the European continent. The activities of the Institute in turn contribute increasingly to the development of a peaceful, mutually beneficial exchange and cooperation.

The participants of this first Conference will scrutinize the experience of the early years and outline research directions for the future. Global problems--such as those of raw materials and energy, the environment, eradication of the most serious and widely spread diseases--that the Institute deals with in one way or another are having and will continue to have their impact on the life of every nation and on the whole system of international relations.

The Council of Ministers of the USSR wishes the Institute success in its fruitful work to further the international cooperation of scientists for peace and progress.

---

†Translated from the Russian; transmitted by Academician Yu. A. Ovchinnikov.

Message from the US Secretary of State[†]

On the occasion of your meeting and in honor of the third anniversary of IIASA, I wish to convey my greetings to the Council.

We have noted with pride that IIASA has made great strides in fulfilling its promise as a unique international organization, where cooperation between our nations is expressed by our scientists actually working together toward solution of critical problems facing mankind. The collaborative international spirit which characterizes IIASA's efforts is heartening and essential. The considerable scientific achievement of the first few years is impressive.

While IIASA has progressed even more rapidly than we would have hoped, so, too, have major global problems become more evident. In congratulating your achievement, may I also encourage you to work even more intensely on the programs before you. Whether it be in energy systems or water resources, food considerations or regional development, IIASA's scientific effort is important not only for our own communities but for the entire world.

I wish you continued success.

(signed) Henry A. Kissinger

[†]Conveyed to the IIASA Council in November 1975 on the occasion of the third anniversary of the Institute.

INTRODUCTION TO THE INSTITUTE

The Concept of IIASA

J. Gvishiani

Slightly more than three years have elapsed since the day in London when representatives of 12 countries signed the document authorizing the establishment of the International Institute for Applied Systems Analysis. All of us, representatives of different continents and socio-economic systems, were brought to this act by a common desire to use the potentials of international scientific cooperation to explore new types of problems faced by humanity, in the era of scientific and technological revolution and rapid social changes.

Having assembled today for the first Conference, in conformity with the Charter of the Institute, we can say with confidence that the noble initiative of the founding members has been fruitful. It has brought together the efforts, experience, and knowledge of numerous scientists and created a genuinely international scientific community. Our hopes are being justified, our opportunities are increasing, our first accomplishments give grounds for believing in future successes.

Having the honor of welcoming today so many distinguished scientists, experts, and representatives of political and business circles, I recall the time when there was nothing but goodwill and a vague idea of what could and should be done. It took time and effort for that idea to mature and become shaped into a preliminary concept of the Institute. I think we have been particularly lucky in that those who were involved in the creation of the Institute from the very inception of this idea were people who strongly believed in the necessity for international cooperation of scientists.

Among those who have made great personal contributions to developing the conception of the Institute, who have been dedicated to it, advocated it, and helped to establish it, we must mention Dr. McGeorge Bundy, Professor Handler, Lord Zuckerman, Dr. Aurelio Peccei, Professor Raiffa, Academician Koziolek, Academician Smolensky, Professor Levy, Dr. Vaško, the late Professor Letov, and other prominent people shared in the formation and development of the Institute.

It has also been significant that the concept of IIASA in considerable part was elaborated on the hospitable soil of Austria. Well before its formal creation, the founders of the Institute were in contact with the Austrian authorities and enjoyed their support and assistance through all the stages of its evolution. A number of preparatory meetings took place in Austria, and it was here in Vienna that the image of the future Institute took more definite shape and the principal clauses of the Charter were worked out and drafted.

His Excellency Dr. Kirchschläger, His Excellency Dr. Kreisky, Minister Dr. Firnberg, and other prominent Austrian statesmen--among whom I must mention the late Secretary-General, Dr. Wodak--not only welcomed the idea of creating the Institute, but generously proposed to set up its headquarters in this friendly country. And now the historical Palace of Laxenburg provides IIASA with perfect conditions for creative work. The Institute's truly friendly and constructive relations with the Ministry of Foreign Affairs, the Ministry of Science, the Austrian Academy of Sciences, the City of Vienna, the Province of Lower Austria, and other Austrian organizations assure the solution of any problem that arises.

Using this opportunity, I would like to express our gratitude to the Government of Austria for taking heed of the Institute's needs. Our indebtedness is expressed not only by the Institute itself, but also by the members of the Institute and by the countries that recognize Austria's contribution to this important joint venture.

Speaking of the formation of IIASA, and particularly the practical implementation of this concept, we must especially stress the role of our first Director, Professor Howard Raiffa, who has made an outstanding contribution to the creation and development of the Institute and the advancement of its objectives. I think he himself expressed very clearly what was and is his standpoint. In his farewell address at the Council meeting in November 1975, he stated: "If IIASA had not been created in 1972, I think we would all be strong advocates of its creation today."

The fundamental principles on which the Institute is built are stated in the preamble of the IIASA Charter. It declares that the establishing of the Institute stems from the common realization by the founding members that:

> ...the spread and intensification of industry through the continued application of science and technology generates problems of an increasingly complex nature in modern societies...

and that

> present methods of investigation and analysis should be substantially improved to make them more adequate to predict, evaluate and manage the social and other repercussions of scientific and technological development....

The Charter stipulates further that:

> ...this aim can best be achieved through international cooperation in the development and application of methods of investigation and analysis which shall make use of computer technology, systems analysis methodology and modern management principles...
>
> ...science and technology, if wisely directed, can benefit all mankind,...[and] international cooperation between national institutions promotes cooperation between nations and thus the economic and social progress of peoples....

There is probably no better way of expressing in a few sentences the principal tenets of the Institute that were present in the minds of the founders when the Charter was signed.

Today they are not just concepts in our minds. Though on a modest scale, they have been tested and verified by IIASA experience. And we are much more confident now that in our complicated world, with our increasing interdependence, scientists representing different disciplines, cultures, and ideologies, by working together, can better identify and analyze the nature of complex problems humanity is facing today and will face in the future.

The objective necessity for organizations like IIASA is ultimately defined by certain prerequisites that reflect specific development trends of the modern world. Because of the rapidly growing social role of science and its influence on all spheres of social life, scientific and technological development is accompanied by profound changes in science, technology, and production. The fast growth in the rate of social development, the ever increasing impact of man on his natural habitat, the positive and negative consequences of scientific and technological progress--these are facts that are becoming more and more evident. The scale of production and its unprecedented role in the life of society, its potentials for the welfare of people as well as the contradictions it generates, give rise to wholly new problems that create justified concern all over the world about the further development of human society.

The essence of scientific and technological revolution cannot be explained only by a number of scientific discoveries, no matter how great they are. Its nature is a qualitative transformation of the whole technological basis of production: from utilization of raw materials, energy resources, the systems of machines, forms of organization and management, to the role of man in the production process. Scientific and technological revolution creates the prerequisites for unification into one system of such main forms of human activities as:

Science - theoretical cognition of the laws governing nature and society;

Technology - the complex of material means and experience for transformation of nature;

Production - the process of creation of material wealth;

Management - means of rational integration of expedient practical actions in achieving production and other goals.

The need for scientific management of development not only at the enterprise level, but also on a national and global scale, is becoming ever more evident under the impact of the problems that accompany scientific and technological progress. Tasks such as prevention of pollution of the biosphere and rational utilization of natural resources can be solved only by reasonable organization and management of all economic activities and by appropriate forecasting of the direct and indirect implications of the decisions made.

In the course of development of science, specialization and cooperation in scientific research acquire ever greater significance as indispensable conditions for its further progress. Progressive scientists everywhere are well aware that science and technology can develop efficiently only in the context of broad cooperation, with an exchange of information and experience, and with direct contacts among scientists and specialists.

Science has always been international, and any new discovery was inevitably based on results obtained by predecessors, no matter what part of the world they came from. The scale and complexity of modern research, the urgency of certain problems that need to be solved for the benefit of humanity, more than ever call for international cooperation. Unfortunately, there are still people who oppose this. I think that those who advocate limitation of cooperation do not understand the essence and distinguishing features of modern science.

During the last half-century, in which research has achieved an unprecedented scale and acquired a great variety of forms, cooperation in science has acquired special significance. It allows the advantages of an international division of labor to be used for the benefit of each country. On the other hand, it is important to stress another, broader aspect of these international links.

Numerous scientific problems nowadays are of global nature, and their solution is relevant to all nations. For research on such problems, requiring a lot of material and human resources, international scientific cooperation is not only the most suitable approach, but also an effective means of expanding the scientific potential of each cooperating country and an important condition for finding solutions. Scientific and technological cooperation serves two main purposes: through the international division of labor, it enables each country to apply world achievements of universal value for its own needs; and it unites the efforts of scientists from different countries for solving common global issues.

Many modern problems are characterized by the fact that their solution can be found only within the context of our entire planet's development. We are aware that many regions of the world suffer from poverty, starvation, economic backwardness, and social injustice. Truly scientific analysis of problems of the development of human society and the future of our planet cannot be achieved if these and other important issues are not taken into account.

Recognizing the need for solving problems is not sufficient; a necessary condition is the growing relaxation of international tension.

Peaceful coexistence and cooperation, or détente, if you like, is becoming a constant factor shaping the relations between different socio-economic systems. It creates favorable conditions for growing cooperation in science and technology, which is becoming a vital component of international relations. Conversely, détente is strengthened and enhanced by intensified economic, scientific, technological, and cultural cooperation of states with different social systems.

Thus, we have a case of dialectic interdependence. Cooperation does not only reflect the materialization of détente, but also, in its turn, promotes improvement of the world political climate.

In the Final Act of the Conference on Security and Cooperation in Europe, the member countries expressed their confidence that scientific and technological cooperation makes an important contribution to the strengthening of ties among them, and thereby promotes the effective solution of problems of common concern and an improvement in the conditions of human life.

Undoubtedly, there still are some who oppose détente, who would risk dragging humanity into a confrontation perhaps involving nuclear war. If we have learned to realize the danger of ecological catastrophe and admit the urgency of concrete steps in environmental protection, we should be still more realistic about the danger of war, and work towards making détente an irreversible process.

What is the place of IIASA among all these important factors and interrelationships?

The creation of IIASA signifies the birth of a new and more advanced form of international cooperation. It became possible owing to major changes in the world, the broadening scope of bilateral and multilateral cooperation among countries, the improvement in political climate. The very existence of IIASA vividly illustrates that it is possible to create an international institution where scientists from East and West investigate problems of extreme importance to humanity.

Considerable intellectual and material resources are required to deal with problems that are new in both nature and scale: raw materials and energy, food and agriculture, environmental management, urban systems, biomedical problems, integrated regional development, long-term forecasting and planning, and others. Scientific and technological progress provides a basis for improving existing methods and developing new ones to cope with these problems. This basis, to a large extent, consists in advances of analytical techniques--operations research, mathematical programming, computer applications, and systems analysis methodologies--generally defined as systems analysis, the systems approach, or systems methodology. Systems analysis is not only a quantitative but also a qualitative means for ensuring better identification, structuring and solving of problems with available resources. It can be regarded as the most suitable tool for this purpose, bringing together knowledge and experience from different fields of science and thus resolving complex universal and global problems.

The creation of IIASA has met the great aspiration of its founders to see world development as a goal-oriented, harmonious, and structured but innovative process that takes into account the world's potentials as well as its limits and constraints. These are still far from being fully understood, farther still from being managed. So it is our task to learn more about the potentials and limitations and all the numerous and complex interrelationships and interdependencies of its parts. This can be done only by pooling all the available intellectual, scientific and analytical resources, which call for a well-structured and creative mechanism of international cooperation.

IIASA should be looked upon as an essential part of this mechanism. Its international character permits the accumulation of scientific achievements of many countries for conducting multilateral comparison and assessment of results, and for systematizing the available knowledge, a basis for national methodological and applied research. Leading experts in various fields have been invited to the Institute to work together on problems of mutual interest on a long-term basis. All the scientists have equal working conditions; they come to work in "their own" Institute. Their joint activity in the historical walls of the ancient Schloss will result, no doubt, in a unified multilateral approach to the analysis of major world problems.

Speaking of the importance of the research conducted at IIASA, it must be noted that this work cannot be done successfully unless other organizations give it their active support. IIASA's small staff is not capable of dealing independently with such a wide range of objectives. A necessary condition for the Institute's effectiveness is cooperation with other organizations in all the various forms such cooperation can take. If the research of the Institute teams is supported by that of national teams, this will have a multiplying effect rather than one of simple summation. The final aim of building up cooperative links is to establish a network in institutions jointly working on problems of systems analysis. As we will see from the presentations of the next three days, an impressive network exists, and this is very encouraging.

One of IIASA's major objectives is defining urgent world problems that can be solved with the help of various scientific disciplines. The Institute, in its methodological research, must not overlook the practical applicability of its findings in real life.

These concerns are receiving great attention by the Institute sponsors and staff, by its founders and supporters. We are trying to make research more relevant to the practical needs of society, and to disseminate and apply useful results of research more rapidly, making them understandable for public and decision-making bodies. It is within this context that we attribute special importance to this Conference.

The founding of the Institute gave rise to the creation of committees and other bodies on systems analysis applications in a number of countries with the purpose of ensuring increasing use of systems techniques for solving national problems. We are very glad that this is happening, since it answers the other aspiration of the Institute's founders: to have the Institute play a catalytic role in promoting relevant national studies. Establishing an international institute was a timely action that reflected the striving of many countries to join their efforts in solving urgent development problems. The fact that a number of topics in IIASA's research program coincide with those singled out in the Final Act of the Conference on Cooperation and Security in Europe as areas of cooperation in the fields of science, technology and the environment attests to the timeliness of IIASA's work.

The first results of the Institute's basic and applied studies contribute to accumulating experience in solving complex economic, scientific, and technological problems of a universal and global nature. The Institute is trying to play its role in elaborating valid methods for tackling these problems. The fact is that the systems approach, general systems theory, and systems analysis have not yet become generally accepted scientific disciplines; and the knowledge gathered needs to be better systematized and defined. Cooperation in developing the methods and techniques of systems analysis will to a great extent prevent duplication of efforts of various countries.

Certain accomplishments of the Institute over the first three years of its existence offer the hope that it will justify it reputation as an institution capable of applying comprehensive means of analysis to the study of major problems of world development.

One more important aspect needs to be stressed. Here at IIASA we actually have an instrument of permanent cooperation by the Academies of Sciences and similar institutions of 14 countries. The number of members of this international network will gradually grow for this reason, and because the Institute can undertake a wide range of studies requiring concentration of efforts, a multinational view, and broad expertise, IIASA might play an active role in furthering and deepening cooperation among our Academies.

And finally I would like to say that the main accomplishment of the past three years is not only scientific advance--the greater part of the work lies ahead--but also the scientific team that has been shaped, and the spirit of cooperation that reigns at IIASA. It would not be an exaggeration to say that at IIASA our new potentials are manifest: the effective collaboration of scientists from many countries and of many disciplines, the striving for mutual understanding, the unbiased exchange of experience and knowledge; goodwill, mutual respect and assistance. This "spirit of IIASA" is one of our major achievements and the basis for future successes of all the key projects and programs. Therefore our main objective is to maintain the IIASA spirit, develop and strengthen its traditions, and pursue the noble and peaceful purposes for which IIASA was created.

Creating an International Research Institution

H. Raiffa

It is hard for me to realize that it was just a little over three and a half years ago that I came to Austria from London with a copy of our Charter in order to start an Institute. My first speech in Austria was in the second week of October 1972 to the Austrian Academy of Sciences, and I opened it with the phrase I have repeated many times since: "Es freut mich sehr, hier zu sein und Sie kennenzulernen." ("I am happy to be here and to meet you.") Well, here today I also say, "Es freut mich sehr, hier zu sein."

It's wonderful to be back in Vienna celebrating the good health and growth of IIASA. It is always a cause of wonderment to realize that the dreams of a few can be of benefit to the many. By which I mean to pay tribute to the founders of the Institute and their supporting organizations; those who had the foresight to dream, and plan, and bring into being the idea of an East-West center for the research of problems significant to mankind.

In setting out to write this speech I searched for some opening words of wisdom. I found some phrases from Albert Einstein that seemed to describe IIASA's goals. He said, "Concern for man himself and his fate must always form the chief interest of all technical endeavors...so that the creations of our mind shall be a blessing and not a curse to mankind." He concluded, "We should never forget this even in the midst of our diagrams and equations."

The preamble to our Charter also stated this theme: "Science and technology, if wisely directed, can benefit all mankind,... international cooperation between national institutions can promote cooperation between nations and improve the economic and social progress of peoples."

With my perspective of eight years of involvement in IIASA's activities, I believe that we have remained faithful to these idealistic and noble aspirations.

I have often been asked, "How does one start such an Institute? What is the formula for such an undertaking?" Well, first you have to find a Bundy and a Gvishiani. No, there is something even before that. One must start with an idea; a good idea: an inspirational idea is even better. Next one must find men and women of goodwill and influence who grasp the real essence of the idea and can run adroitly with it. This we had in abundance; and we had it across national boundaries, ideologies, and scientific disciplines.

Flexibility, compromise, humor, and earnest determination about the undertaking also distinguished IIASA's founding members. A willingness to give a little on national pride here, and on semantic clarity there, and the Charter was, without too much pain, achieved.

Many remarkable compromises were made before our founding in 1972. Driven by an idealistic desire for scientific cooperation, the founders of IIASA deftly sidestepped some difficult political obstacles. For greater freedom of action, they decided that IIASA would become international but officially non-governmental. It would be supported, de jure, not by governments but by academies of sciences or similarly prestigious institutions. As far back as 1968 the founders creatively put major political differences aside in order to achieve what they all felt was a desirable goal: international scientific cooperation.

There were literally hundreds of little issues that they could have stumbled over in the drafting of our Charter. But there was a burning desire on the part of our founding members not to stumble, and they found the necessary compromises. There is no ex ante formula one can write down about how negotiations of this kind should be carried on. As a student of game theory, however, interested in bargaining and negotiation, I learned a basic truth from observing these negotiations: a spirit of goodwill is the key to compromise. Sure, you can push hard and win a little point here or there by being adamant; but the really big breakthroughs come when the atmosphere is cordial and the other fellow knows that you empathize with his problems. I think that spirit of cooperation, so manifestly present in those last-minute negotiations in the early autumn of '72, has not really diminished. In fact, in innumerable small ways I think the desire for real, meaningful cooperation at IIASA has grown.

All right, so you want to create an international research institute. Fine. But:

- What are you going to do there?
- Who will do it?
- Why will they do it?
- Can you get good people to come? For how long?
- What will be the mixture of applied and methodological research?
- What about laboratories? A library? Computers?
- Where is it going to be?
- Who will pay the bills?

- Who are your clients?
- Whom are you going to try to influence?
- How can you sustain interest after the honeymoon is over?
- How will you resolve internal conflicts?
- What language are you going to speak?
- How will you achieve quality control? Will you try?
- What about geographical balance?
- Will you have national quotas?
- How are you going to get the mathematicians to speak to the behavioral scientists?
- Are you going to be politically relevant?
- Are you bypassing the United Nations?
- Is this going to be a rich man's club?
- What are you going to do about the Club of Rome?
- What about members from the developing countries?

The list of these *easy* questions goes on and on. The really tough questions are a bit different:

- Should X from country Q get more money than Y from country R?
- Who should get the office with the view?
- Should X get more secretarial help than Y just because he is more productive? Who says he is more productive?
- Should scientists be asked to wear jackets when receiving foreign dignitaries? How about shoes in the dining room?
- Should coffee be free?

It is more appropriate on this august occasion to say something about the first class of questions--the easy ones. But since there are so many questions and since they are so obviously interrelated, I would like to share with you some of the guiding principles that the Council members and I used to shape this Institute.

First of all IIASA is a unique international experiment. There are no similar models. It is important both scientifically and politically that IIASA succeed in its mission. There are other multidisciplinary institutes, and other international institutes; but there are no other scholarly institutes jointly conceived, jointly managed, and jointly manned by representatives from the socialist countries of Eastern Europe and the countries of Western Europe, the United States, Canada, and Japan. Our source of strength, our comparative advantage, and our distinctiveness come from our East-West coalition.

It is on the basis of these observations that I believe that no significant, long-range project of IIASA should be supported without deep involvement and commitment by both East and West. Of course, modest research tasks can be spawned and developed by one group or another, but ultimately these efforts should gather widespread interest in order to justify their continuing support at IIASA.

It is no secret that there are strains between East and West. It has been so in the past; it is so today; and we expect it will be so in the future. But our world is too interdependent and too volatile a place for us not to cooperate with one another while we compete. There can be differences--fundamental differences--but still in this non-zero-sum world of ours there are areas for joint cooperation with joint gains for all. IIASA has a mission to keep its doors open, so that scientists who have a broad vision of tomorrow's world can communicate with each other. We cannot afford to let these doors shut tightly because of some ephemeral problems. IIASA's continued existence is of paramount importance. In fact, if IIASA did not exist today, many of us would propose that it should be created.

Because of IIASA's importance and because of its politically precarious existence, we have to be realists. We do not want to get involved *prematurely* in politically sensitive arenas. My emphasis is on the word prematurely because I believe that, in the long run, IIASA will have to justify its existence by making substantial contributions to real problems--which, alas, are usually politically sensitive ones. And if some progress is to be made in the long run, the time to start building up experience is now--not necessarily by plunging all at once into turbulent waters, but at least by getting our toes wet. And as with all good adaptive mechanisms, if the experience is painful, we must withdraw only to try once again from some other vantage point.

Although IIASA was started with just a dozen National Member Organizations (NMOs), our Charter is clear that the benefits of our work should be of potential significance to all mankind. In its last annual meeting in November 1975 the Council encouraged the Director to seek outstanding scholars from the developing countries, and I understand that this desire will become a reality in 1976. Also new NMOs will join our ranks. But the aim is for an orderly increase. Care must be taken that IIASA remain a scholarly, research-oriented institution and that we not become a pawn in international polemics.

It was a welcome and complete surprise to me how well we are now received in the family of United Nations agencies. This warm cooperative feeling was not always present; there was considerable distrust of IIASA at first. But the UN agencies realized that we were sincere in our desire to undertake truly collaborative research projects with them, and that IIASA, as a scholarly Institute with ties to research establishments of both East and West, has some comparative advantages. It should be our continuing policy to nurture these good relations.

There was a general consensus way back in '68 that this Institute, if it were ever to be created, should work on significant applied problems from an integrative, holistic, systems orientation. This meant bringing together teams of scientists from different disciplines and different ideologies. While many universities around the world employ physical scientists, biological scientists, behavioral scientists, applied mathematicians, lawyers, and management specialists, they very rarely work together on significant enterprises. IIASA's ambition was, and is, more focused: we want to do *applied systems analysis*, which roughly means to do systematic analysis of applied problems...from an integrative perspective...with interdisciplinary teams; and since we are an *international* Institute, we want to do this applied research with a team of players from different cultures and ideologies.

These rather vague words having been said, you must realize that the menu of possible research topics for IIASA is vast; but IIASA's financial resources are limited--too limited, in my opinion. Therefore, it was felt from the start that in comparison to the needs, IIASA could do no really significant amount of research with its own scientists located in a central place. It would have to seek some multiplier effect. We decided therefore that, starting from a firm research base of its own, IIASA should try to establish, and partially orchestrate, a decentralized but coordinated research program that would draw upon the vast research potential within the countries of our NMOs. This would mean, for example, that while IIASA would do in-house energy systems research, it would also work closely on similar problems with outside institutions and scientists from both East and West.

Easier said than done. In order to get sincere, meaningful cooperation with external groups, our internal group of researchers has to command the respect of outside groups. So the logic of these observations leads me to my next topic: how does one get a good in-house research effort going?

Overwhelmingly, my answer is: by getting good people! And how does one get good people? Well, first by having a good research effort going; second, by recruiting like mad; and third, by making IIASA an intellectually exciting and stimulating place to be.

Let me amplify a bit. You need good people to get a good program and a good program to get good people. But if you recruit hard enough, some idealistic, brave, and trusting souls--like Professors Häfele, Letov, Dantzig, Rosanov, Koopmans, Aganbegyan, Holling, Knop, and Kaczmarek--will come to start good programs. Effective recruiting is the key ingredient in determining IIASA's quality and quantity of output...and thereby its acceptance in outside circles.

Good researchers are in demand everywhere. They are not coming to IIASA for long-term careers, and they are not going to keep coming, even for one or two years, unless they and their families are happy with their total experience at IIASA and in Austria. This means that IIASA has to create a scholarly and intellectually stimulating institution; that it has to cater to the just concerns of its scholars and staff; that it must provide an atmosphere which encourages productivity and is at the same time friendly and non-hierarchical, where social amenities are not forgotten. It should be a place where scholars can occasionally be seen working all night and on weekends; where the staff is called upon to work overtime if need be; but also it should be a place where there are spontaneous parties and festivities, and where children and spouses feel welcome. In short, scholarship *and* skiing; hard work *and* Heurigen; a productive and exciting stay for the whole family.

Edith Wharton, an American novelist, seemed to be describing IIASA's modus operandi when she wrote, "There are two ways of spreading light: to be the candle, or the mirror that reflects it." In just this way IIASA's mission is not only to do research by itself, and in collaboration with others, but also to be a coordinator, synthesizer, and disseminator of work done exclusively by others. IIASA has in the past, and will continue in the future, to plan, organize, host, and publish proceedings of international conferences on important subjects of applied systems analysis. But to go back to Mrs. Wharton's imagery: how brightly *does* IIASA's candle shine today--three and a half years after its birth? How well does the Institute reflect the ideas and the progressive research in the world about us? These are some of the questions of evaluation this Conference will address. Further,

- What of IIASA's accomplishments and plans to function as a catalyst for the initiation, dissemination, exchange, and critique of concepts in systems analysis?

- What can IIASA do to bridge the gap between scientists and decision makers?

- How can IIASA contribute to the education of the expert and the interested non-expert?

- How can IIASA make the non-expert aware of the dangers inherent in considering complex global problems in fractional parts isolated from each other?

In 1972 no one could tell us how a non-governmental institute should go about performing and implementing analysis of world problems. We had to decide what topics to explore, how we would approach them, and what skills we would need. As I said before, there was no blueprint for IIASA.

When we discussed topics for research with the Council, there was no clear consensus about which to pursue. There was no shortage of critical problems--energy, food, environment, for instance--that IIASA could profitably have studied, but the NMOs placed different priorities on them. We had no way to gauge which of them to tackle first or on which issues IIASA might have greatest impact. We did not know which scientists or what caliber of scientists we would be able to attract to a brand new institute.

We decided to begin with nine activities experimentally. Six of them were applied, three were supporting projects. The applied projects were: Biomedical, Ecology/Environment, Energy Systems, Industrial Systems, Urban and Regional Systems, and Water Resources. The supporting projects were: Methodology, Design and Management of Large Organizations, and Computer Science.

We have experimented in a difficult arena. It is extraordinarily difficult to do interdisciplinary work, especially when teams comprise researchers from vastly different educational and cultural backgrounds. It was hard for me, for one, to predict ex ante which projects would work and which would not. I had my own prior favorites, but I was wrong about some. We had to start with a portfolio of topics in order to get agreement. In three years we learned what we probably could or could not do. We learned that we must exploit our comparative advantages.

First, IIASA is ideally suited to examine problems from an integrative, comprehensive viewpoint. Second, it bridges borders between different societies and nations. Many world problems--food, population, global environment, energy--require the constructive inputs of all nations. One country or group of countries cannot, by itself, solve these interdependent global problems. IIASA should strive to concentrate its efforts on those problems where an interdisciplinary team from East and West can have its biggest payoff. IIASA should concentrate, I believe, on problems where it can build up a sense of trust. In this endeavor, we must work amicably together and demonstrate to the world that scientific cooperation is desirable and feasible.

In 1968 we did not know whether organizational hurdles could be surmounted to found IIASA; in 1968, we did not know whether good scientists could be induced to come to IIASA; in 1968, we did not know whether good scientists at IIASA could overcome the barriers of nationality and professional discipline to collaborate on worthy research. In 1975, IIASA has been founded, outstanding scientists have come and have cooperated in ways that exceed our prior hopes. Many of the Council members will recall that only four years ago one of IIASA's founders predicted that there would be no working scientists in Laxenburg before 1976 at the earliest. By the end of 1975 many fine scientists had been working in Laxenburg for two full years. Outsiders and insiders alike were astonished that by the autumn of 1973 we already had a scientific program under way. In large part, this was due to a series of fortunate circumstances that made possible the rapid recruitment of many scientists. I must confess that I was among those surprised by our speed in launching a research program. The energy of our project leaders, and the positive actions taken by the Council and its Committees in the first half of 1973, deserve much of the credit for this feat.

There were many people in those early stages who should share the credit, but I would be remiss if I did not personally single out just a handful of my very closest associates: I shall not forget the charm, spirit, and goodwill of the late Alex Letov, our first Deputy Director; the scientific drive, inspiration, and commitment of Wolf Häfele; the organizational and managerial skills of Andrei Bykov; and the sage cousel I received from my close friend from the GDR, Konrad Grote.

Next I would like to thank Mr. Bundy for getting me involved in IIASA affairs; President Handler for talking me into becoming the first Director; Dr. Gvishiani for making my life so pleasant and productive while I was Director; and finally, Dr. Roger Levien for letting me retire with the peace of mind that things would get better and better.

Finally, I would like to say something about our host country Austria. Austria as a neutral State is symbolically the right place for an Institute that brings together scholars from East and West. Many of us worried at first that we would be isolated in the small quiet village of Laxenburg, but this has not proven to be the case. IIASA is now well enough recognized that a steady stream of stimulating researchers visit Laxenburg and there is no sense of intellectual isolation. And the Schloss with its surroundings is a magnificent place in which to work.

But what is far more important than the beauty of the site is the attitude of the Austrian authorities. President Kirchschläger and Chancellor Kreisky not only know about IIASA but take a personal interest in our welfare. Frau Minister Firnberg is also a stalwart and effective supporter. The Austrian Academy of Sciences, through former President Schmidt and then President Hunger, has continued to be an effective collaborator. Our earlier official contact with the Austrian government was through the late Secretary-General Walter Wodak who was a true friend of IIASA. He was instrumental in getting IIASA to come to Austria, and he saw to it that once we were here we would remain pleased with our choice. His dear wife Frau Dr. Wodak--Erna to her many friends--completed many of the tasks her husband initiated. She more than anyone else is responsible for our productive relations with the Austrian industrial community, and she has helped integrate our group into Austrian social and cultural activities. All in all, Austria is absolutely right for IIASA; I only hope that reciprocally IIASA will prove to be right for Austria.

I think we have created at IIASA an institute uniquely designed for our times. I suspect that there might come a crucial period in world affairs--a time of crisis perhaps--when IIASA will be called upon by our world leaders to play an increasingly important role: a role that might include examination of radically new solutions to truly global problems.

In my last address to the IIASA Council I offered three sentences of advice for the future. In conclusion I would like to repeat them here: "Let us be courageous. Let us believe in ourselves. Let us create an institution that is relevant for the precarious world we live in."

Applying Systems Analysis in an International Setting

R.E. Levien

Howard Raiffa's legacy was an Institute that had been brought from a vague ideal to a functioning reality. In October 1972 there had been a Charter and a wish; in November 1975, there were over 60 scientists, 11 research projects, and a growing body of research results.

At the beginning of Raiffa's term there were questions about the meaning of systems analysis in an international setting, about the proper role for IIASA, and about the appropriate strategy for IIASA to pursue. By the end of those years, enough experience had been gained to enable us to formulate answers with sufficient clarity to guide the Institute in its next phase of development.

I shall first address the answers to those three questions:

- What is the meaning of "applied systems analysis" at IIASA?
- What is the proper role for IIASA?
- What strategy should IIASA follow to fulfill its role?

Then I shall explore the likely results of IIASA's efforts, and try to define what might reasonably be expected by our Member Organizations and the international community from our activities.

APPLIED SYSTEMS ANALYSIS AT IIASA

When IIASA began there was no experience with the conduct of applied systems analysis in an international, East-West, setting. Many nations had traditions of analysis of complex systems as an aid to decision makers; but these traditions were by no means identical. The stages of development differed widely in different countries, as did the meaning, the purpose, and even the name of the activity.

What in some places was called "systems analysis" was elsewhere called "policy analysis", "operations research", "cybernetics", or "qualitative planning". What in some countries was still a field of academic inquiry was in others a working tool for real decision-making agencies. And although in several nations the emphasis was on the study of complex systems to gain understanding of them, in others it was on providing analytical assistance to decision makers.

These differences existed within countries, as well; there were in many nations groups of scientists and decision makers who were skeptical about the validity and potential benefits of systems analysis.

Thus, the phrase "applied systems analysis" did not sharply define what the Institute would do or how it would go about it. Rather, it set a tone and an aspiration, which had to be given form and content through invention and experimentation.

Now, from the initial three years of experimentation some answers are beginning to appear. The first--and perhaps most important--conclusion is that there is no single model that all systems analyses at IIASA can follow. Instead, there are a number of distinct patterns, adapted to the circumstances of the system being studied and the decision problem being investigated. Let me explain.

One type of systems analysis is illustrated by the first study made by the Ecology project at IIASA. The problem was to determine and evaluate alternative policies for control of an economically significant forest pest: the spruce budworm of northern forests, particularly in New Brunswick, Canada. A detailed report of this work is given elsewhere in this volume.* I want here only to point out some of its features as a systems analysis.

The left side of Figure 1 shows the problem schematically. There is a forest of trees, some of them infested by budworm, which are in turn subject to predators. Affecting this system are policies implemented by the government, logging enterprises, and land owners. These policies include decisions about spraying, logging, and tree planting. The direct consequences of applying the policies to the forest system will be a temporal and spatial pattern of budworm infestation, tree growth, and harvesting. This will be translated into economic costs and benefits to individuals, enterprises, and government, and into social and recreational benefits to individuals. Now the problem that systems analysis addresses in this case is: which policies should the decision makers select to achieve the most desirable consequences?

The decision maker would ordinarily rely on his trained intuition and the lessons of experience to decide upon a policy. But there are severe limitations to trial and error or intuition when systems have complex interactions over long distances in space and time.

The systems analyst can provide useful help here, because ecologists and biologists have learned enough about the spruce

---

*See C.S. Holling.

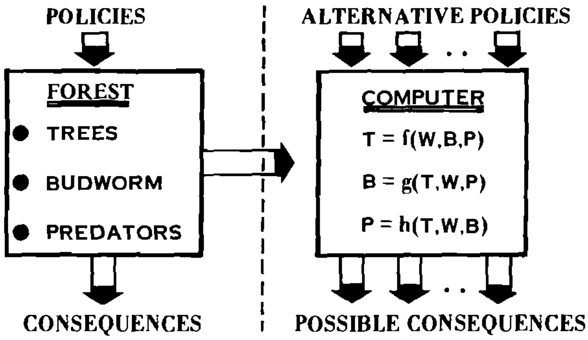


Figure 1. Systems analysis, Type I: forest pest management.

forest and the budworm to be able to predict their responses under most likely conditions. The systems analyst can use this scientific knowledge to create a mathematical and computer model that satisfactorily simulates the behavior of the forest and the budworm under a very broad range of circumstances. This then opens the possibility of testing possible policies *in the model*, rather than *in the real world*; especially since the model can trace the forest's evolution over 150 years in less than 150 minutes.

So on the right side of Figure 1 we see a mathematical-computational simulation of the forest, which the systems analyst uses to test alternative policies and determine their possible consequences. With this information, the decision maker is in a much better position to select, from the options he faces, the one that best serves his needs.

But the role of the systems analyst in this case extends beyond the development of a descriptive systems model based on biological and ecological knowledge. Most decision makers know what consequences they would like to achieve, but not which one of a large number of policies they should pursue to achieve them. The systems analyst can help by developing a prescriptive or optimizing model that, using mathematical techniques, finds the best policy to attain a specified goal or to optimize a specific criterion.

Often, furthermore, the systems analyst assists the decision maker to clarify his objectives, the relationships between them, and their priorities over time. When there are many independent decision makers, the systems analyst can help them to trace the consequences of their interacting policies. This happens, for example, when analysis displays the interaction between the logging policies of the lumber enterprise and the recreational policies of the government environmental agency.

At each step, in each of these roles, the systems analyst must be skillful in dealing consistently and honestly with uncertainty and complexity, and with the distinction between facts and value judgments.

This type of systems analysis is possible ordinarily only when decisions must be taken about systems that are physical or ecological. Science has generally learned enough about the behavior of such systems to permit construction of adequate descriptive models. Consequently, policies can be tested in the model, instead of the real world. But most significant problems facing decision makers concern systems comprising individuals and groups, whose behavior is by no means well understood. Systems of that kind generally cannot be adequately modeled as a whole, and policies therefore cannot be tested all at once in a comprehensive computer model. One approach to such complex social-technical systems is illustrated by our Global Energy Systems program, which is described in detail in another presentation.*

In Figure 2, I have followed the same conventions as in the previous figure. The left side schematically portrays the problem. But in place of the relatively simple forest system of the previous example, we have here a complex interaction among technologies, economics, environment, and social attitudes. Instead of a compact geographic region in northern Canada, we have the full globe. And in place of a few decision makers, we have a very large number of independent policy makers in industry, national governments, and international enterprises and organizations.

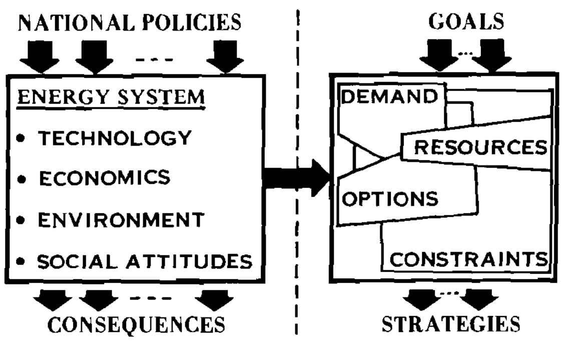


Figure 2. Systems analysis, Type II: global energy systems.

The role of IIASA systems analysis in this setting, therefore, cannot be to determine a single best policy for a single

*See W. Häfele, this volume.

global decision maker. Instead, it is to try to provide a broader perspective against which the autonomous decision makers can make their choices. Systems analysis here must look beyond single system components, in single nations, in the short term. It must identify and improve understanding of the important interactions among energy system *components*, among the energy policies of *nations and regions*, and among energy choices in the *short, medium, and long term*. The system analyst's--and IIASA's--hope must be that, armed with this knowledge, the decision makers will choose policies that are better not only from the standpoint of their own nations, but for the globe as well.

On the right side of this figure, I have shown schematically our approach to this type of systems analysis. In place of a single comprehensive computational model--impossible, because of our lack of validated knowledge and the size and complexity of the system--there is an overlapping, interlinked series of investigations of the principal questions affecting the global energy system:

- What will be the evolving pattern of demand?
- What resources are available to satisfy it?
- Which technological options will be feasible?
- What constraints will limit selection among the options?

And instead of a quantitative evaluation of alternative policies, there is the identification of a range of strategies responsive to different possible national and international goals. Here, as in many analyses, the desired result of analysis is synthesis--the design of alternatives that satisfy specified demands by selecting from among various options those that satisfy the constraints and best serve given goals. The decision makers can then use these strategic alternatives as guides in forming their own policies.

Another approach to the analysis of complex systems that include social and economic components as well as technical ones is illustrated in our study of systems for the planning and management of regional development, described in another presentation.*

This third type of systems analysis is illustrated in Figure 3. The left side shows three examples of regional development systems: the Tennessee Valley Authority (TVA) in the United States, the Bratsk-Ilimsk Territorial Industrial Complex in the Soviet Union, and the Shinkansen project in Japan. Each is affected by policies that produce consequences, denoted by the entering and leaving arrows. Each is internally organized and managed in different ways to achieve its goals within its specific setting.

*See H. Knop, this volume.

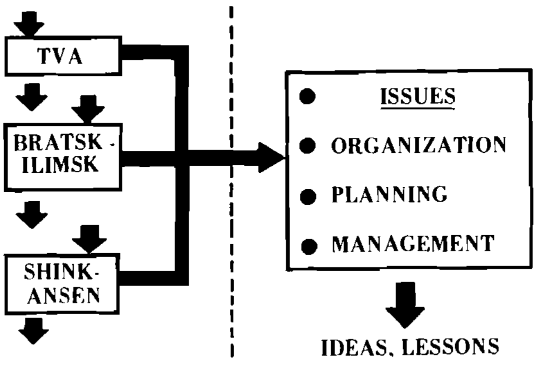


Figure 3. Systems analysis, Type III: regional development.

Although the conduct of regional development involves complex systems that defy realistic descriptive modeling on computers, it differs from the setting of global energy policy in that it is not unique; numerous regional development activities are occurring at different places simultaneously, and at different times as well. This means that the systems analyst can learn about the potential consequences of different policies by carefully examining the experience of the "natural experiments" under way around the world. Our systems analysis in this instance is intended to help decision makers concerned with regional development to select effective planning, managerial, and organizational means by studying the experience of real cases. We replace the testing of alternative policies in computer simulations of reality by their testing in reality itself. But the difficult task of systems analysis in these circumstances is to develop procedures for deriving conclusions from what, of necessity, are unstructured, uncontrolled "experiments". How can the effects of a particular organizational arrangement be separated from those of the other factors that also change from case to case?

The answers to this question are by no means clear. Our approach so far has been to try to develop conceptual or qualitative models of the processes under investigation that guide and structure our examinations, and second, to be clear about the nature of our findings. We cannot expect to be able to say that one approach or another is best, or even better, under all circumstances. Our goal at this stage must be more modest: to identify approaches that appear to have been useful and that warrant adaptation and trial in other settings.

These three types of systems analysis do not exhaust all the possibilities, but they do span the range of experience IIASA has had during its first three years. Moreover, despite their significant differences, they share a number of features, which serve to establish a common meaning for the phrase "applied systems analysis".

All three types have as their purpose the provision of aid to decision makers in making difficult decisions about complex systems. In each case, the analyst seeks, to the extent possible, to separate the determination of factual, objective information--which is the role of analysis--from the making of value judgments, which is the role of the decision maker. Although this separation is often difficult, it is always important. In each case, too, the systems analyst has a broad viewpoint that cuts across the conventional disciplinary or organizational divisions to establish boundaries of investigation appropriate to the problem. This means, in turn, that the analysis must rely upon and draw together the knowledge and approaches of many distinct disciplines.

A characteristic of modern science that has underlain the evolution of systems analysis is the development of quantitative and computational tools to deal with complexity and uncertainty. Many, but not all, systems analyses use the computer or sophisticated mathematics to organize and trace the consequences of complex system interactions, to account for uncertainty, or to search for optimal policies. But despite its reliance on the findings of science and the precise tools of mathematics and computation, systems analysis remains, like science itself, an inherently human enterprise calling for individual judgment, skill, and creativity. Like science, it is an art.

THE PROPER ROLE FOR IIASA

Against this background we can now turn to the question: what is the proper role for IIASA? The answer to that question follows from a consideration of the features that give IIASA its uniqueness. There are two of them.

First, IIASA is an international institute that is, nevertheless, non-governmental. Consequently, it can address international issues in a non-political setting. Furthermore, it is the joint creation of countries from both East and West, and can therefore bring together scientists from widely differing economic, political, and social systems to work on problems faced by all societies.

Second, IIASA is an interdisciplinary institute, that is, furthermore, applied. This means that it can bring together the findings and insights of many special scientific disciplines to solve practical problems. But it also means that methods must be found to bridge the gap between natural and social scientists. It is generally harder to develop effective communication between an American physicist and an American sociologist than between the American physicist and a physicist from the Soviet Union.

These two characteristics lead directly to the definition of the two dimensions of IIASA's proper role.

The first is that IIASA should address problems of international importance, leaving for others matters of strictly national relevance. Problems of international importance may be *global*--that is, they cross national boundaries, involve inherently more than one nation, and cannot be resolved without the joint action of more than one nation; or they may be *universal*--that is, they lie within the boundaries of single nations and can be resolved by their individual actions, but are shared by almost all nations.

Global problems include, for example, the preservation of the global environment and climate, and assurance of adequate global food and energy supplies. Universal problems comprise regional development within nations, design of national health care delivery systems, and development of automated management systems. In both cases, IIASA can play a unique role. It is the only place in the world where scientists from East and West can work together on the global issues that all nations face. And it can facilitate the exchange of experience across social, economic, and political boundaries on universal issues confronted by every country.

The second dimension of IIASA's proper role is a comprehensive approach. There are many studies that focus on one aspect or another of, for example, energy problems--studies of energy resources *or* environmental problems; of urban energy needs *or* health effects of nuclear power; of new technologies *or* methodologies for studying energy demand. In contrast, IIASA's goal is to analyze international problems such as energy in a comprehensive way, identifying and investigating the interrelationships among the pieces of the overall problem.

IIASA'S STRATEGY

These two dimensions of IIASA's role determine its dual strategy: *first*, to build a solid base of competence in those areas of science and technology that are essential components of a comprehensive approach to international problems; and *second*, to draw upon this base of competence in conducting major cross-cutting studies of both global and universal problems.

We have identified four research areas that constitute the pillars of our competence.

The first we call *Resources and Environment*; it is concerned with the Earth's natural endowment--its climate, environment, water, renewable and non-renewable resources, and ecological systems. The activities begun by our Ecology/Environment, Water Resources, and Food and Agriculture projects now fall within this area.

The second is *Human Settlements and Services;* it is concerned with the Earth's human endowment--its populations, their distribution and collection in settlements, and the health, education, communication, and transportation services they need. Our Urban and Regional and Biomedical projects have come together here.

The third is *Management and Technology*; it is concerned with the man-made contributions to the global endowment--institutions, economic systems, and technologies. We have brought together in this area our work on integrated industrial systems and large organizations.

The fourth area differs from the first three by dealing with analytical processes rather than with the objects of analysis. We call it *System and Decision Sciences*, to emphasize its concern with the mathematical and computational tools that support studies of large systems and provide aid to decision-making. It embraces our formerly separate Methodology and Computer Science projects.

Cutting across these four basic areas of competence, we have established two major applied studies, one global and one universal.

Knowing that we could hope to complete our studies only in the long run, we chose as our problem of global concern the question of *the path of global development over the next century*. The dynamics of global population growth, and the parallel growth in the aspirations of all people for adequate food, clothing, and shelter, for education and health care, and for at least minimal amenities, will place severe pressures on the Earth's capacities. To meet the expanding needs of an expanding population, while husbanding the Earth's resources and preserving its environment, is likely to demand far more perceptive care and joint action by national and international decision makers than have ever been applied before. IIASA's unique position gives it the responsibility to assist, over the long run, in the analysis of these global prospects.

But we believe that in the short run IIASA cannot address this vast problem comprehensively. There have, of course, been efforts by a number of groups to build comprehensive global models; we have chosen another approach. Instead of beginning with a study of the linkages among the various sectors that comprise the global system--energy, food, water, environment, industry, and so on--we will begin with sector-by-sector studies. Our hypothesis is that we do not yet know enough about each sector at the global scale to do truly satisfactory intersectoral modeling. The first sector we are studying is energy; that investigation began in 1973 and will be completed in 1978. I have stated the nature of that study earlier. This year we are beginning our analysis of the global food sector.

The problem at the universal level is different. Here we have chosen to concentrate on issues arising in the development of regions within nations. In contrast to the situation at the global scale, sectoral studies are well advanced at a regional scale; but there has been relatively little work on the integrated consideration of these sectors. Thus, IIASA's effort is being addressed to the planning and management of integrated regional development. These problems are common to many nations, especially those that are beginning to exploit new resources.

The two aspects of IIASA's strategy come together, as is shown schematically in Figure 4, through a matrix form of organization. The columns are the four research areas, each comprising a wide range of research skills. The rows are the two cross-cutting research programs: Global Energy Systems and Integrated Regional Systems. Each program has a three- to five-man core group and an interdisciplinary team drawn from the experts in the research areas. About half of IIASA's research effort is allocated to the cross-cutting programs; the remainder constitutes studies made within individual areas or jointly between two or more areas.

	RESOURCES & ENVIRONMENT	HUMAN SETTLEMENTS & SERVICES	MANAGEMENT & TECHNOLOGY	SYSTEM & DECISION SCIENCES
GLOBAL ENERGY SYSTEMS				
UNIVERSAL REGIONAL DEVELOP-MENT				

Figure 4. IIASA's matrix organization.

The strategy I have sketched is ambitious; it would strain the resources of a major research institution. Yet IIASA's internal resources are limited. The Institute has a core staff of 70 scientists. While it occupies marvelous facilities in Schloss Laxenburg--which have been provided with the generous assistance of the Austrian government, the government of Lower Austria, and the City of Vienna--it has only a modest library and medium-sized computing facilities. Its annual budget is 110 million Austrian Schillings, or about 6 million dollars. Although significant, these resources are below those needed to fulfill IIASA's large ambitions.

For this reason, we are trying to find ways to amplify the efforts of IIASA's core through ties with the external research community. The founders of the Institute saw its true purpose in stimulating and linking collaborative research in the participating countries. But Professor Raiffa and the Council felt strongly that such an external network could only be built on the base of significant internal research; without that, there would be little reason or capacity for external scientists to collaborate with the Institute. In the last year this policy has shown results. The way in which external resources expand the Institute's capacities is shown in Figure 5.

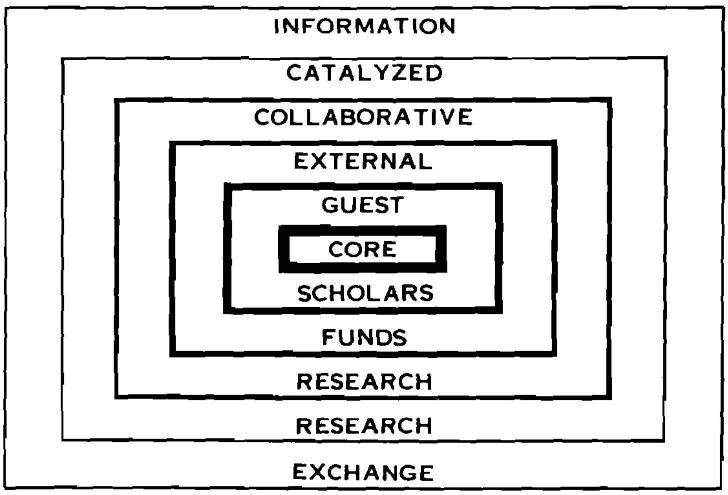


Figure 5. IIASA's external resources.

Around the central core of scholars who are supported by the contributions of the National Member Organizations (NMOs) there has been added a group of guest scholars--scientists supported by outside organizations. There will be 10 guest scholars at IIASA this year--paid directly by research institutions in France and industrial corporations such as

Shell, IBM, Arthur Andersen, Siemens--who participate with the rest of the staff in the research program approved by our Council. These guests enlarge our staff to about 80.

The next addition to the core is made possible by funds we receive from external sources--foundations, international and national agencies--in order to extend or deepen the treatment of specific portions of our research program. This year we expect to receive about 20 million Austrian Schillings--somewhat more than 1 million dollars--from such sources. They include the United Nations Environment Programme (UNEP); the Volkswagen, Ford, and Rockefeller Foundations; the Austrian Ministry of Science and Research, the Austrian National Bank, and the Ministry of Research and Technology of the Federal Republic of Germany. This is about a 20 percent increase in our total budget, and--of greater importance--almost a one-third increment in our research budget.

We value these monies for three reasons. First, they enable us to pursue important research topics more fully than we could with our internal resources. Second, they often provide a direct link with interested decision makers, which is one way of assuring the practical relevance of our work. Third, they implicitly represent an independent, disinterested review of the quality of our program. They mean that an outside agency, after examining our work and our plans, has judged it valuable to provide funds to continue toward those objectives. In many cases these organizations contribute more than the annual membership fee of one of our members. With these funds our staff increases to somewhat over 90 scientists.

Up to this point, the additions to the core have been within the halls of Schloss Laxenburg. Guest scholars and external funds enable us to establish and retain a critical mass of research activity in Laxenburg. But even so, the problems that IIASA addresses exceed the capabilities of any single, centrally located staff: they are international and demand international attention. Thus, we pay special attention to the development of a network of collaborative institutions. The establishment and nurturing of this network will be a significant indicator of IIASA's success.

One of the first of these collaborative relationships began here in Vienna, with the International Atomic Energy Agency (IAEA). We have established a joint group on the assessment of risk, with particular emphasis on the role risk estimates play in the choice of energy options. The IAEA and its member countries contribute staff to the group, as does IIASA. Its leader is at the IAEA, and the team collaborates closely with our Energy program.

We now collaborate with research organizations in almost all the countries having IIASA National Member Organizations, and this network is continually growing. A very promising development is the establishment in our NMO countries of research groups that will work in parallel with and serve as links to our research activities. Bulgaria, for example, is designating laboratories that will work in conjunction with our Food and Energy programs. Thus our findings can be implemented in Bulgaria through the efforts of persons and organizations who are aware of the specific situation and needs in Bulgaria. At the same time, we have obtained a channel through which our program may draw upon Bulgarian experience, needs, and reality.

An additional example will help me to illustrate how the collaborative network amplifies and extends IIASA's efforts. As part of our study of global energy systems, we are exploring the possibilities of returning to coal as a major source of energy. In our core research program, however, we have allocated less than one man-year of effort to this problem. Obviously, the ability of one man, no matter how competent, to evaluate the coal option is quite limited; you might feel justified in questioning the seriousness of our commitment. But IIASA's internal effort is only the tip of an iceberg. To amplify that effort we have created a Coal Task Force, which draws upon representatives of the coal authorities in Czechoslovakia, Poland, the Federal Republic of Germany, and the United Kingdom. We expect additional countries to join in. This Task Force meets regularly at IIASA, and its members then return to their home institutions to carry out the work that they have agreed upon. The results will be of obvious value to our Energy program, but the participating institutions expect to benefit more directly as well.

There are many other examples of our collaborative research network. Sometimes IIASA's external influence occurs through a less tight linkage than I have just described. In such cases we identify in the course of our work problems that demand deeper treatment than we with our own resources can give them, and attempt to stimulate research in national research institutions among our NMO countries.

One example of this is the matter of climatological effects of energy production. As global energy production increases, two waste products may influence the global climate. They are *heat* and *carbon dioxide*. We became interested in these potential problems early in our energy studies, but did not have the resources to explore them adequately ourselves. Instead, we approached organizations in countries having NMOs to ask for help. Two of them, the British Meteorological Office and the National Center for Atmospheric Research (NCAR) in the USA, offered us the use of their large, computer-based, global-circulation models. Another, the Nuclear Research Institute in Karlsruhe, FRG, offered us computing assistance. Interesting results for our own work have come from these efforts. But of equal importance has been the catalyzing of work at one of those centers that might not otherwise have been undertaken. Let me quote from a letter we received from the President of the NCAR:

> ...we are very appreciative of the kind of synthesis that IIASA is attempting in the area of energy systems, since it helps us to see where some of the more important practical problems lie, and where we can contribute most fruitfully. I foresee a long-term interaction between our two organizations, each working on the problems that we understand best, and with a continuing dialogue in which we exchange ideas and latest results.

This is an excellent statement of the role that we see ourselves playing in relation to many research institutions around the globe.

The last ring in the web of external resources is formed through IIASA's capacity to facilitate international exchange of information, and thereby to strengthen national research efforts and help to identify issues of global and universal importance. One example of this is our series of international conferences on global modeling. As I mentioned earlier, IIASA has chosen not to develop a comprehensive global model of its own. We have, however, felt it important to provide a forum through which the methodologies of the various global models can be reported, discussed, criticized, and disseminated. There have been three such conferences thus far, with the fourth to be held this fall. Each will result in a proceedings volume, which in some cases provides the most complete available documentation of the various models.

So the efforts of IIASA's small core--70 scientists--are amplified many times as they travel outward through the successive layers of our international network.

IIASA'S RESULTS

I have already described several consequences that IIASA's work has had. Of course, the nature and extent of our results are matters that every participant in this Conference will be considering. Each will ask: is IIASA worth what it costs? Can it promise results commensurate with the resources it engages?

Each of you will, of course, form his own answers to those questions. As an aid during those deliberations, it may be helpful to have a classification of the types of results we expect to produce.

1. Findings Applicable in a Single Nation

The first and most direct result of IIASA's work will be specific findings applicable in a single nation.

- The work of the Ecology project on the management of the spruce budworm in New Brunswick is already being employed in Canada.

- The Energy project's determination that with current oil prices solar electric energy may be economically viable in Austria has led the Austrian government to investigate that possibility in more detail.

- The work our Water project is doing in conjunction with the Hungarian National Water Authority on development of the Tisza River Basin is of direct value in Hungary's current planning.

2. Findings Applicable in Many Nations

Although we are happy to have achieved such results for individual nations, we feel that IIASA's role does not consist *fundamentally* in producing single effects. Rather, we work in individual nations as part of the discipline of preparing findings that have universal value--that can be used by many nations.

Thus, the next step in our Ecology project is to extend the findings on the spruce budworm so that they become relevant to control of that and similar forest pests in other countries. In the same way, we are extending the results of our case study of solar energy in Austria to other countries in central Europe. We are looking, as well, at the general problem of integrating the naturally fluctuating electric energy supplied by solar means into existing energy systems. These studies will be of value to all nations contemplating solar electric power generation.

Similarly, our work on the Tisza basin in Hungary is part of a larger activity whose purpose is to derive findings of value to river-basin managers in many different countries, including Poland, Bulgaria, and Italy.

3. Methodologies to Aid National Decision-Making

Some of our results will be of relevance to particular decisions or groups of decisions. But one of IIASA's distinguishing features is its concentration on problems that demand and inspire the development of new techniques. At the same time we have a first-class team of methodological specialists. Consequently, we expect that a major part of IIASA's results will be new, refined, or extended methodologies. For example, the overall goal of our Ecology project has been to develop methodologies for ecological system management. In particular, one case study has focused on methods for studying the environmental consequences of alternative regional energy policies. You will hear more about this work, carried out in the USA, France, and the GDR.*

---

*See W. Foell, this volume.

4. Global Context for National Decision-Making

Sometimes the important result of our work is the global context we can provide to assist national decision makers. For example, both our global energy and our global food studies will examine the likely patterns of global supply and demand in these key resources. These studies, conducted at IIASA with the collaboration of scientists from many different countries, will, we hope, provide better information about global trends and interactions than can be constructed by national groups acting alone. Their availability should prove valuable to national decision makers and their staffs.

International decision makers are not so easily identified as national ones. They occupy positions in international agencies and enterprises; they sit on international commissions and attend international conferences; in large measure, all of us--when acting in our national capacities--are international decision makers in this interdependent world.

5. Information for International Decision-Making

One of IIASA's central goals is to assist in international decision-making. An important way in which we can do so is by providing information. Because the community of decision makers is so diffuse, this information may not take the form of precise recommendations for particular persons. Rather, it may appear as a report addressed to a very wide audience. Our examination of the medium- and long-term prospects for the global energy system will include such reports among its products. They will provide a broad global perspective about the future supply of energy and the options for satisfying demand, as well as an indication of alternative strategies that might be pursued nationally and internationally. No single decision maker will be able to implement our findings; thousands of decision makers should find it useful to have them.

6. Methodologies to Aid International Decision-Making

Another type of contribution we can make to international decision-making is methodological. For example, we have received a three-year grant from UNEP to develop and disseminate methods for comparing energy options. We shall be working jointly with the IAEA and the World Health Organization (WHO) in this effort.

7. Contribution to Scientific and Technological Knowledge

Although we are an applied research institution with our primary focus on preparing results of value to decision makers, it is both essential and natural for us to produce results of general scientific and technological relevance. For example, our ecologists proposed early in IIASA's development that an important criterion of system performance was what they called "resilience". Intuitively, they defined the term as a system's ability to absorb and recover from unanticipated shocks. The concept quickly gathered support from other projects, especially Energy. But there was no practical quantitative definition of resilience that could be used in system evaluation. In recent months our methodologists have developed a promising approach defining resilience. Should these results gain acceptance, they will constitute a contribution to the wider scientific community as well as a practical benefit to IIASA's own research.

8. Exchange of Experience and Methods

Because IIASA is a meeting ground for scientist from many countries who come as long- or short-term staff members, visitors, and conference participants, it naturally facilitates the exchange of experience and methods. For example, the central focus of our work in the biomedical field is the development of dynamic models of national health care systems through the collaboration of individuals and groups in the Soviet Union, Great Britain, Austria, Canada, and Japan. A core group at IIASA interlinks the efforts, but more direct exchange will occur through visits to IIASA of several months or longer by scientists from each participating activity.

9. Stimulating Research Elsewhere

A crucial part of science--both basic and applied--is asking the right question. We feel that IIASA has an important function in this respect. Our international setting and interdisciplinary approach give us a view of issues and scientific developments that differs from those open to national research institutions in a single descipline. Often this leads us to identify important gaps in knowledge or application that are not so visible elsewhere. At the same time, we have neither the resources nor the inclination to pursue all these questions ourselves. Thus, we seek to stimulate research in national institutions, as we have done in the NCAR and other research groups with which we are in contact.

10. Linking Research Elsewhere

Sometimes we are able to serve better as intermediaries than as stimulators of work. An example is the work in our Human Settlements and Services area on the dynamics of urban growth and national settlement policy. This, with support from the Ford Foundation, is engaging research institutions in North America, Eastern and Western Europe, and Japan, in the coordinated gathering, structuring, and analysis of data about the dynamics of urban economic regions. This linked network of institutions would have been extremely difficult to create outside the IIASA framework. Not only does IIASA benefit, but so do the participating institutions, who obtain comparative data in comparable formats that would otherwise have been inaccessible.

Another example is our work on management and control systems in the steel industry. Through the cooperation of industries in Europe, North America, and Japan, scientists in the Integrated Industrial Systems project prepared a state-of-the-art survey on integrated control systems. This was followed by a major conference at which participating industries could exchange experiences and methods for industrial management. This is a case where IIASA's results are directly transferable to decision makers in industry, and we have received favorable reactions to the survey and the conference from many of the participating industries, including the United States Steel Corporation and the Ministry of Instruments and Automation in the Soviet Union.

I cannot leave this category of results without mentioning one effort that combines both stimulation and linkage. This is what we call the IIASA computer network project. It arose from two types of need: first, our need to gain access to computing resources in the home institutions of our scientists and in collaborating institutions; and--reciprocally--the scientists' need to retain contact with IIASA when they return to their home institutions, and our collaborating institutions' desire to have access to our programs and data. IIASA's activities have triggered an international effort by teams in many of our NMO countries, coordinated not only through us but directly with one another.

11. Education in Systems Analysis

The final type of results that I want to mention concerns human resources. I feel that the most important impact of IIASA's activities will be their effect on the people from many different countries who will have spent time at Laxenburg or come into some contact with the Institute.

Some of this effect will occur through educational programs. We expect to organize formal courses in the near future; and we have begun an activity whose purpose is to determine, systematize, and disseminate the international state of the art of applied systems analysis. The results of this Survey project will include a Handbook of Applied Systems Analysis and a series of volumes on particular aspects of the subject.

12. Preparation of Systems Analysts for Advanced Careers

But I feel that the most important benefits will occur through the effects of the IIASA experience on the scientists who spend time at the Institute. What a scientist publishes in his reports can be only a small portion of what he has learned in studying a problem. This is expecially true of those who work in interdisciplinary research teams addressing real policy issues. The knowledge they gain is a form of intellectual capital that can be drawn on over and over again, and that remains with them as they return to their home institutions. Thus, a result of considerable value to each NMO country is the knowledge embodied in each IIASA alumnus. Of course, what seems to us most important is that the learning experience is different from that available elsewhere; for at IIASA, each scientist has the opportunity to see problems from a broader perspective--both international and interdisciplinary--than he would have at his home institution.

So I hope that those who are concerned about IIASA's benefits will keep this categorization of results in the back of their minds. Although not yet complete, it suggests the multidimensional view we have of our objectives.

Perhaps I can summarize what I have said as follows: IIASA brings together scientists from many nations--having widely differing economic, social, and political systems--to consider the important problems facing mankind. It makes their findings available to national and international decision makers, the scientific community, and the public.

CONFERENCE PURPOSES

The IIASA Conference is an integral part of IIASA's activities. According to the Institute's Charter, signed by representatives of the 12 founding Member Organizations in October 1972:

> The Conference of the Institute is the major forum for providing broad scientific and technical advice to the Council and the Director; for encouraging the programs of the Institute and linking them with the research efforts of other national and international institutions; and for fostering understanding of the work of the Institute.

In organizing the first IIASA Conference we tried to serve all three purposes.

As you examine the Conference papers, we would like you to keep three questions in mind. They are:

- What should IIASA's future research program include?

- How can IIASA improve its linkage with other research efforts?

- Who should know about IIASA's work, and how can they be reached?

Each of these questions corresponds to one of the Conference purposes. As we plan the development of the Institute, it would be a significant help to have your responses to these questions.

I hope that the spirit of the first IIASA Conference will be the spirit that pervades IIASA--one in which persons from many nations can work together in an objective, frank, and friendly way on the problems that all of us, as residents of the same planet, share.

Dinner Address

McGeorge Bundy

It's an enormous pleasure to be here and to see what has happened to the dream that not I alone, but many others had almost ten years ago.

One should begin, I think, by expressing again our deep indebtedness to our hosts in Austria. At the beginning of this century, Woodrow Wilson tried to describe what he thought the modern institution of higher learning--in his case, Princeton University--should be. He used a phrase that I have had in my mind all day today: "A great institution will give an atmosphere to breathe." This is what Austria has done for IIASA, and we are all deeply in her debt.

Beyond that, one must understand how deep the origins of this institution are. In the initial diplomatic phases, I went to Ambassador Dobrynin; he communicated with Moscow, and I soon found myself talking with Gvishiani. I did not know until that meeting that the study of management science, and a concern with its meaning beyond the boundaries of the Soviet Union, had been in Gvishiani's mind for years. I perhaps knew, but did not fully understand, how great the interest was in the United States at that time in gaining an understanding of complicated problems that went beyond the boundaries of that nation.

I have been reminded this evening by friends from the United Kingdom that before there was systems analysis there was operations research. I think if we were to go back in the intellectual history of every nation that is now a party to this enterprise, we would find that systems analysis did not begin four years ago, or eight or ten years ago, but a long time back. What did happen was that a confluence of streams of intellectual activity was joined in 1966 and 1967 by a political concern. My instructions to discuss this matter came to me from the President of the United States; and less than a year later they were reaffirmed by the President and by Prime Minister Kosygin at their meeting in Glassboro.

The Institute was a political undertaking and an intellectual one, and neither could have succeeded without the other. That is, of course, how I got into it: I had learned about intellectual matters by working with John Fitzgerald Kennedy, and about political matters as Dean of the Harvard faculty for seven years.

The fundamental principles that have made the Institute succeed are two. One is the enormously imaginative decision that it should be non-governmental, the invention of my friend Gvishiani. The other is a shared judgment that, as the enterprise was subject to many hazards--it would involve many languages, many different peoples, much uncertainty about its purpose, considerable doubt whether there was in fact a scientific discipline of systems analysis--it must be governed by a rigorous insistence that intellectually it would be first class. And indeed, IIASA has displayed a splendid sense of academic and intellectual excellence: without that it would not be what it is. Right from the beginning, those who saw a political value in the Institute, and they were many, understood that there could be no value of any kind without the intellectual status of a research institution whose members could match their peers around the world in terms of the quality and integrity of their work.

Now I don't claim to understand systems analysis. But I can understand that what has been achieved here in a relatively short time is, in simple terms, the establishment of an institute whose members, if they are not the best when they come, will be among the best very soon after. The Institute has put itself on the rising curve of intellectual quality in the world in which it chooses to work. This is an astonishing accomplishment for any organization whose real life is as short as ours. To stay on this rising curve is the requirement, and the guarantee, of our success.

Now all this is splendid. But there is one serious difficulty. Here are some questions I am asked all the time, and they are not trivial: "Are systems analysts human? Are they people, or organic machines? Are they cheap copies of the latest computer? Are they the mechanical version of intellectual entropy? Do they live?" My answer, because I have optimism and good faith, has been "Yes, they are human." And I am going to defend that proposition.

Now who asks these questions? There are those who don't believe that logic is a useful contribution to human affairs, who think that all organization is bad. They don't believe in systematic thought, so they disapprove of systems analysis. That doesn't seem too serious; graver criticism comes from within the trade. As always, danger lurks among those who know us best.

I choose to steal my point for this evening from Ralph Strauch of the Rand Corporation--himself, I think, an analyst of quality. His view is that the process of maintaining good judgment while engaged in complex numerical analysis is not one to be ignored. He makes the point that the power and the undoubted value of systematic analysis require that a model be abstracted from reality. With luck, you can then put the model either on the back of an envelope or into the computer. If you are careful, the things that happen on the back of the envelope are honest; and the things that happen in the computer, if you are equally equally careful, are also honest.

But then you confront the interesting question whether what you have on the envelope or in the computer can return to reality. According to Strauch, there are two possibilities. You may have what he would call a genuine "surrogate": your abstraction did not do too much violence to the reality from which you abstracted it and to which you return it. Where that is true--and it can be true in important cases--with a trim and a slice here and there you will be able to say that your skills have produced something important and immediate, more than a first approximation, indeed a first answer to what is needed in the real situation.

But, says Strauch, a lot of the time what you get from reality in your first abstraction is a "perspective". You can take that perspective and perform upon it logically, analytically, and even mathematically, and produce some answers. But the perspective represents only part of reality; if you put it back directly and take that for an answer, you will probably be wrong. It is possible, in the process of getting figures, to leave out enough of reality that when you take the answers and put them back, you can be in terrible trouble. The hazard is that in the enthusiasm of the operation one might forget, or minimize, or not take the time to tell someone else, what the risk is.

Strauch suggests--and I find this very persuasive--that the best insurance against that kind of error is in fact to be human --to know the limits of the process and care about their impact. And he makes a further assertion that I would strongly endorse: that the kind of people who perceive the limits of the process are most often those who understand it best. I do not claim that there is no mad genius with an enormous skill in mathematics and no perception of the real human condition. I am saying that's not the normal situation, and that it is a grave error to assume a natural opposition between the capacity to count and the capacity to care. I think it's the other way around, and I think that's what IIASA is about. I believe that in our assertion--that analysis counts for the whole world today as it never has before--there is implicit the assumption that caring about humanity counts as it never has before.

This is no appeal to desert the numbers. We must make sure we use them for all that they have in them. In one sense what I am saying is no more than a gloss on Howard Raiffa's splendid quotation from Einstein.* To understand the genuinely enormous problems confronting mankind requires analysis. But it also requires strong human awareness of the full-blooded reality to

---

*See H. Raiffa, this volume.

which the analysis relates. It is in this double requirement of high intellectual capacity and high humanity that I find the meaning of IIASA. I find there the explanation of the distance it has come and the distance it can go.

The distance we have come: why did Gvishiani persevere? Why did Handler pick up a labor to which he owed nothing? It's very rare, when torches are passed from one management to another, that the second stage is stronger than the first. Why did so many people in so many countries, West European countries, East European countries, Canada, and Japan, as they heard about this enterprise, put aside national pride to join in this common venture? Why did Austria understand it from the beginning? Why did such good people come, and why do we expect such good people in the future?

There may have been practical motives; but they are not enough to explain what has made this institution happen. The reason for IIASA is human beings who are looking at the enormous problems of mankind with a growing conviction that sharing what they know, and what they know how to learn, can help. And the reason for the hope that IIASA can help is that it has that joint political and intellectual root.

So I will ask our Chairman, if he will, to join me in offering a toast to the staff of IIASA: past, present, and future, may they go from strength to strength as scientists because they do the same as people.

GLOBAL PERSPECTIVES

Introduction

R.E. Levien

The following section deals with two studies of global issues that IIASA is conducting: the Energy Systems study, directed by W. Häfele, and the Food and Agriculture study, directed by F. Rabar. The two studies have in common their concern with problems that cut across national boundaries, affecting in an inherent way more than one nation. Eventually, what we learn in them will form the foundation for a more comprehensive investigation of future global development. But at this stage, they are addressed to essentially sectoral issues, and their findings will be directed to sectoral decision makers.

There are a number of significant differences between these studies, as well. One of the most important contrasts is in their stages of development. The Energy project was one of IIASA's first two research activities; it began in May 1973. Consequently, it is almost exactly half-way through its five-year lifetime. It is thoroughly engaged in the problem-analysis stage of its work, with a growing collection of results.

In contrast, the Food and Agriculture study is just beginning this year, so it is in the problem-definition stage of its work. Thus, while Häfele reports some of the initial findings of his three years of work, Rabar discusses the problem perception that is shaping the first steps of his study. Such an initial perception is essential, but experience has shown that one early result of good systems analysis is a re-evaluation of the nature of the problem. Thus, we are not so concerned whether the first conception is exactly right, as whether it seems to be a fruitful point of entry into the problem area.

Another difference between the two studies is their time horizons. The Energy program is focusing on the medium to long term, while the Food program is addressed initially to the short to medium term. This difference follows directly from the problem analysis each group has conducted, which led each of them to see the problem's critical phase in different time intervals.

A third difference between the two examples is in their analytical direction. The Energy program proceeds from the top down. It studies the global energy system as a whole and from that view derives consequences at the national level. The Food study, in contrast, proceeds from the bottom up. It will begin with studies of individual national policies and then examine how they fit together. It is not possible to say whether one or the other of these approaches is "the right one". Rather, each seems to be appropriate in the given circumstances.

The final contrast between the two cases concerns the type of issues emphasized. In the Energy study, the central focus is on technological matters. The Food study, however, is concentrating on institutional matters. Again, these differences seem entirely in line with differences between the topics.

These two studies, as I noted earlier, are the first in what will eventually be a series of examinations of such global issues. Other candidates include population, water, climate, and environment. But since each study can be expected to take about five years and to engage large teams both at IIASA and in collaborating institutions, with our current resource levels these other topics will have to wait.

Both studies--Energy and Food--will address their results to several different audiences. These results include information, methodologies, and alternative strategies or policies. They will be directed to decision makers having international responsibilities, to those at the national level, to the scientific community, and to the general public.

Both issues are crucial to future global development. IIASA cannot solve them; but we hope that by bringing our international, analytical approach to bear, we can make a significant contribution to their eventual resolution.

Energy Systems: Global Options and Strategies

W. Häfele

INTRODUCTION

IIASA's work on energy systems concentrates mainly on the medium- and long-range aspects of the problem. This is natural, since a number of national groups are concentrating on the short- and medium-range aspects. The latter studies require large data bases, are manpower-intensive, and vary significantly from country to country, and their methodological implications seem to be understood, at least to some extent. By contrast, the medium- and long-range questions tend to be global in nature, and pose partly new methodological problems. They require strong international cooperation, and it appears that even a small group can make a contribution here.

Our study of the energy problem is an example of systems analysis of a global issue. Emphasis is given to the methodology of the analysis, in the hope that the format and methods can be more generally applied. At the same time, a contribution in substance is to be made. Large investment decisions are ahead of us; exploitation of the North Sea oil, and the deployment of large-scale nuclear power or hot-water district heating installations, are examples. Investment problems are particularly pressing in the developing countries, where demands are great and resources low. Thus a focal point of our work on energy systems is to assist the decision maker.

ENERGY DEMAND

For an understanding of global energy demand in the medium- and long-range future, it is helpful to realize that there are three reasons for the persisting increase in demand: the rising per capita share, particularly in developing countries; industrial growth in developed countries; and the growth in the world's population.

Figure 1 shows the present distribution of energy consumption per capita, with a mean value of 2 kW/cap. The majority of the population lives with a consumption close to 0.2 kW/cap. It is probable that this very uneven distribution will smoothen; while at present the per capita consumption increases by 0.2%/year, this would lead to a greater increase in the mean value.

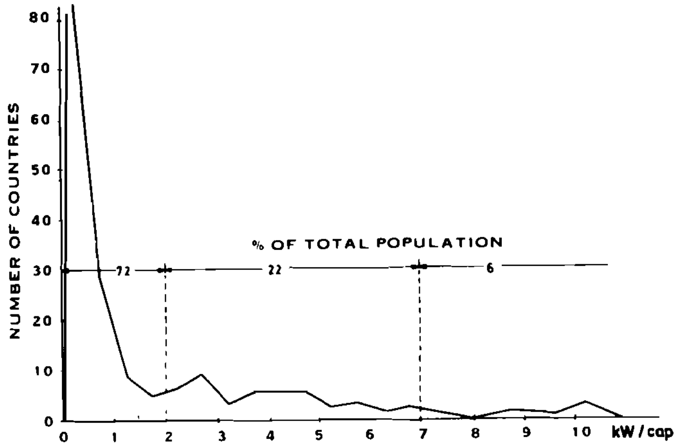


Figure 1. Distribution of per capita energy consumption in 1971.
After: Charpentier, IIASA

It is revealing to study consumption patterns in the triangle formed by industry, services, and agriculture (Figure 2). Work on the energy content of goods and services--also known as energy analysis--concentrates on the construction of certain life-style scenarios without explicitly dealing with prices, as an aid to the study of longer-range considerations. For shorter-range aspects, it is econometric methods that help one to understand energy demand. Nordhaus and Tsvetanov have conceived an econometric schema for treating statistical data from East and West on the same basis. Much information was collected at a IIASA conference on energy demand [1].

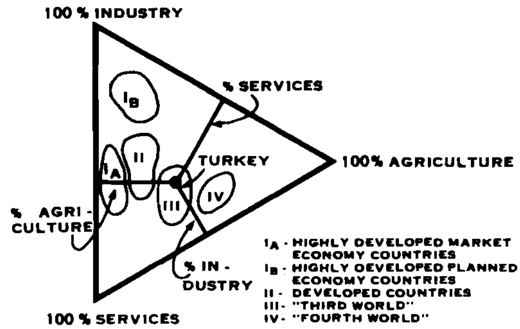


Figure 2. GNP structures of countries.

Figure 3 gives a rough scenario for long-range energy demand based on UN estimates of world population growth. The 3 kW/cap figure refers to a per capita increase that coincides with that of the past; 2 kW/cap represents the present mean. In view of the anticipated smoother distribution of per capita consumption, 5 kW/cap is more likely; and perhaps we can expect even higher values. Starting from today's value of 7 TW, this leads to something like 70 TW. We must therefore reckon with a factor of 10, and this may be on the low side.

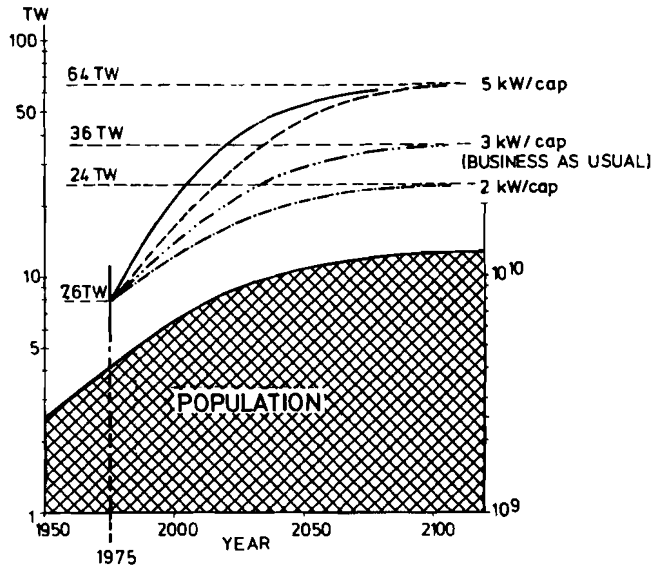


Figure 3. Global energy scenarios.

Source: [2]

RESOURCES AND OPTIONS FOR LARGE-SCALE ENERGY SUPPLY

The traditional approach to the energy problem is to ask for energy supplies sufficient to meet a given or anticipated demand. One may call this the supply-oriented approach. Accordingly, the observation is often made that we are short of fossil fuel. This is true for cheap oil and gas. With the existing technical infrastructure and the related energy prices, it is unlikely that the expected demand can be met for more than 50 years or so. But these 50 years do not reflect a limit as such.

Coal, nuclear and solar power, and probably also geothermal power provide the possibility of very large amounts of energy. But fundamental problems of changing the existing infrastructure always come up. A first case in point is coal.

The Coal Option

Table 1 gives data on fossil energy resources. It is striking to realize that in principle there is more coal in the FRG than oil in the Middle East. Worldwide coal resources are about 20 times as large as oil resources. This appears to be reassuring but is not of immediate help. The accessibility and the economic attractiveness of such resources pose severe limits. The harvesting of coal also involves the handling of large amounts of groundwater, requires energy investments, and has strong implications for land use, the consumption of auxiliary materials, and manpower. McKelvey, of the US Geological Survey, introduced his now famous diagram as late as 1974 (Figure 4). It distinguishes degrees of geological assurance and economic recoverability, thus leading

Table 1. Fossil energy resources in 10^9t of coal equivalent (1 t.c.e. $\hat{=}$ $2.92 \cdot 10^{10}$ Wsec).

	FRG	Western Europe	Middle East	USA	World
Coal & Lignite	258	422	---	2459	9294
Oil & Gas	0.43	15	160	50	400? Possibly More

Source: [3]

to the fundamental distinction between resources and reserves. This approach was extended by M. Grenon of our group and labelled WELMM--water, energy, land, material, manpower--a multidimensional space in which the harvestability of resources must be assessed.

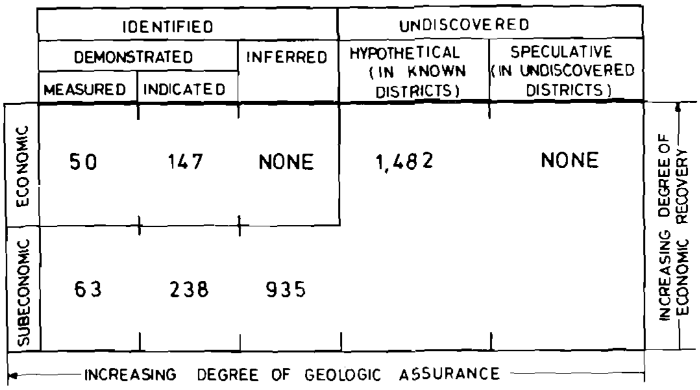


Figure 4. USGS-USBM reserves/resources classification; McKelvey diagram (1974 US coal data in 10^9t).

In Table 2, data are given for lignite mining in the FRG. It is seen that the mine is mostly a facility for handling water, second for overburden, and only then for lignite itself. A conference held at IIASA in May 1975 dealt with these generalized constraining aspects of existing resources; the proceedings form the basis of a book to be published shortly [4].

Table 3 shows the relation of resources to economically recoverable reserves, and the non-uniform distribution of known reserves. The USA, the USSR, and China have the lion's share, and the remainder is also unevenly spread. The distribution of reserves accessible by strip mining, leaving aside the limited lignite, is very unfavorable for Europe and favorable for the USA. This geographical imbalance, with all its political implications, must be kept in mind if one wants to prepare for the large-scale use of coal in the long term. Transportation over large distances, be it of primary or secondary energy, will almost certainly be a principal feature of the global large-scale use of coal. But this is by no means the only problem. Coal has run into a fundamental dichotomy: even at the present scale of availability, for instance in Europe, its market share is constantly going down. This is shown for the case of the FRG in Figure 5. Figure 5a shows the relative market share between 1950 and 1980, falling to an expected value of 10% around 1980. Figure 5b shows a continued increase in coal consumption only for the steel industry and electricity generation, while all other uses are virtually eliminated.

Table 2. Material balance for Garsdorf mine, FRG.

Material	Output	Comments
Lignite	$15 \cdot 10^6$t per year	Maximum (30-35) $\cdot 10^6$t
Overburden	$226 \cdot 10^6 m^3$ in 1974	Estimated Total $2 \cdot 10^9 m^3$ for 40 years
Water	$350 \cdot 10^6 m^3$ per year	Total for 13 years $4.6 \cdot 10^9 m^3$

Table 3. World coal resources and reserves in 10^9t of coal equivalent (1 t.c.e. $\hat{=}$ $292 \cdot 10^{10}$ Wsec).

	Resources	Economically Recoverable Reserves
3 Countries ≥ 1000	7352	338
3 Countries $100 \leq 1000$	541	53
7 Countries $10 \leq 100$	280	58
19 Countries $1 \leq 10$	67	28
World Total	~8400	480

After: [3]

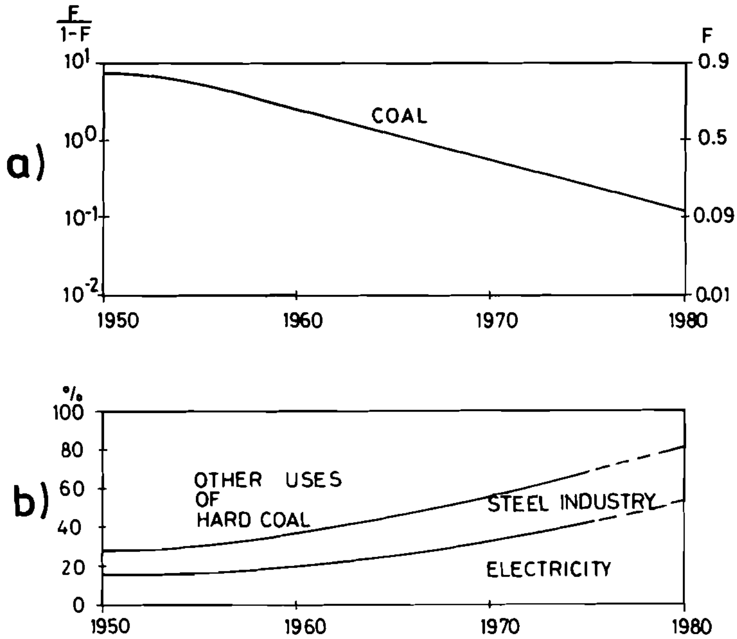


Figure 5. Market shares F of coal, FRG.

The steel industry is a special case, as it requires coal largely as a chemical. The case of electricity explains this phenomenon: the market tends strongly to the use of a clean and versatile form of secondary energy. Figure 6 illustrates this trend for secondary energy in general, again for the FRG. Solid fuel has a marked downward trend. Within a characteristic time period of 25.4 years, the equivalent of 50% of the market would be lost. (Note that in this diagram a logistic curve is a straight line.) Liquid fuels have experienced a sharp increase: the penetration constant of the logistic curve is such that within 18 years 50% of the market would be conquered. Energy delivered by networks is also on the way up; the penetration constant refers to 110 years for 50%. It is larger than for liquid fuel because it requires the installation of electric grids and pipelines.

All this points to the growing significance of the difference between primary and secondary energy. This is conceptualized in Figure 7. Before 1950, the direct uses of wood and coal had a significant share, and the distinction between primary and secondary energy was irrelevant. The advent of cheap oil and natural gas further clouded the issue: the conversion from crude oil to the refined product is comparatively a less complex and therefore cheap step, and with natural gas the difference is non-existent. But for all major energy sources of the more distant

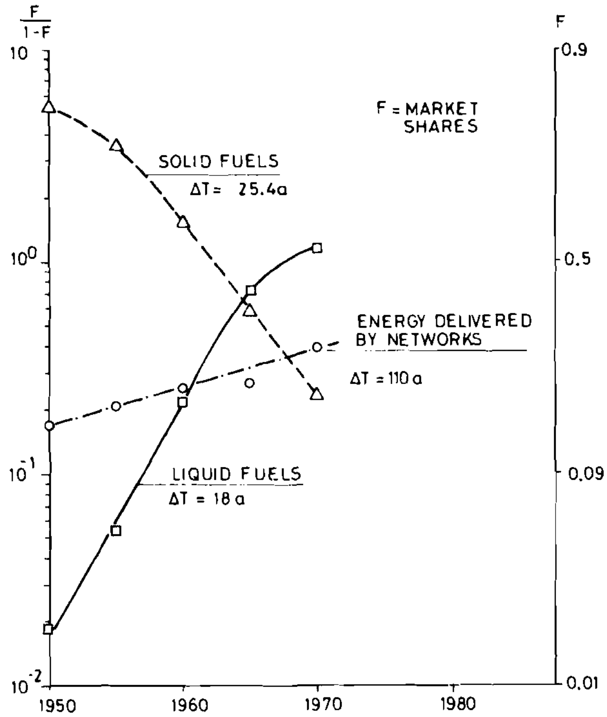


Figure 6. Market shares of substitutable forms of secondary energy (stationary conversion), FRG.

future, conversion into a convenient form of secondary energy becomes dominant, and this is true also for coal. New coal-mining technologies, the handling of WELMM constraints, long-range transportation, and conversion to energy forms adapted to the existing infrastructures of the end-use markets thus are the problems to be dealt with if the large coal resources existing in principle are to be exploited.

The IIASA Energy program has formed a Task Force, jointly with the British Coal Board, the German Ruhrkohle in Essen, and Polish and Czechoslovak groups, for the elaboration of long-range coal strategies taking account of the systems aspects outlined. We hope that such task forces will enhance IIASA's interaction with the outside, with the bodies that have particular expertise and those that are facing hard decisions.

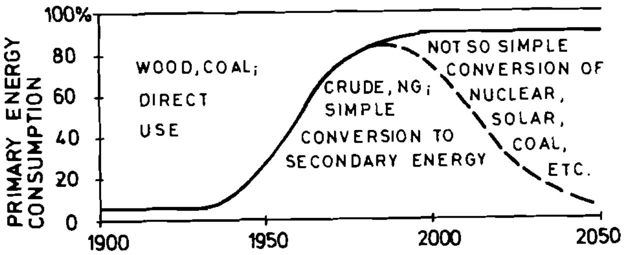


Figure 7. A widening gap between primary and secondary energies, FRG.

The Solar Option

In contrast to coal, the use of solar power has no tradition suggesting certain approaches that must be overcome in the medium- and long-range future. Solar power is in many respects an extreme case, particularly compared with the oil and gas used at present. The latter require comparatively low capital investment and today have high fuel prices, while solar power requires significant capital investment and has zero fuel costs. Again the WELMM approach is revealing: for the installation of collectors over large areas, the investment of water, energy, land, materials, and manpower is needed. In fact, it is one of the results of our studies that, with a true accounting of all side effects, the WELMM implications of a power plant of given size are comparable for coal, solar, and the light water reactor (LWR), shown in Table 4.

The figures refer to all materials to be handled, including for instance the overburdens that accompany mining. Against intuition, the materials that must be handled over a 25-year operating period are in the same ball park for all three cases; only the fast breeder reactor (FBR) is qualitatively different.

Much emphasis is given these days to local solar heat. As it requires the least change in an existing infrastructure, it is felt that this would be the most promising way to tap solar energy. For large-scale uses of energy, however, the size of the heat market must be examined. Table 5 gives some rough figures for the USA. The estimated 30 million new households installed between now and the year 2000 are those to adjust to solar heat. But the share of heating households is a mere 10% of the total demand, so that solar heat could meet only a small fraction of the primary energy requirements in the foreseeable future. Important as the savings in oil and gas are, this is

Table 4. Materials requirements for a 1000 MW(e) power plant.

Fuel	Weight of Station (10^6t)		Total Use (10^6t)	
Coal	0.3-0.35		50	Coal (25 years)
Nuclear	0.5-0.6	Light Water Reactor Fast Breeder	2.5-75 0.04-1.2	U 0.2%-U Shale (25 years)
Solar (Tower)	0.35 0.3-3	(Conversion) (Heliostat)	1-30	Mineral Ores (~5-7 years)

Table 5. Solar heat market (rough estimates), USA.

	1972	New Households 1972-2000	2000
Number of Households	$68 \cdot 10^6$	$32 \cdot 10^6$	$100 \cdot 10^6$
With (Hybrid) Solar Heating	---	100%	33%
Share of Primary Energy	10%	50% of heat requirements from solar, 50% from auxiliary systems	10%
Solar Share			2%

Source: [5]

not a viable route if truly significant amounts of energy are to be provided.

Let us recall the case of coal. A new primary energy source must be consistent with the infrastructure of the end-use market, which clearly tends toward secondary energy networks. As the electrical net is highly developed, one obviously looks for electricity generation by solar power. In the USA and elsewhere, the technological aspects of solar electric power stations have been studied in detail. It is not IIASA's aim to duplicate these studies, but rather to concentrate on their systems aspects and to communicate with groups in its member countries. A case in point is the work of the Aerospace Corporation in Los Angeles on electric power plant costs for the tower concept. This concept provides for optical transmission of light beams from ground collectors to the peak of a tower where a boiler for a conventional steam cycle is located (Figure 8). Direct sunshine without clouds is therefore required. Practical heights for the tower are a few hundred meters, and so the output is somewhere near 100 MW(e). One tends to assume that the scheme is good for sunny areas, but not for Central Europe. With this reservation in mind, J. Weingart and N. Weyss made contact with the Austrian authorities in Vienna and examined local insolation data, availability of land, and other factors.

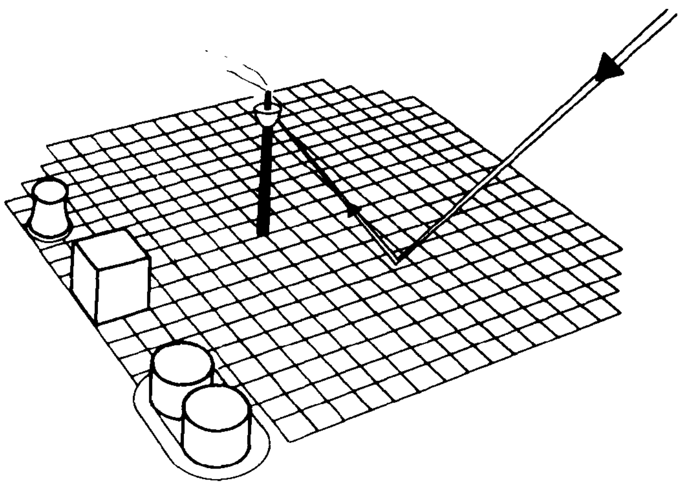


Figure 8. Hybrid power plant facility combining fossil-fueled plant and solar plant.

The result, which goes somewhat against intuition, is partly presented in Figure 9--a nomogram relating capital costs, insolation, the present oil price, the discount rate, and the resulting payback time for the investment. Assuming an isolation of 175 W/m^2 and capital costs of \$50/m^2 for tower and mirrors, one goes from point A to B, and then horizontally to point C, which relates to the present oil cost. Continuing from there to D, one meets the assumed interest rate and arrives at E, the resulting payback time. The interesting result of this example is

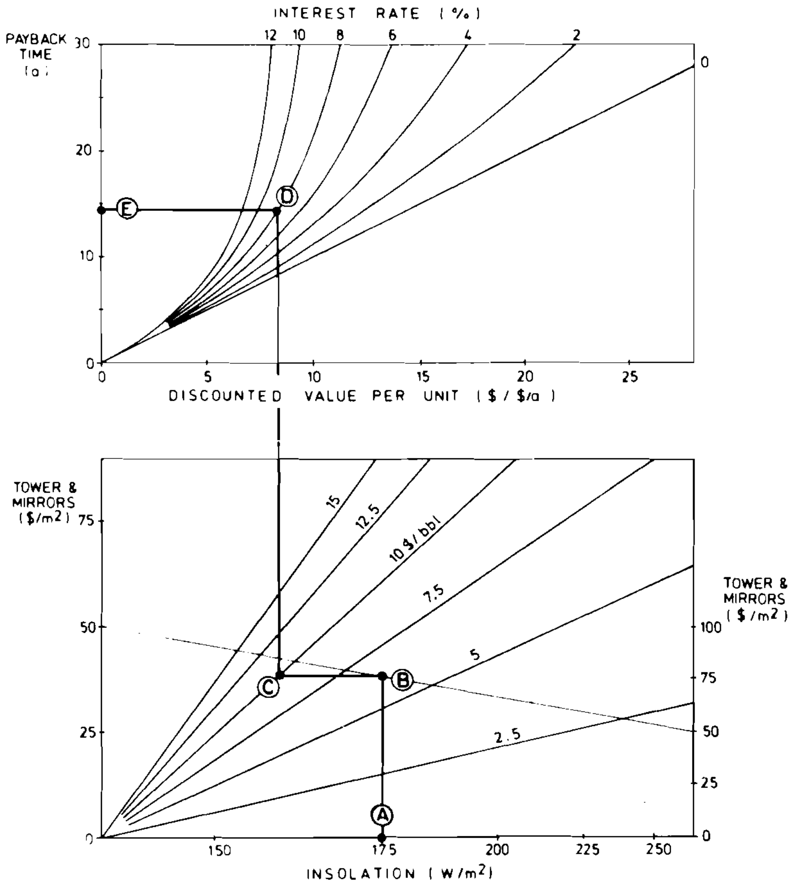


Figure 9. Tradeoff between solar specific investments and savings in fuel oil costs (hybrid concept).

that at \$10/bbl the payback time for the original investment is only 14 years. While the nomogram allows for any parameter variation, it is obvious that at a few \$/bbl a hybrid solar electric power plant would have no chance whatsoever. But the oil price changes the situation. Let us recall the basic assumption: a solar electric tower plant operates when the sun is shining; when it is not, electricity must be produced by an oil-fired station. Sunshine therefore directly replaces oil. This concept is of course somewhat stylized and not fully realistic. The real question is the value of the bits and pieces of solar power that have to be integrated into an existing electrical grid, and we are only now investigating this jointly with Electricité de France and the Austrian Verbundgesellschaft. A crude analysis has already revealed another somewhat unexpected feature: integrating bits of solar electric power requires energy storage--at present, by hydrostorage.

Table 6 gives data for total generation and storage capacity for three cases. Both France and Austria have a 6% storage capacity, far more than that of the FRG, and therefore an inherent potential for such integration. At the moment we feel that it is the storage capability rather than the land use that actually limits the applicability of solar electric power. With C. Bell as the principal investigator, we are continuing these studies jointly with a number of institutions in our member countries, to a large extent on the basis of a contract with the Ministry for Research of the FRG.

Table 6. Energy storage in electric grids.

Grid	Total Generation	Storage Capacity (Hydropower)	
		TWh	%
Electricité de France	180	12	6.7
Bratsk-Ilimsk, Siberia	135	30	22
Austria	34	2	6

The Nuclear Option

The nuclear engineering community has been forced from the outset to long-range thinking, as the development of nuclear power was clearly a long and tedious task requiring the formulation of technological strategies. Also, owing to the work of large national laboratories in many countries, a good deal is known about the nuclear option.

It is not IIASA's function to compete with these large and capable groups. Instead, we have been concentrating on three urgent topics that in our judgment have not yet been fully treated. The first of these concerns the deployment of a large nuclear fuel cycle. In the OECD countries, the installed nuclear power capacity is expected to touch the TW domain by the end of this century (see Table 7), demonstrating that this technology is well advanced and of global potential. The handling of fresh nuclear fuel is also well in hand; that of irradiated fuel, and the related development problems, can be faced only now, when technically significant amounts are becoming available. The time lag between ore and reprocessing requirements illustrates the size of the tasks still ahead of us. A study by Avenhaus, Häfele, and McGrath [6] indicates the regulatory and licensing decisions necessary if nuclear power is to be fully installed. It is this soft aspect, and not the hard technology, that poses the problem.

Table 7. OECD nuclear fuel cycle estimates: low estimate, without Pu recycling.

		1976	1980	1990	2000
Power Capacity [GW(e)]		86	171	773	1685
Ore Requirement [10^3t U]	Annual	19	45	124	202
	Cumulative	36	171	1023	2748
LWR Fuel Reprocessing [10^3t H.M.]	Annual	1.2	3.3	14	31
	Cumulative	2.1	10.7	102.3	377.3
Fissile Pu Availability [t Pu]	Annual	8	18	84	190
	Cumulative	14	79	614	2374

Source: [7]

The second topic is that of nuclear power beyond electricity generation. Figure 10 gives the projected shares of final energy uses in the FRG. Electricity expects a limited share; it is gas that is building up quickly. One should recall that natural gas will involve a large, partly existing, infrastructure that any future primary energy option must use if it is to be successful. To that extent, nuclear power has a limited potential if no applications other than electricity generation are envisaged. A IIASA study elaborates on these questions [8].

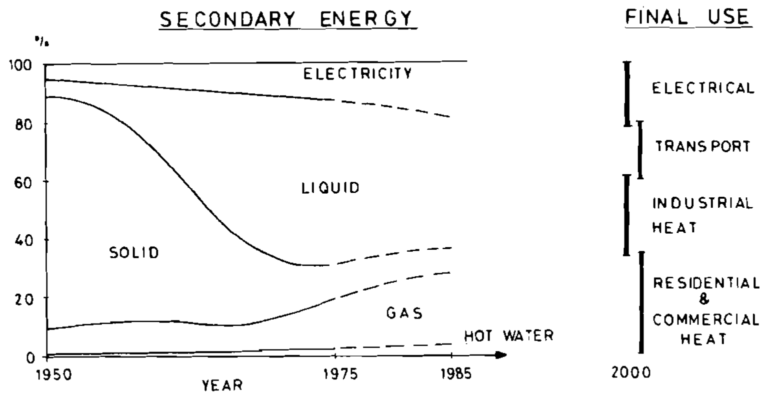


Figure 10. Partitioning and final use of secondary energy, FRG.

The third topic is the comparison of the fission and the fusion breeder. It is the breeding principle that makes nuclear power an option for a practically unlimited energy supply; without breeding, only amounts comparable with those of oil and gas can be provided. The fission breeder of reference is the fast breeder, which gives access to abundant amounts of U238. That technology exists. The French fast breeder reactor Phénix, with a capacity of 250 MW(e), has successfully operated since April 1974. Its availability is beyond 80%. Fusion in the form now conceivable is also a breeder. It gives access to large amounts of Li and so also offers a practically unlimited energy supply. That technology does not yet exist. Contrary to widespread belief, the two breeders have a number of striking similarities--such as radioactive inventory, waste disposal, and fast neutron material damage--as well as some differences. We are conducting these studies jointly with institutions in the USSR, the USA, and the FRG; a voluminous report will be finished this year.

Remarks on Five Options

Besides coal, nuclear fission, and solar--and nuclear fusion, not discussed here in detail--the dry geothermal option must also be mentioned. It should be distinguished from wet geothermal energy, which is definitely limited in quantity. Dry geothermal refers to the energy content of the Earth's crust. It can perhaps be harvested if a fairly tight heat exchange device is installed underground. We have not yet investigated this option in detail, and are looking forward to cooperation, especially with French groups, to fill this gap.

Table 8 summarizes our observations on five options for a practically unlimited energy supply and the side effects that will increasingly act as constraints. Quite contrary to a common belief, we are not resource-constrained; but even so, the energy problem remains a difficult one. In view of side effects--or better, systems inplications--the comparison of options will be arduous and complex. Many countries, in particular developing countries, are facing hard choices. The IIASA Energy program has received a major contract from the United Nations Environment Programme (UNEP) for a three-year study, jointly with the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO), on the methodology of a comparison of options. This is a main component of our program.

CONSTRAINTS

The scenario of Figure 3 calls for the build-up and substitution of an infrastructure for the supply of energy. Engineers are used to looking for optimal solutions, and most often optimal means cheapest. This implies a certain maneuverability. Our studies at IIASA suggest that it is more the constraints than the optimization that will characterize possible technological strategies. We therefore emphasize the identification and investigation of constraints. In particular, we have to some extent studied the following constraints: time requirements for market penetration; possible restrictions through waste heat disposal; risks and standards; and capital. These are briefly discussed below.

Time Requirements for Market Penetration

Following an observation of Fisher and Pry on the general validity of the logistic curve behavior applied to the market penetration by new goods, C. Marchetti has extended this work to multiple competition among primary energy sources. It is striking to see the robustness of his model over a period of more than 100 years, irrespective of drastic changes in technology and infrastructure. Figure 11 gives some of Marchetti's results. (Note that the straight lines are logistic curves.)

Table 8. Options for "unlimited energy supply".

	Reserves TWa	Technological Maturity	Side Effects
Coal	$7 \cdot 10^3$	Mature at present scale To be developed for large scale	Unfavorable working conditions Land requirements CO_2 waste & other pollution
Fission (Breeder)	$\approx 2 \cdot 10^8$	Sufficient for power plants Not yet sufficient for large Scale fuel cycle	Storage of fission products Emission of radio nuclides
Solar		To be developed for large scale	Land & materials requirements Climatic disturbance? Storage & transportation
Fusion (D-T)	$\approx 4 \cdot 10^8$	To be developed	Storage of activated material Emission of radio nuclides
Geothermal	$2 \cdot 10^5$ (???)	To be developed	Storage of waste? Emission of pollutants? Earthquakes?

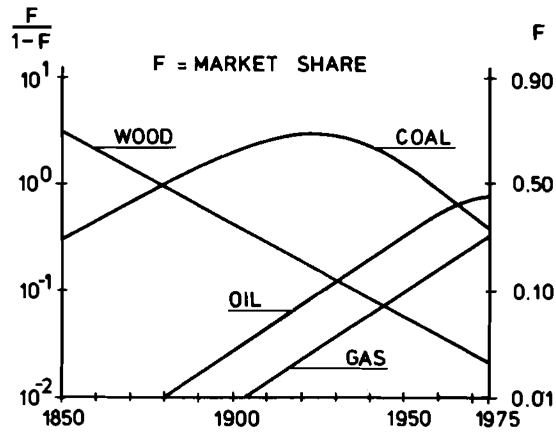


Figure 11. Energy market penetrations: world.

Wood was pushed out by coal, and coal by oil and gas. In the USA it consistently takes about 60 years to conquer 50% of the market, starting from 1%; the periods for the world as a whole are longer, for some European countries shorter. IIASA's Energy program has received a contract from the Foundation Volkswagenwerk to investigate these problems in greater depth jointly with the University of Karlsruhe in the FRG. Note that considerable lead times for technological strategies--the lag before a new technology can enter the market--must be added to the time horizon of market forces. In fact, time might well turn out to be the most precious resource.

Possible Restrictions through Waste Heat Disposal

In Europe and elsewhere, cooling water for the disposal of waste heat from energy conversion, e.g. from electric power stations, is becoming short. In the FRG, for instance, all new power stations are required to have wet-cooling towers, as the warming up of rivers and runoffs is considered to have reached its limits. Detailed studies show, however, that waste heat disposal by wet-cooling towers will also reach a limit within the next 15 to 20 years. Placing power stations offshore on floating platforms or artificial islands will provide a solution for the decades ahead, as offshore currents, if properly chosen, are larger than continental runoffs.

This reasoning has led in the past few years to the question whether or not waste heat disposal capabilities will add up to a global constraint for man-made energy production. A comparison of man-made power densities with those of nature shows that on the regional scale such concerns are well founded.

A. Weinberg and P. Hammond were the first to investigate this question. They asked the Natural Center for Atmospheric Research (NCAR) in Boulder, Colorado, to provide them with a scenario of very large waste heat release (2,500 TW) with a distribution following that of today's population distribution. W. Washington of NCAR conducted a run of the NCAR Global Circulation Model (GCM), obtaining results that were difficult to interpret (one must remember the inadequacies of the present GCM's). In view of the major investment decisions for energy strategies and their possible consequences, the IIASA Energy program--with A. Murphy, on leave from NCAR, as principal investigator--followed up by making contact with NCAR and the British Meteorological Office (BMO). With the cooperation of the latter, the GCM was run at the Kernforschungszentrum, Karlsruhe. IIASA operated the runs and provided two admittedly unrealistic scenarios: the IIASA 1 and IIASA 2 numerical experiments. In each case $4 \cdot 10^{18}$ BTU/year was assumed to be released to the atmosphere at two locations. Figure 12 shows these two places for the IIASA 1 experiment. $2 \cdot 150$ TW is about 30 times the present world energy consumption, and not inconsistent with the high estimates for global demand outlined earlier. It is unrealistic to assume that all power generation would be concentrated in only two places, still more so to assume the release of waste heat directly into the atmosphere. But the intention was to get an idea whether there is an impact. The evaluations of the computer run turned out to be extremely tedious and complex. At last, in cooperation with A. Gilchrist of the BMO, tangible results were arrived at. The figure shows the change of precipitation in northern Europe. An impact is clearly visible: the rainfall appears as having been shifted to more northern areas. Similar results were obtained for temperature, pressure, and other variables. Again one must recall the inherent limitation of the numerical models and use great caution in drawing conclusions; it is probably prudent to say only that more attention should be given to these questions, and that one cannot claim that there is no cause for concern. With a second contract from UNEP, the IIASA Energy program will continue with these studies during the next two years.

Let us return to the fact that the assumption that all the waste heat is released directly into the atmosphere is quite unrealistic. Any engineer would immediately give waste heat to the surrounding waters. The global mechanism transports energies in the order of 5,000 TW from the equatorial regions to the North Pole; Figure 13 illustrates that. The Gulf Stream carries something like 600 TW. Realizing that conceivably 150 TW of conversion losses would be distributed over a number of facilities, one is reassured that the waste heat can probably be disposed of even in the long-range future, provided this is done intelligently and in consistency with global mechanisms.

C. Marchetti at IIASA is extending these studies. He conceived large energy parks in the midst of the Pacific west-east equatorial ocean stream, for instance in the lagoon of the

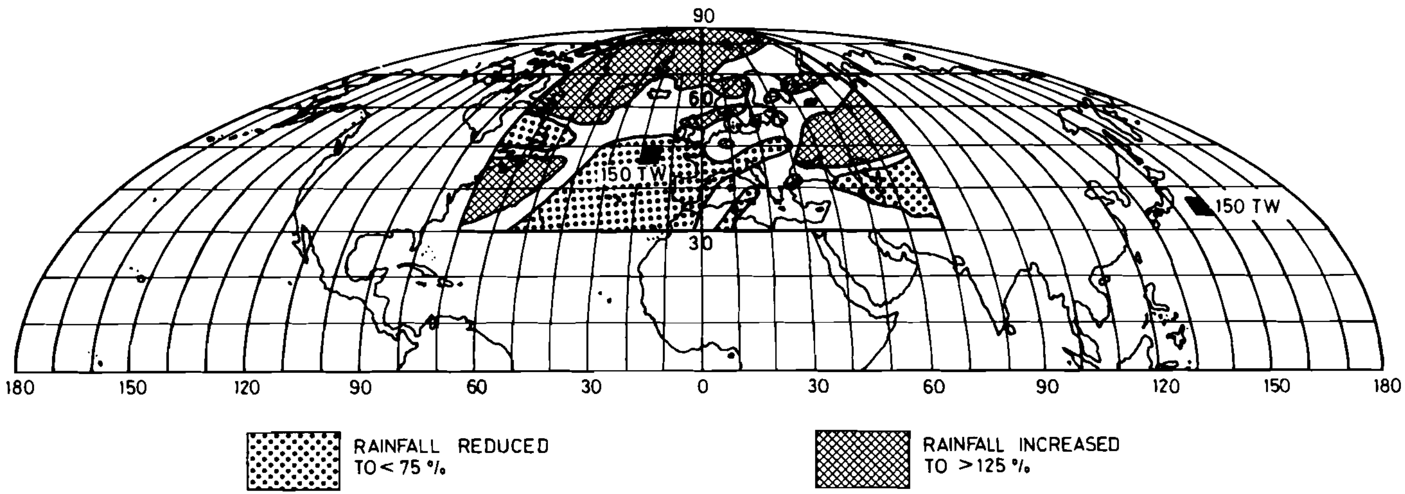


Figure 12. Experiment IIASA-1: locations of nuclear parks and change in rainfall pattern.

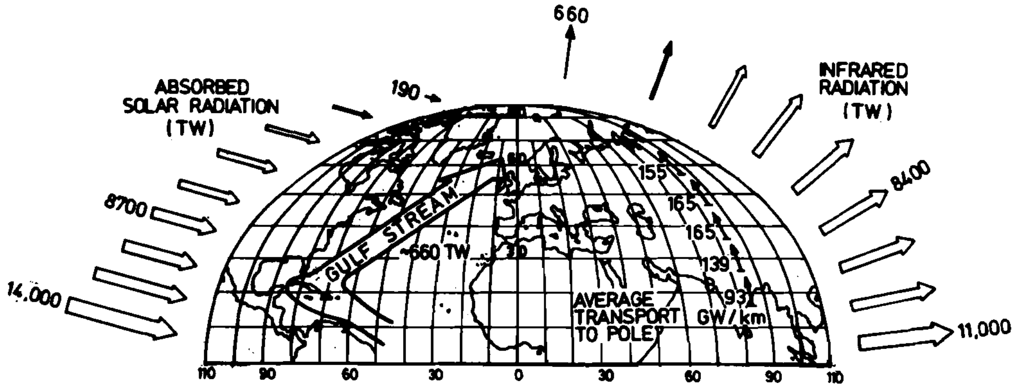


Figure 13. Natural global energy transport.

Canton Island (see Figure 14). Nuclear energy parks could be expected to generate a gaseous secondary energy carrier, to be transported by a fleet of tankers much as oil is being transported today. In fact, such energy parks would become a man-made substitute for oil fields.

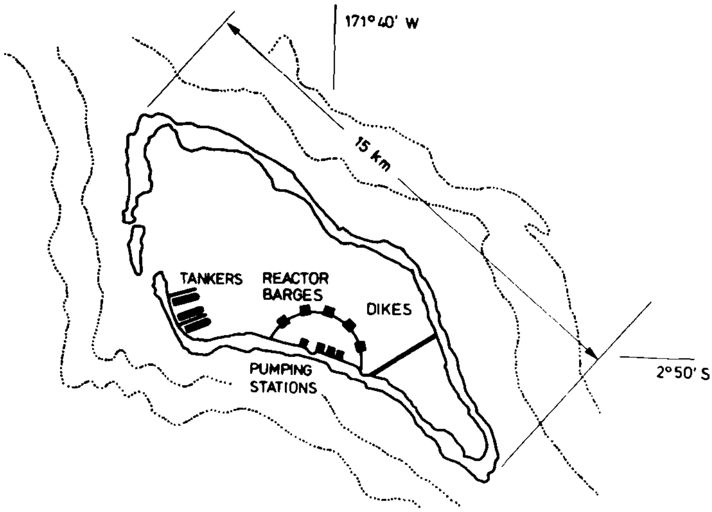


Figure 14. Canton "energy island".

Risks and Standards

The public has expressed great concern over environmental pollution. Most if not all environmental pollution is due to normal operating losses, and these are being studied by a number of national groups. It is methodologically more difficult to deal with accidental losses, especially when the accident probability is exceedingly low. Climatological impacts of large CO_2 releases due to the large-scale use of fossil fuels are a case in point, major underwater pipeline or tanker ruptures another. Particularly striking is the case of nuclear power. Its normal operating losses are very low, but attention is concentrated mainly on accidental losses. Residual risks can, by proper engineering, be reduced to preconceived levels if these are established by regulation. This leads to the famous question of C. Starr, the pioneer of risk analysis: "How safe is safe enough?" The design of procedures for establishing standards thus comes into focus. A further research contract from the Foundation Volkswagenwerk allows the Energy group to study this topic jointly with the University of Mannheim in the FRG; R. Avenhaus is the principal investigator.

A major area here is risk analysis. In view of its importance, IIASA combined forces with the IAEA here in Vienna by forming a joint study group on risk analysis--another example of the rich and multilateral modes of doing research at IIASA. IAEA's involvement is substantial. On the initiative of its Director General, Dr. Eklund, a number of IAEA's member countries seconded scientists to that group; it now embraces physicists, engineers, psychiatrists, psychologists, and ethnologists. Their main task is to identify the objective and subjective determinants of risks. In Figure 15, H. Otway, leader of the group, has outlined the approach. The engineering and operation of facilities for safety are constrained by the regulatory process, and give rise to the individual's perception of actual residual risks. A detailed understanding of the size, the mechanism, and in particular the expected frequency of accidental events is the objective input for the regulatory body, the engineer, and the individual. For the individual there are also psychological determinants; and through group processes and societal attitudes, the regulatory body is again influenced. Some aspects of the psychological determinants of risk perception as investigated by P. Pahner are outlined below.

- Event

    Man-made > natural hazard
    Difficult > easy to conceptualize
    Large, infrequent > small, frequent consequences

- Situation for the Event

    Involuntary > voluntary participation
    Passive > active involvement

Non-transparent > transparent situation
Indirect > direct confrontation

- Individual

No experience > experience in situation
Difficult > easy to imagine
Future > present oriented
Unconscious psychological factors

(X > Y means that X causes risk to be perceived higher than does Y).

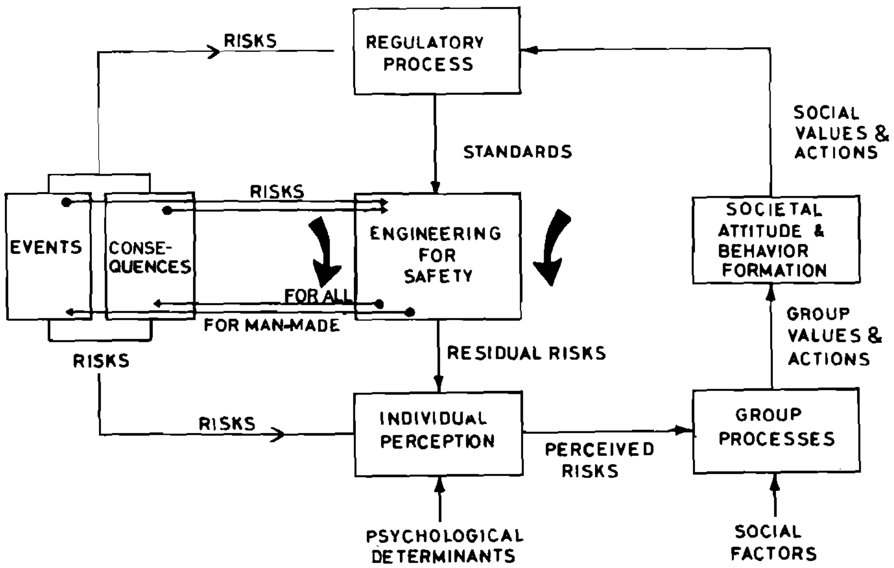


Figure 15. A conceptual framework for risk assessment.

Pahner is also studying the psychological displacement of anxiety in the case of nuclear energy. There is growing evidence that the fear of peaceful nuclear power is subconsciously based on the threat of military nuclear power. The individual's fears are displaced from the military domain, in which he has no power, to the domain of peaceful nuclear power, where he feels he can exert influence.

Another problem of standard setting is the screening of methods for assessing the value of a life, as pursued by J. Linnerooth. If the consequences of possible standards are characterized by only one attribute, such as changes in mortality, alternative standards can be compared simply in terms of their cost effectiveness, that is in terms of mortality risk reduction. If, on the other hand, the consequences are characterized by multiple attributes, e.g. changes in mortality, injury, and property damage, these must be expressed in common units to allow comparison. One way is to place a monetary value on each attribute, a procedure which makes possible a formal cost-benefit analysis. A method for quantifying mortality risk in monetary units is to value each expected life lost according to the capitalized earnings of the potential victim. Alternatively, each attribute can be expressed in terms of utility, reflecting the preferences of those affected. These methods are an alternative to a less formalized procedure: the judgmental approach, where the decision maker personally weights the importance of the attributes characterizing the decision consequence.

Risk research is a young and extremely complex branch of research. But in view of the issues at stake, it must be pursued.

Capital

It seems that the long-range options for a large-scale energy supply are all capital-intensive while having low or zero fuel costs. An extreme case in point is solar power. Used not only for supplementary purposes but on a large scale, it may cost \$3000-4000/kW. Capital availability will therefore be a severe constraint, not only in highly industrialized countries but throughout the world. Work on this topic has just begun in IIASA's Energy program and will be discussed under the notion of strategies. The various aspects of the present energy situation--resources, demands, options or, almost certainly, combinations of options, and constraints--must be identified and ordered so that we can tackle the problem of the next few decades: namely, to manage the transition from today's energy situation to a satisfactory long-range solution, which requires the design of appropriate strategies.

STRATEGIES

At the very beginning of IIASA's work on energy, A. Manne and W. Häfele conceived a linear programming (LP) model for the transition from fossil to nuclear fuels. The task was how to meet an exogenously given energy demand in view of limited oil and gas reserves and limited potential for investments. The number of years that oil and gas reserves would last was a parameter: 40, 60, 80, and 100 years were considered. Investment potential was crudely modeled by a certain interest rate and a limited production capacity to install new power plants. The question was the optimal timing and allocation of investments. The model has meanwhile been generalized by A. Suzuki and L. Schrattenholzer, and now incorporates solar electric power, coal, and potentially also other sources. An example of a typical result is shown in Figure 16, where a given electricity demand is met by the various primary energy sources with a certain time dependence. This, of course, must be seen in the context of certain assumptions on prices.

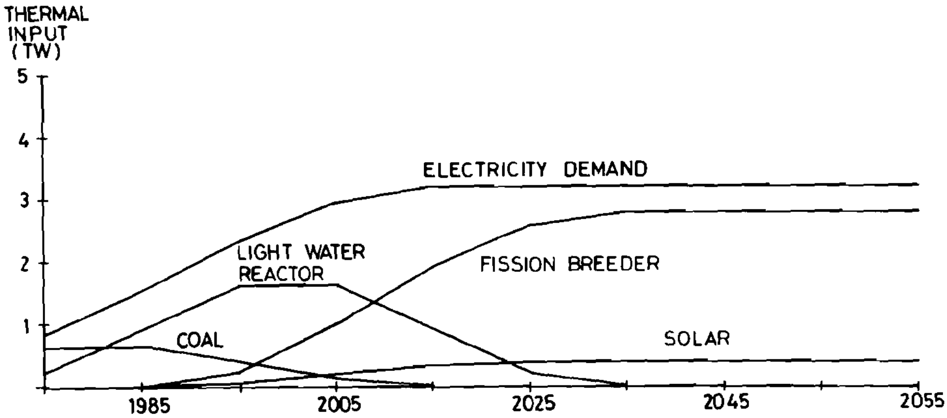


Figure 16. An example of optimal allocation of primary energy sources for meeting electricity demands: oil and gas supply for 60 years.

The point of these LP results is that the strategies have a time horizon of 75 years, and the annual allocations form a sequence that is optimized as a whole. More important than the allocations over time are the possibilities of arriving, by the use of shadow prices, at an ordering of alternatives for technological development. The question of the integral share of the electricity supply over the planning horizon can also be handled. Figure 17 illustrates a typical result. The integral share varies with the price of coal. The results are very close to another for oil reserves assumed to last for 60, 80, and 100 years. In other words, the prices are not yet a critical parameter: they do not really influence the degree to which coal comes into the picture. This is radically different for only 40 years of oil supply. Despite high prices for coal, its share is high; its use becomes a necessity in the scope of the model.

The LP model presented here becomes meaningful only when the energy demand and the capital availability are internalized within one model or group of models. This touches on perhaps the most important point of all our investigations. As observed earlier, in the transition from today's infrastructure to one

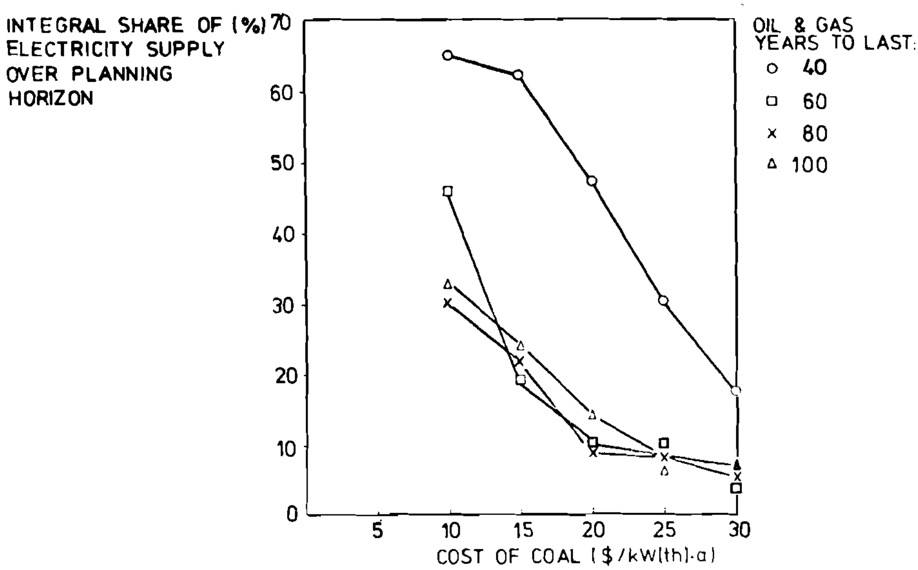


Figure 17. Contribution of coal for electricity supply as a function of current annual cost of coal.

that is able to meet the requirements of tomorrow's heavily populated globe we must concentrate on the structural changes. Present modeling efforts often use Leontiev's procedures by referring to the coefficients of an input/output matrix as given by today's conditions. The evolution of inputs and outputs is then considered, but changes of the matrix--the underlying structure--are not. This limits the meaningful time horizon. In contrast, technological strategies change the infrastructure and the input/output matrices representing it. Therefore, we have to deal with an economy in a transition induced by forces beyond traditional market forces, which are fairly well understood from an equilibrium standpoint.

By means of energy analysis, we hope to identify life-style scenarios and energy demand patterns for the long-range future and use them as targets for transition. This is the context in which the internalization of energy demand and capital availability must be viewed. We arrive at a scheme, shown in Figure 18, devised by Yu. Kononov. Here we distinguish among various strata. The second stratum refers to a number of economies, and it is necessary to regionalize, much as Pestel and Mesarovic did [9]. The regional economies interact by trade and exchange, and this interaction is on the stratum of the world. The three time periods define the existing infrastructure, the transition period, and the long-range future. Once we have obtained energy

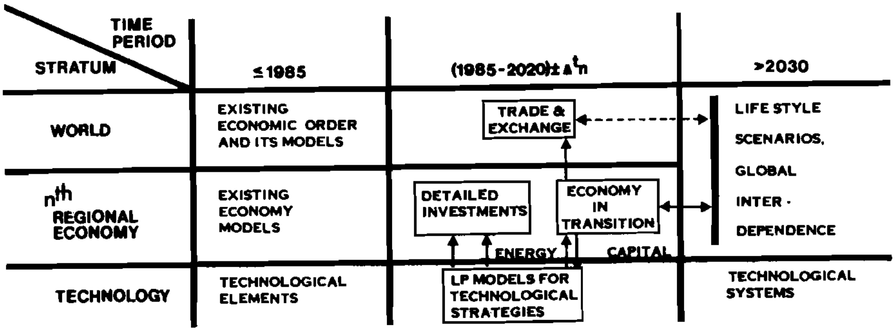


Figure 18. Interlinking models for energy strategies.

demand and capital availability during the transition period, we can use our LP model to identify the best technological strategies. The model for an economy in transition must be an aggregated one, if only because of lack of data. This in turn necessitates the detailed identification of investment consequences, as was done in the USA with Project Independence. We are fortunate to have received the computer model of the Bechtel Corporation identifying the first-order investment consequences of energy strategies, as well as that of the Power Research Institute of the Siberian Branch of the USSR Academy of Sciences, our partner institute at Irkutsk. L. Belyaev is pursuing certain methodological questions raised by interlinking these models. We therefore have the possibility of engaging the codes from East and West in parallel.

Clearly, the aggregated model for an economy in transition becomes the cornerstone for the interlinked models that together allow for evaluation and comparison of regional energy policies and the consistency among them. The USSR Academy of Sciences in particular has asked us to make such an investigation, and we put great emphasis on the task.

Economies can collapse. Structural changes may be absorbed by the system 21 times; the 22nd change might lead to collapse. Instinctively, many of us feel that this danger should engage all our interest. Avoiding collapse will ultimately be more important than achieving short-range cost optima. Thus traditional optimization for discounted costs need not be the right routine. The Energy group has been much influenced by the Ecology group, and in particular by the notion of resilience conceived by C.S. Holling to express a systems behavior that strives for the capability to absorb shocks. The system changes through absorption but continues to exist. The methodological tool to express this is differential topology--the discipline of which Thom's famous catastrophe theory is a product. Catastrophe theory relates fundamentally to nonlinear phenomena. In particular, Thom's distinction between fast and slow variables seems to reflect exactly the distinction between yearly economic variables and the slowly changing variables that represent an economic infrastructure. Thus the enlightening ecological approach of Holling and his group leads us to the conceptualization of an economy in transition by means of differential topology.

A modeling effort of this kind must be done step by step. What we are after can best be described by an artificial, oversimplified model with only two variables: population and per capita energy consumption. Figure 19 shows the topological representation of that model. There are two distinct basins (A+B and C+D) with two attractors for the trajectories. These attractors lead in one case to a growing population with a finite per capita energy consumption, in the other to a vanishing population with an ever-increasing per capita energy consumption. They are divided by a distinct line, the separatrix that originates from the governing saddle point. If through an unknown event the system state is thrown across the separatrix, it will suffer a qualitatively different fate. Let me stress again that this is an oversimplified model whose purpose is merely to illustrate how one can describe methodologically the mechanisms leading to our economy. H.R. Grümm is pursuing the resilience concept in rigorous mathematical terms.

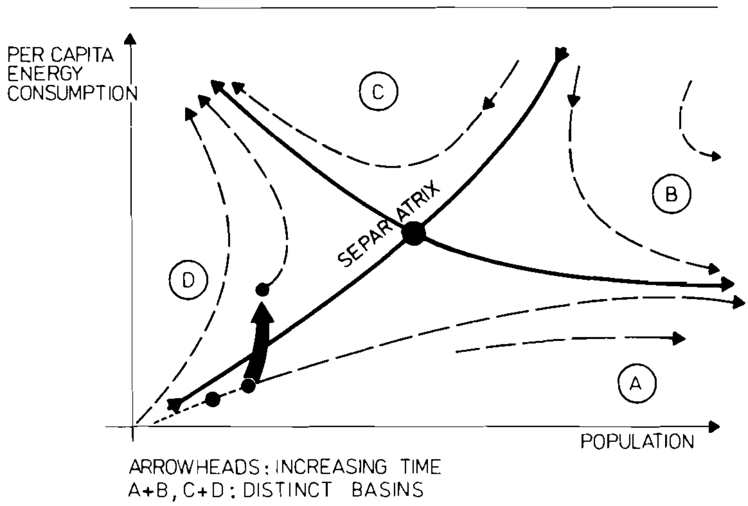


Figure 19. Resilience and systems evolution.

Figure 20 shows the economy model we are working on. It comprises the structure of an economy as slow variables and the economic yearly production as fast variables. It shoots for a normative consumption and distinguishes between investments that follow traditional mechanisms, mostly for purposes of growth and replacement, and those made as strategic substitutions. This work is well under way but has not been finished. Our intent is to integrate the resilience notion in the economy model, in much the same way as it is integrated in the budworm studies and the related policy questions pursued by Holling's group. If we are successful, it is likely that other problems of strategy can be dealt with in similar fashion, perhaps including that of appropriate strategies for food and agriculture.

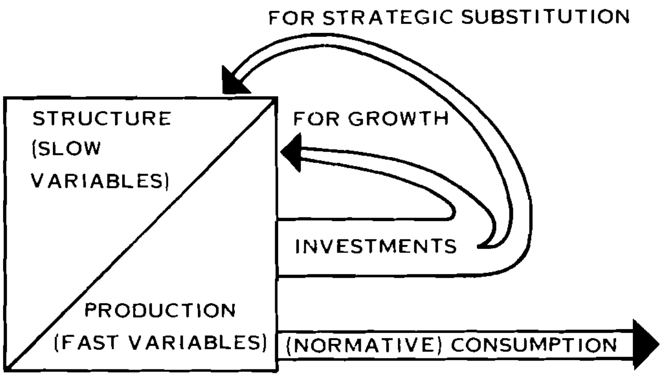


Figure 20. Dynamic model for an economy in transition.

GLOBAL ENERGY SYSTEMS

The studies of IIASA's Energy program are only at the halfway mark; the target for finishing them is the end of 1978. It is therefore premature to expect results in the true sense, but a summary can be given. Global energy systems are viewed in terms of their inherent capability to meet very large energy demands. It is thus important to realize what the present situation is. This is shown in Figure 21. From our studies on secondary energy and the detailed features of energy consumption, we have learned to appreciate the importance of the local and regional consumer systems. They distribute secondary energy down to the kW level and so cover distances of 5 to 50 km, say within a city or group of cities. Secondary energy is fed in over distances of 100 to several 100 km, as electricity in overhead lines and as a gas in high-pressure pipelines. Barges,

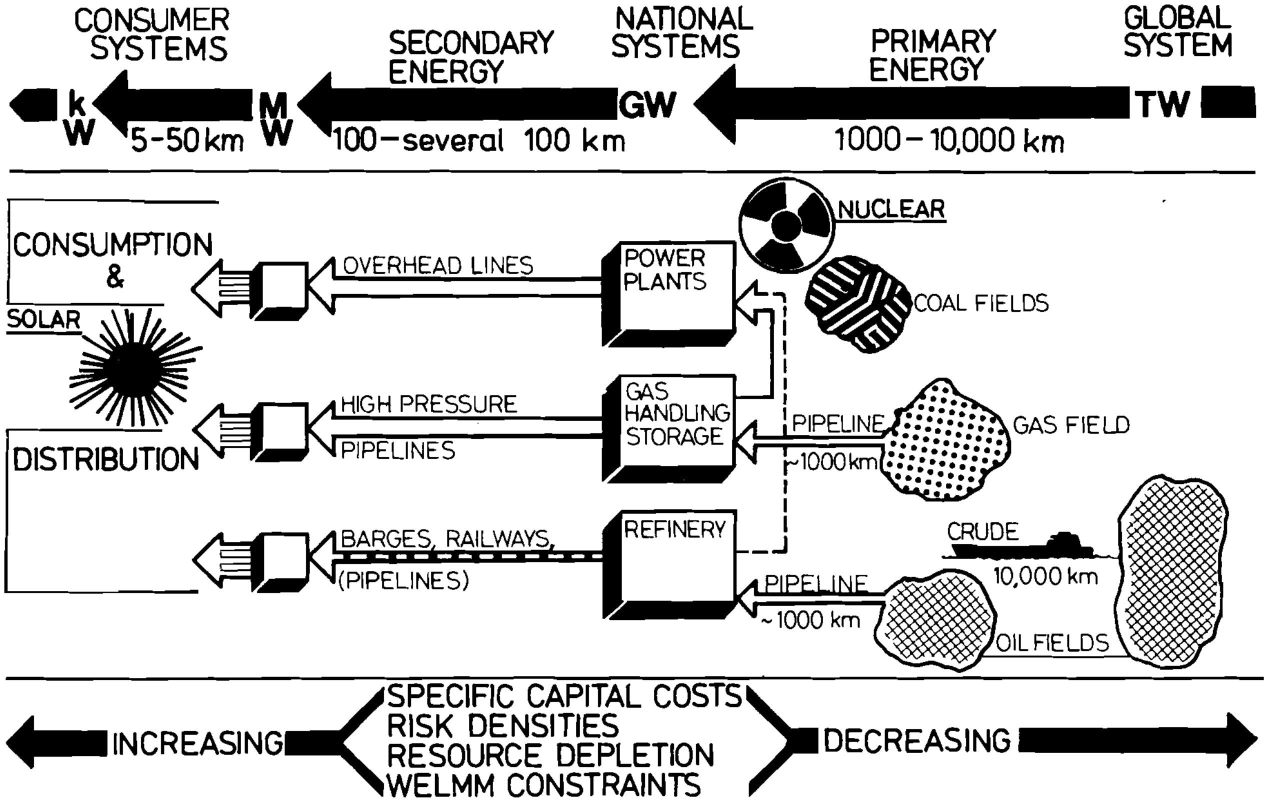


Figure 21. Present structure of the global energy system.

railways, and other means of transportation deliver refined oil products. On the level of national systems, the GW level, we then have large energy-conversion facilities, electrical power plants, refineries, and gas-handling storages. Only now does primary energy come in. Coal fields may or may not be close to the conversion facilities. The same applies to gas fields. The crude oil so important today is transported over several 1000 km in large tankers, which connect the national systems and the fields of cheap oil. Thus today's oil supply system is already global in nature and has reached a size of about 1.7 TW. Specific capital costs, risk densities, resource depletion, WELMM constraints factorially become of greater concern the more we remain on the regional level; the spread to the global level tends to decrease their role somewhat.

It is important to realize the position of nuclear and solar power as indicated in the figure. Nuclear power is placed on the national level, that is the GW level, and attached to electricity. Solar power is placed in the kW to MW domain on the side of the consumer systems. Probably neither can meet the supply challenge, which is in the TW domain where the oil supply is--at global level already today. Figure 22 shows possibilities for structuring future global systems. Let us recall our earlier observations. Changing the local structure for energy consumption and distribution is expensive and cumbersome. In market countries, it may go against market trends, whose strength we have seen in the case of coal. Above all, it will be time-consuming. Further, modern energy systems in the medium and long range will increasingly depend on the not so easy conversion of primary energy, of which power stations for electricity are a forerunner. This entails the disposal of large amounts of waste heat, suggesting the seashore if not the open sea. Then, the law of scale presses for large units; mastering energy transportation will allow for very large stations, guaranteeing availability and redundancy of the secondary energy supply. The handling of chemical and/or nuclear wastes also demands concentration of conversion facilities, as do risk considerations. The notion of embedding that engaged us during the early stages of IIASA's Energy program is still relevant; we are continuing to consider the embedding of energy systems into the hydrosphere, the atmosphere, the ecosphere, and the sociosphere.

All this leads us now to a few possibilities, outlined in Figure 22. The point is not to alter the local and regional supply and distribution system. Neither the electricity grid nor the grid for natural gas should be drastically changed; the distribution grid for liquid hydrocarbons should possibly be adopted. Methanol is the key word here. We have related the kW, the MW, the GW, and the TW domain to geographical distances, so the coastline offers itself as the border between the GW and the TW domain, with two forms of primary energy at this interface. We have seen that coal, if harvested on a large scale, must be surface-mined and thus transported over distances of

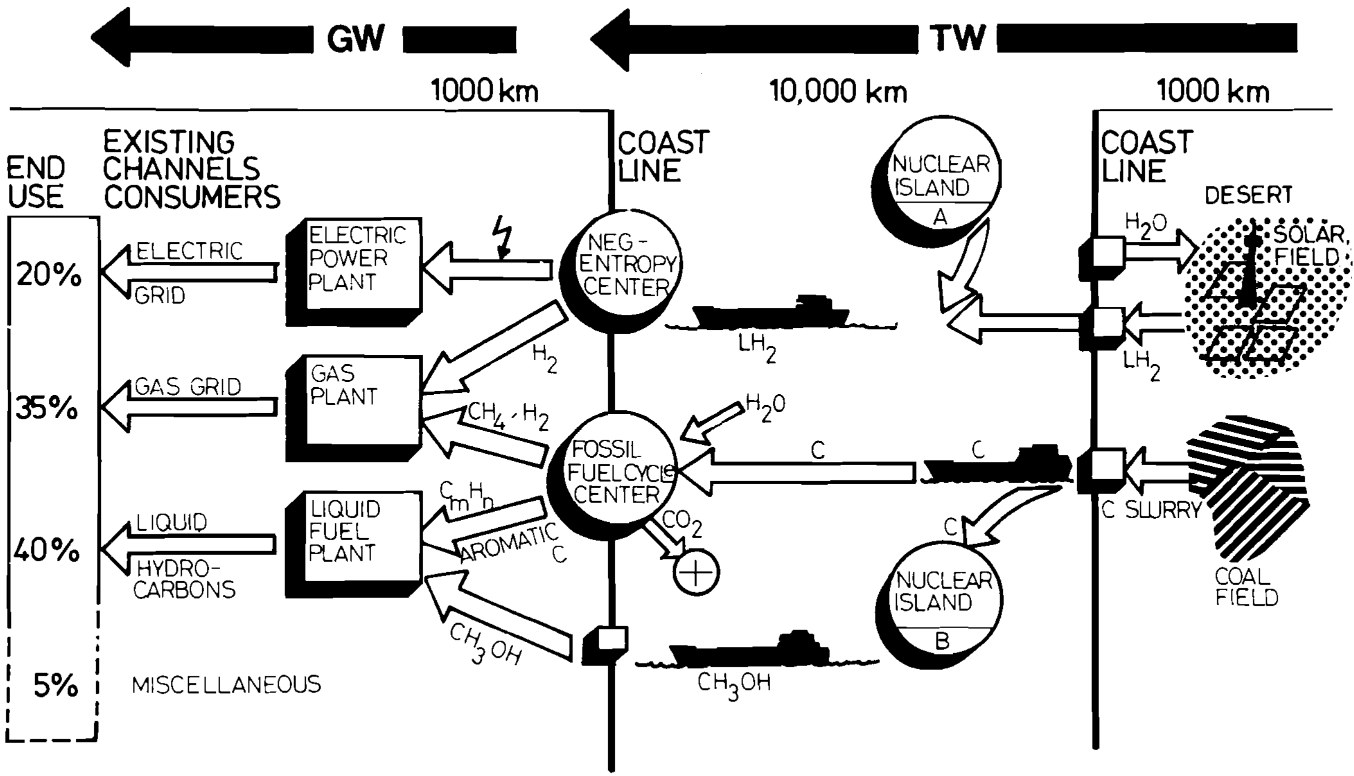


Figure 22. Options for structuring a global energy system.

1000 km or so, for instance to Western Europe or across the USSR. This introduces the need for fossil fuel cycle centers. Further, large-scale solar power requires land and materials to cover that land. Areas selected on a global basis suggest themselves, and again we face transportation in the TW domain--several 1000 km. Nuclear power fits into that scheme naturally; also, for inherent reasons, it belongs in the TW domain. Thus nuclear energy parks, beyond nuclear fuel cycle parks, enter the picture. A remote possibility for energy transport, liquefied hydrogen, offers a number of environmental conditions that are surprising. The negentropy contained in liquefied hydrogen would have to be used in cold turbines that usefully bridge the pressure gaps.

Following this line of reasoning, one is led to reflect on levels of utilities and their links to levels of abstraction. This is illustrated in Figure 23. In the early centuries, mankind was restricted to mechanical energy production by animals--the kW domain. Civilizations expressed themselves in the form of buildings and agriculture. With Newton, physics was the understanding of visible phenomena of matter. Dealing instead with the invisible domain of molecules and atoms--electrodynamics and thermodynamics--was a significant step.

LEVELS OF UTILITY/ABSTRACTION

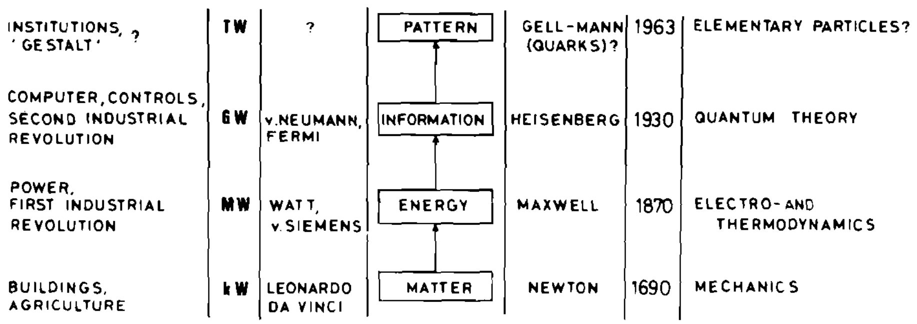


Figure 23. Levels of utility/abstraction.

With the steam engine of Watt and the dynamo of von Siemens, mechanical energies of the MW level became available; adequate power led to the first industrial revolution. A further step led to quantum theory and information, a distinctly new level of abstraction and utilization that von Neumann and Fermi may stand for. It opened the GW domain, together with the dimension of automatic data handling: the second industrial revolution. A further step of abstraction is ahead of us: it leads from the level of information to that of patterns. Gell-Mann's quarks as elementary particles are more a structure than a particle. We conjecture that this leads us into the TW domain. The problems here are not so much technological hardware elements; we have learned to master these. Instead, they concern institutions and the soft aspects of complex management and decision-making--licensing, regulations, standard-setting. Our limited capability to deal with these questions, including that of a global political order, will establish the real limits. Indeed, the possibilities for global energy systems outlined in Figure 22 pose severe soft problems. Who guarantees safety, and the security of supply; who is in charge of the timely and adequate supply of secondary energy; which organization--possibly international--responsibly sees to the disposal of all sorts of wastes? And who regulates the pollution and risk standards to be applied? It is not clear that we can create institutions that can do it. It is this quest for a "gestalt" that will ultimately characterize the energy problem.

In view of these difficulties, the proposal is often made to use the "soft option"--wind power, biogas, solar power, local hydro, and so on--because that decentralizes the energy supply and thus becomes secure and resilient. We have doubts that it can be done for 12 billion people at 5 kW/cap each. But in view of the importance of the issue, we have started to evaluate related questions in greater depth. It is indeed necessary to understand and sense the limits of the "soft option".

FINAL PRODUCTS OF IIASA's ENERGY PROGRAM

IIASA's Energy program has taken the end of 1978 as a target. By then, it is intended to have three tangible products.

1. *A set of methods and procedures for comparing options for the supply of energy.* This largely follows the lines of the contract with UNEP in Nairobi. The aim is not to preempt the judgment of the decision maker. Nor is it possible for a small group like ours to go into the data-intensive and hence region-dependent part of such a comparison; this can be done only on a local or regional basis. But it is natural for IIASA to concentrate on the *methods* for doing so, and to give typical examples.

2. *A set of methods and procedures for evaluating and comparing energy policies* of world regions in view of global constraints. This is not drastically different from Product 1, and we hope to achieve it largely by interlinking models as outlined in Figure 18.

3. *A set of comprehensive conclusions and recommendations for alternative strategies*, in report or book form. This is necessary if IIASA's Energy program is to come to a meaningful end.

References

[1] Nordhaus, W.D., ed., *Proceedings of the Workshop on Energy Demand*, CP-76-1, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[2] United Nations, *World Population Conference*, August 1974, Bucharest, Romania, United Nations, New York (in press).

[3] *World Energy Conference Survey of Energy Resources*, Detroit, 1974, U.S. National Committee of the World Energy Conference, New York, 1974.

[4] Grenon, M., ed., *Proceedings of the Workshop on Energy Resources*, May 1975, International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

[5] Bethe, H.A., The Necessity of Fission Power, *Scientific American*, 234, 1 (1976), 21-31.

[6] Avenhaus, R., W. Häfele and P.E. McGrath, *Consideration on the Large Scale Development of the Nuclear Fuel Cycle*, RR-75-36, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[7] Crawford, R.E., and W. Häussermann, *OECD Projected Nuclear Fuel Cycle Demand and Supply*, OECD, Paris, 1975.

[8] Häfele, W., and W. Sassin, *Energy Strategies*, RR-76-8, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[9] Mesarovic, M. and E. Pestel, eds., *Multilevel Computer Model of World Development System*, Vols. 1-6, CP-74-1/6, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1974.

Food and Agriculture:
Global Aspects of Supply and Demand

F. Rabar

After the global energy problems, let us now turn to the field of food and agriculture. My presentation must be different in structure and style from Häfele's for two reasons. First, we are at a different stage of research; as we are just beginning our work, problem assessment is based more heavily on the findings of other groups and derived from debates on food and agriculture. Second, our field differs substantially from that of energy in several ways, of which I would like to mention just three.

- Biological need sets a lower limit on the food requirement. If this minimum is not met, human life is in direct danger. This adds an emotional and moral undertone to what would otherwise be simple technical statements.

- Hunger exists now, while the energy crisis just threatens. Lack of time for short-run technological solutions suggests remedies in the fields of distribution and economics, and investigation within the present institutional framework.

- While energy consumption depends on life style, food production is life style itself for most of mankind. Thus, it is closely interwoven with social, cultural, and traditional problems. Reducing it to a scarce-resource problem would be a complete misconception of its significance.

These differences do not preclude a growing cooperation between the Energy program and the Food project. As our work advances more and more common problems will occur, and joint work, as well as complementary research, will be needed to solve them.

When we consider global food supply and demand, we begin with a question that is far from rhetorical; neither is it trivial. The first symptom of the food crisis--and perhaps the more characteristic--is that there is no agreement on whether we have a crisis at all. This fact is significant and may remind us that, while arguing about the reliability of predictions, we sometimes forget our main problem: how to understand the present. In the past, history was a guide to the present. In our quickly changing world, we orient ourselves more in the light of the rapidly approaching future. Thus, predictions of the future also give reliable information about the present.

Predictions about the food situation are varied and contradictory; our information about the present is ambiguous and unreliable. Do we have a food crisis? The spontaneous, intuitive answer of some unspoiled people might be an unhesitating yes. After all, we seem to agree that we have hundreds of millions of hungry people. No one questions the existence of hunger, though some might argue about the numerical results of the related statistics. Yet there are several ways of answering this question with a no--further evidence of how difficult it is to understand the present.

The reasons for denying the existence of a food crisis become clearer if we investigate them in connection with the symptoms that are taken to indicate there is a crisis. This approach contains some lessons for IIASA's research.

Perhaps the most obvious symptom is the decrease in food reserves. When discussing the food crisis, most authors begin by describing the depletion of international stocks. Figure 1 illustrates this problem. The recent drop in food reserves below the level of weather-induced variability was cause for concern by many experts and rang the bell for a food crisis. Ever since, discussion has been going on about whether 1972 was "aberration or permanent turnaround" (Poleman, 1975). Some experts explain the events of 1972 as essentially being due to transitional factors. Many argue along the same lines: "if we had a different policy..."; "if there had been no droughts in different parts of the world at the same time..."; "if international stocks had not already been depleted...". In their view, the food crisis is a temporary imbalance between supply and demand. It is an ad hoc, random problem due to droughts, floods, disasters at a particular time; and the long-term trends do not justify our fears.

The solution offered by those who think that the crisis is accidental is generally the creation of international stocks with a well-determined safety level and thus, through the stocks, of stable prices to avoid the detrimental effects of price fluctuations. However, to regard this as a solution we must accept two important assumptions: that the food problem is adequately reflected in international trade, and that the imbalance is temporary and accidental. Neither of these is supported by sufficient evidence.

International trade does not reflect the food problem. If we look at the data of Table 1, we can see that, for instance, Bangladesh (with 77 million people) participates in 0.3% of the world food imports, and the average daily calorie intake of its people is 1,840 compared with the FAO minimal requirement of 2,385 Kcal. The situation is similarly grave in India, Indonesia, and Pakistan. These countries together with China have 1,717 million people, 44% of the world population, and participate in 4% of the food imports. It is quite clear that the picture may change if we combine the imports with the production figures, but it does illustrate the magnitude of the problem. The average food demand in many developing countries is below the nutritional requirement; and according to the FAO estimates, this will still be the case for 34 countries in 1985--countries representing 800 million people. This simple example may suffice to show why the real problems may be neglected if we concentrate just on trade and on the traditional economic concepts of supply and demand. Behind the large international food stocks, widespread hunger may still prevail. The demand on the international market is not manifest and measurable, as some countries cannot buy the food. Thus, here we have for our prospective research:

Table 1. Participation of some Asian countries in international trade (1972).

Country	Population (in millions)	% Participation Food Imports	Intake per person/day Kcal	Grams
Bangladesh	77	0.3	1840	40
China*	821	1.7	2170	60
India	581	0.7	2070	52
Indonesia	128	0.5	1790	38
Pakistan	69	0.5	2160	56
Philippines	41	0.3	1940	47
44.5% of world pop.	1717	4.0		

*Estimated

Lesson 1

If we want to grasp the real problem of hunger, we must find out which economic processes lead to a situation where demand will approach the nutritional requirement, and how international trade and national agricultural policies influence the hidden, latent part of demand.

If we now turn to the implication that the food problem is temporary, a glance at Figure 1 will show the contrary. The graph indicates--apart from the dramatic drop in 1972--a general decreasing trend in stocks.

We see from this figure how myopic we are when predicting the future. In spite of the more or less clear trend, the main concern up to 1972 was how to get rid of "excess" stocks. Even the *FAO Commodity Review and Outlook*, published in 1972, predicts that "...[wheat] supplies in exporting countries appear likely to be more than sufficient to meet the foreseeable import demand in 1972/73".

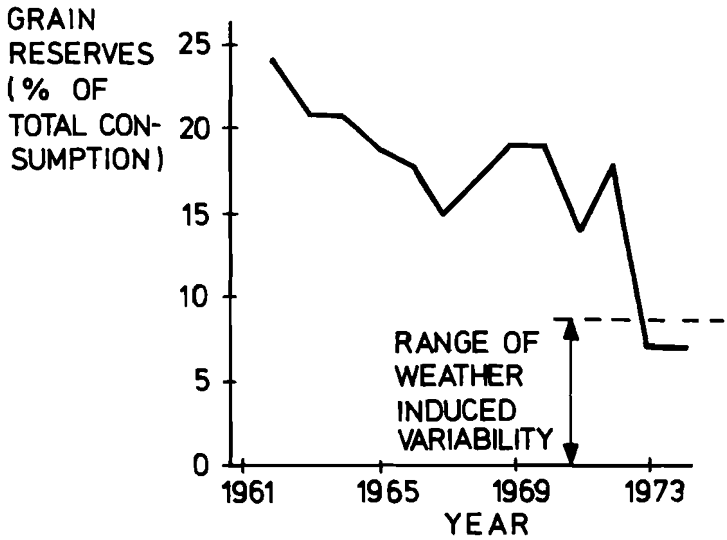


Figure 1. World reserves of grain as percent of total consumption.

Source: Brown and Eckholm, *The U.S. and the Developing World: Agenda for Action 1974*, Praeger, New York, 1974.

As the figure also shows, the real problem is not how to optimize the inventory level so that with a certain probability the supply will not be affected by weather-induced variability--in other words, how to eliminate random disturbances in a stable system; rather, it is the long-term trend that has led to the present situation. From this fact we can draw:

Lesson 2

The problem cannot be reduced to one of optimum stock-level determination well known from operations research. International stock and price policies must have broader objectives and take into account their adverse consequences in different nations and income groups and to the latent demand. Only a highly complex model can show the secondary effects of such policies.

We have thus arrived at the second symptom of the food crisis. There are many who emphasize the long-term problem. Some --still stressing the trade aspect--draw attention to the global supply structure: the dramatic shift that has taken place in the past four decades in the distribution of net grain importers and exporters. The USA, Canada, Australia, and New Zealand became net exporters, and the rest of the world net importers. This in itself would not represent a danger, but when the problem is investigated in the proper economic context, an increasing tension seems to appear. Some importers are already struggling with balance-of-payment problems, and the long-run shifts show that this will be further aggravated. In India in 1961 the debt service ratio (percent of interest and repayment of exports) was 13.74%, and in 1970 27.44%. Without general economic development, for which time is needed, the balance of trade of some developing countries cannot be restored. According to the *Assessment of the World Food Situation* (FAO, 1974), the import requirements of developing countries will rise from 16 million to 85 million tons of grain in 1985--estimated at $10 billion. According to an expert, "the transfer of the surplus to cover the deficit of poor countries would have to take place on concessional terms, which seems neither desirable nor likely"; but he offers no alternative.

In the long run, economic development may solve this problem. In the short run, no economic solution other than food aid seems to be possible. However, food aid is a controversial issue. Its direct and indirect short-run and long-run effects, in the donor and the recipient country alike, are complex and dependent on government policies. Up to now, food aid seemed to obey the "push effect" of high stocks much more than the "pull effect" of need in hungry countries. Not only did its volume decrease as stocks were depleted, and did the terms progressively harden, but its structure also changed, since in 1966 a progressive shift from local currency sales to long-term dollar sales was decided. Apparently, food aid was used as a local tactical means instead of a long-run complex policy. Hence:

Lesson 3

Different forms of food aid must be investigated in a larger context, together with all the possible short- and long-run effects on production in food-deficit countries as well as in those with surpluses.

Those who approach the long-run problems in terms of population, nutrition, and natural quantities of production (without using the economic concepts of supply, demand, and prices) generally start by comparing the population explosion with the possible increase in production. The most disturbing symptom, according to them, is the fact that because of the population explosion, the per-capita food production is not increasing in the developing nations (see Figure 2). But the fastest population growth is just in those countries where the food problem is the gravest.

I do not think it is necessary to discuss here the predictions for population growth (see Table 2). It seems to be more or less a hard fact that the world population will be above six billion at the end of this century (*UN World Population Prospects 1970-2000 as Assessed in 1973*). The margin of error of demographic predictions does not influence the essence of the problem. The difference between minimum and maximum was 2 billion in the 1957 forecast, 1.5 billion in the 1966 forecast, and 0.8 billion in the 1973 forecast. The difference is due to changes in the estimated minimum. The maximum has not changed substantially: a case for the pessimists.

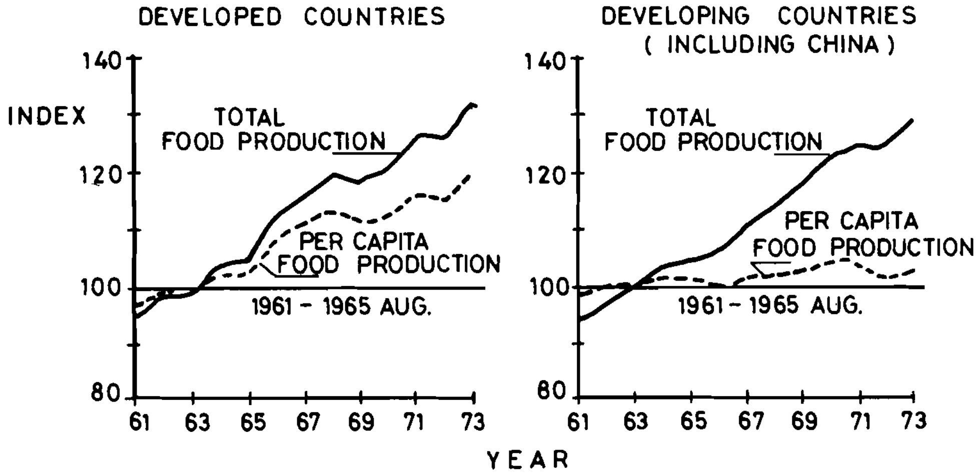


Figure 2. Total per capita food production.

Table 2. Estimated world population in the year 2000 (in millions).

	Minimum	Medium	Maximum
World population	5838	6253	6637
Developed countries	1308	1360	1434
Developing countries	4530	4893	5203

As the population increase cannot basically be changed within the next 25-30 years, we must turn to various ways of increasing food production. Generally, the resources for food production are evaluated in a very complex way. Many factors are considered; a glance at Figures 3 and 4 shows how rich the field of alternative technical improvements is. (Including leaf protein in Figure 3 was somewhat arbitrary, this being a border case between agriculture and non-agriculture; but as an important possible future technology it had to be represented somewhere.) For raising agricultural production, the cultivation of more arable land is the most-discussed possibility. There is a wide range of estimations, some of them assuming that we can double the present cultivated area. However, the low quality of the new land would require considerable capital investments.

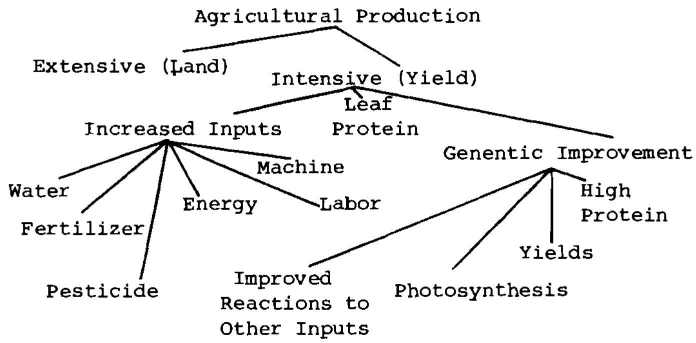


Figure 3. Agricultural production.

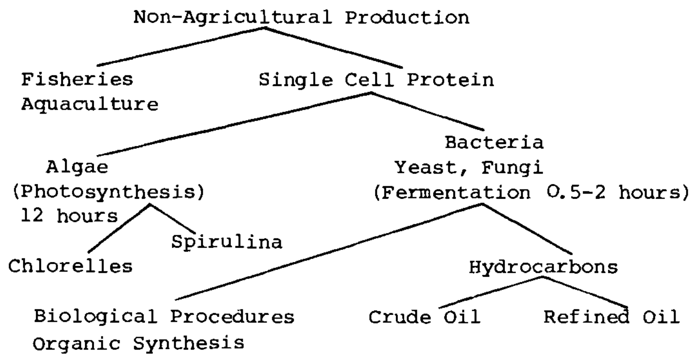


Figure 4. Non-agricultural production.

Raising yield is also hopeful. Increasing different inputs as well as genetic improvement are promising areas for increasing yields; among the latter, high-yield varieties (HYV) must be mentioned, as they are the basis for the green revolution which we shall discuss later on.

Non-agricultural production (Figure 4) is perhaps less promising. Seemingly, we have reached the limits of increasing the volume of fish catches. Single-cell proteins using photosynthesis are negligible. After the hope that chlorelles would provide mankind with enough food, it soon turned out that they are no more efficient at photosynthesis than conventional plants:

they must be supplied with CO_2, which conventional plants collect from the air; they must be shielded from other organisms. In some places spirulina (blue algae) serve for human consumption. They seem to be more useful. However, the real possibilities in this area are bacteria, yeast, and fungi, fed either on hydrocarbons or on another basis.

We can see now that food as such is not a natural resource. It is a product of various primary inputs. Yet we use this complex term when estimating our future resources. Thus, the estimation procedures inevitably involve our views, intuitions, and investigations into the various factors presented in figures 3 and 4. The estimations become even more uncertain when future development has to be predicted in all the different fields. Veritable waves of optimism appear from time to time on the food scene, trusting now in green algae (chlorelles) and then in the green revolution. True, all the new technologies bring some improvement, but they never revolutionize production. From the first inventions to widespread commercialization, a long time span is needed; side effects and disadvantages are realized only later.

The field is challenging, though. The quantities we deal with are so large that the slightest improvement can have an immense effect. For example, "...by photosynthesis, yearly, 200 billion tons of atmospheric carbon are turned to sugar, which is 100 times more than the combined weight of all that man produces in that time" (Hellman: *Feeding the World of the Future*). In addition, only 0.1-1.0% of the light falling on a plant is utilized at present. This can be raised by new techniques to 3-8%. Another example is the growth of SCPs. The doubling time of the weight of bacteria is 1/2 to 2 hours; of algae, 12 hours; of crops, 7-14 days; and of animals: 30-60 days. So it is understandable that optimism prevails concerning future technical development. However, the options are often competitive, at least with respect to the resources for research and development. Not all options can be realized. The problem of technical development today is one of choice, not of capability.

We are like the Regent during the minority of Louis XV, referred to in a book on population, "...who had all the talents except the talent to make use of them". Clearly all the options have side effects and far-reaching consequences. Any choice has to take into account the immense complexity of the problems, which was illustrated by the history of the green revolution. Exaggerated hopes were followed by exaggerated disappointment when it was found that the long-run trends were not dramatically changed (see Figures 5 and 6). No one questions its immense advantages, but no one thinks nowadays that a real breakthrough in agriculture has been achieved. Most of the experts agree that the main constraint was that the combined increments in many inputs could not be realized. HYV were not enough; more fertilizer and more irrigation would have been needed. The changes required were too complex, and the bottleneck was the old system itself.

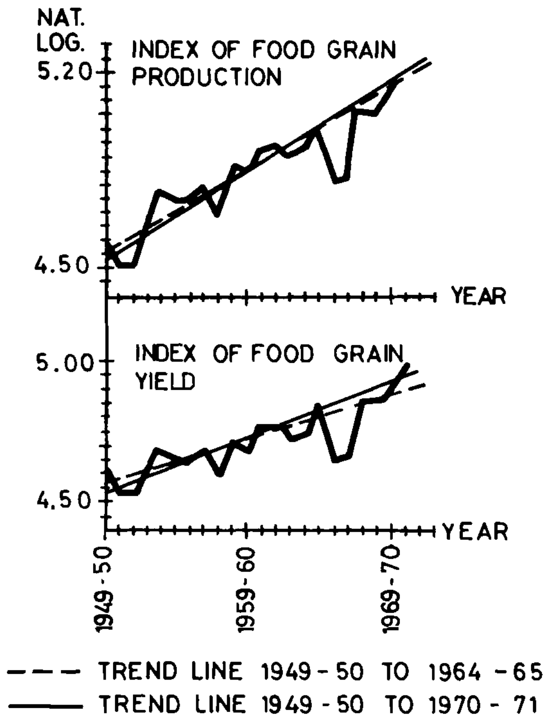


Figure 5. Extent of the Green Revolution in India: food grain.

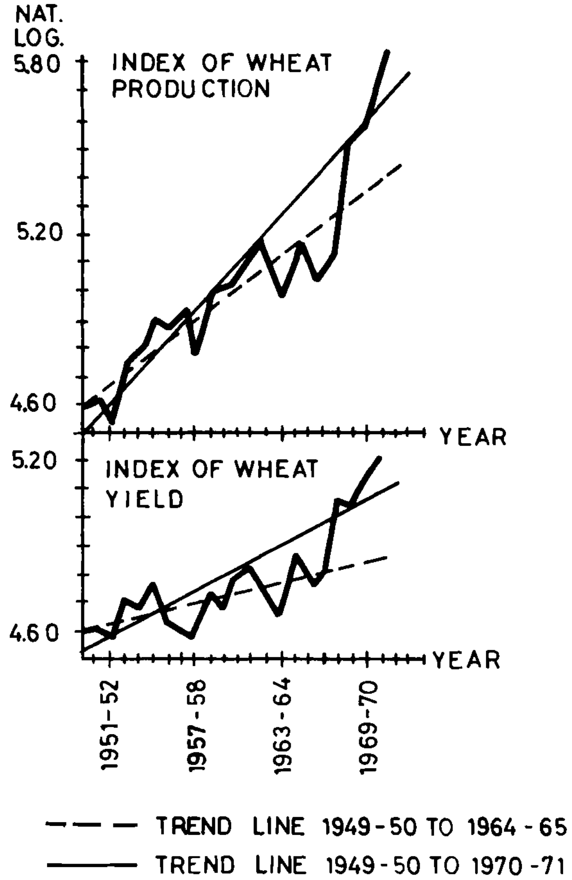


Figure 6. Extent of the Green Revolution in India: wheat.

Growing complexity, in addition, means growing dependence on fertilizer and pesticide imports, and thus growing vulnerability through international trade situations. Thus we may state:

Lesson 4

When technical development is modeled, the complementarity and interaction of the different elements of the food production system and the inducements and constraints of the international environment cannot be neglected. The model must deal with the whole intersectoral and international complexity of the problem.

Of course, not only the production technology offers new possibilities. There is another field where adjustment will be possible. It is no less complex; and, being more bound to tradition, it is more irrational. This is the field of diet. By introducing new diets in various parts of the world, we could shorten the food chain and dispose of a lot of inefficiently used calories. Yet habits are hard to break. Religious, social, and cultural problems appear when we try to introduce new foods.

We can see that estimating food resources is a highly complex task involving the problems of technical development and dietary changes. That is why the predictions are generally based on long, elaborate studies, and why the estimated figures are so different. It is impossible to go into a detailed analysis of the assumptions and calculations of those who will be cited. I shall list just some results (summarized in Table 3).

- According to a study of the University of California (*A Hungry World: The Challenge to Agriculture*, 1974), *8 billion* people can be fed, using the 1970 level of technology and all potentially arable land.

- According to Roger Revelle (Food and Population, article in *Scientific American*, September 1974), *38-48 billion* people can be fed, using the 1970 level of technology and all potentially arable land.

- According to J. Klatzman (*Nourrir dix milliard d'hommes?*, 1975), the figure is *10-12 billion*. He calculated with 14.5 million km^2 land, added a maximum of 10 million poor-quality land, and deducted 1 million excellent-quality land for urban development. A threefold rise of the water requirement (from 2000 billion to 6000 billion m^3) will be needed. Single-cell proteins in large quantities can be expected only from "bacteria on oil" technology. Klatzman thinks that a production of 2 million tons will be possible (1 gram per person per day for 5 billion people).

- Colin Clark (*Population Growth and Land Use*, 1967) is convinced that *150 billion* is the final number, counting 77 million km^2 arable land and a calorie intake of 1600-2000 Kcal per person per day. He has another estimation of *45 billion*, calculated with 14 million km^2 and an average North American diet.

- Linnemann and others, in their model MOIRA, made a purely theoretical estimation of the upper limit of food production. They found that the 1965 production was a mere 3.2% of the theoretically possible quantity. In other words, *from a technical point of view*, about 30 times as much consumable protein could have been produced.

Table 3. Food resources in terms of estimated number of people that can be fed.

Studies made by:

University of California		8	Billion
R. Revelle		38-48	Billion
J. Klatzman		10-12	Billion
Colin Clark		150	Billion
Colin Clark	(different assumption)	45	Billion
Linnemann	(purely technical capacity 30 • 1965 production level)	90	Billion

Though these resource estimations show a wide spread (which also shows their high uncertainty level), they are reassuring, as even the lowest population figure is higher than that predicted by the UN for the year 2000.

As food is a renewable resource, ecological limits will determine the sustainability of its production. There are some dangerous trends. Deforestation and increased use of mountain slopes leads to erosion and flooding; as a secondary effect, when wood disappears, people use dung for cooking, which deprives the soil of organic matter. Overgrazing leads to the spread of deserts; expanding irrigation systems lead to waterlogging and salinity, and excess silt fills the reservoirs. The use of chemicals may lead to long-range pollution. Although they evaporate, the time of evaporation ranges from a few hours to nine months for DDT (which, as is well known, also accumulates more and more as it gets higher in the food chain). Evaporated pesticide rises by upward diffusion to the upper atmosphere, into the ozone layer which breaks up any organic molecules. Besides the ground-level sink, we therefore have a perfect sink above 50 km. But this sink is also in danger. Expert interest in upper atmospheric chemistry is increasing. Depletion of ozone, by nitrite oxides liberated by supersonic high-altitude aircraft and by atomic chlorine derived from aerosol propellants, has been predicted. The upper atmosphere is where we must look for long-term pollution chemistry. It is a region where the ultimate cleanup of all organic misfit chemicals takes place, but there is a possibility of disastrous interference with the present chemical balance (G.S. Hartley).

All the technical options lead to grave ecological consequences because of the large scale on which they must be applied. These consequences must be measured and calculated with all their secondary and long-range effects. The farther the new technology is removed from decentralized and more natural ways of production, the more difficult it is to calculate a stable artificial system. The danger in the present process is that we are industrializing the last natural process (agriculture) just when we have realized that we need to create a circular technology in industry that is more analogous to biology.

Whatever the ecological consequences of the different options are, we are far from reaching the limits in the near future. The technical limits of production easily allow a leisurely attitude in this field. However, something is wrong with stating the problem this way. All the disputes about the limits to growth, the population explosion, and the fast increase in use of natural resources center around the following three questions.

1. Is the growth curve exponential or logistic: will it level off in the foreseeable future?

2. Can we neutralize one growth curve with another (e.g. population explosion, or depletion of natural resources, with rapid technical development)?

3. How much time is left before the limits are reached?

All these questions are connected with the future, and however reassuring the answers might be--in most cases they are not--they do not touch upon the most important problem of the present.

I will give just one simple example to illustrate the nature of this problem. What would be the reaction of the national governments if the immigration quota were to be raised to a modest 15 million people per year (USA), 1 million (Poland), or 0.3 million (Hungary)? They would certainly not rely only on traditional mechanisms and old, proven institutions. The vision one gets is much more reminiscent of emergency and disaster. The example I used was just the present increase of the population in India, proportionalized to the countries mentioned, and was not extreme.

When talking about future limits, we forget this obvious problem of the present: the inconsistency of old adaptation mechanisms with the present rate of population change in the developing countries. Thus we have:

Lesson 5

Understanding dynamics is understanding the present rate of population change, with all its implications for the existing adaptation mechanisms.

Quite independently of the dynamic problem, we also have a problem in the present. Most of those looking far into the future forget that the crisis is present (Figure 7).

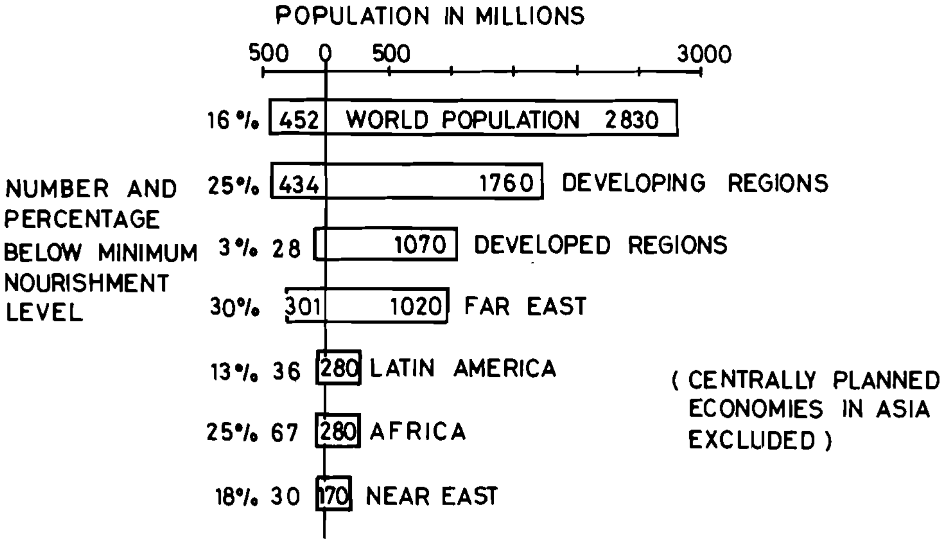


Figure 7. World hunger.

Technical development, diet change, cultivating more arable land--all these need time, in some cases a very long time. But malnutrition and starvation are present as measurable facts, and they need an immediate solution. Thus, only one possibility is left for denying the existence of a global food crisis: saying that it is a local phenomenon, not a global one. There are millions of malnourished people, but this is not a world problem; it is the problem of Bangladesh, India, the Sahel zone countries, and so forth, and should be solved by them; it may be local mismanagement, governmental ineptitude, historically conditioned backwardness; but whatever it is, it has local causes and requires local solutions.

The answer to this reasoning is simple: in some of the developing countries, no local solution is possible in the short run. Local solutions would need time, but as hunger is present, we have but two alternatives: to solve it globally or not at all. Thus, we can draw the main lesson for IIASA:

Main lesson

To reach a global solution a global model is needed reflecting all the direct and indirect effects of national and international agricultural policies.

In arriving at this point, we have gradually specified the basic requirements that our model should meet. Let me repeat some of the important lessons and their consequences, appropriately structured for the model to be built.

The model will be a policy model whose final aim is to find policies that can reduce or even eliminate hunger in the short run, and help to reach an adequate level and structure of sustainable production in the long run.

By investigating symptoms, we have found that hunger exists now; that it is temporary, stemming from the different rates of population growth and food production, and local, occurring in the developing countries; and that it can be influenced by national and international policies. This influence should be measured in our model.

Besides their influence on hunger, policy measures such as food aid and international stocks have secondary effects on the level of production in the affected countries, on their technical development in agriculture, on their economies, and on long-run structural changes. These effects also have an impact on water and energy systems, on the environment, on migration patterns, and on social structure. The model should show these direct and indirect effects.

Without reflecting the dynamics of the system--the time lags and the consequences of the different rates of change in population growth, production increase, and technical development--the results would not be useful. The main problem will be how to minimize hunger while at the same time introducing constraints to prevent long-run detrimental effects on the listed areas.

Before international policies are planned it must first be understood how these policies work. Therefore, before developing normative models we must start with an adequate description of the existing institutional framework, using a bottom-up approach. Accordingly, we would like to start on the level of individual nations (see Figure 8). Our first objective will be to describe the agricultural structure of the most important 20-25 countries, representing 70-80% of the world's agricultural production, consumption, and trade. In this national model, the capacity of primary input factors, the present conversion coefficients representing actual technology, the intermediate production, and final supply, demand, and prices, will be represented with all their dynamic interactions. An integral part of the description will be the possibility of expressing any consumption structure in terms of nutritional values. Thus, indirect effects of policy changes will be measurable in terms of nutrition.

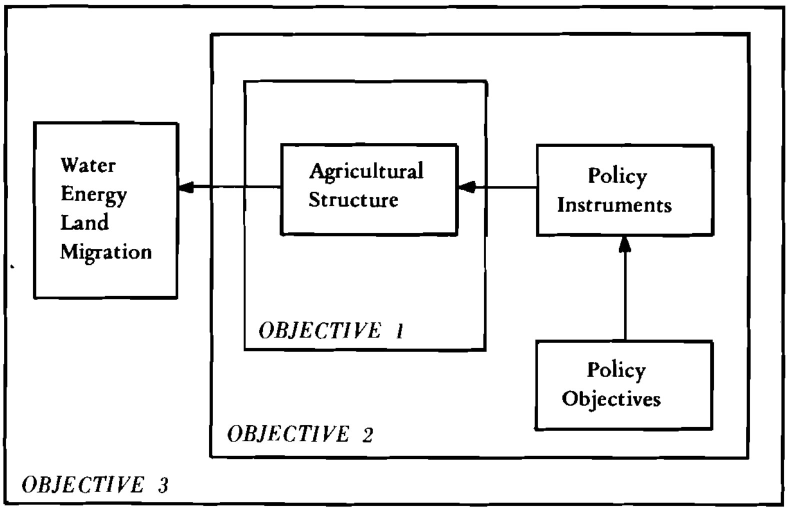


Figure 8. Hierarchy of objectives on the national level.

The second objective is description of the agricultural policy objectives and instruments of the selected countries, and of the consequences of the policy alternatives on their agricultural structure. The experience is that a veritable policy wilderness exists. Policy measures are generally taken in the interest of some well-defined groups inside the system. Price subsidies, export subsidies, protectionist measures, and the like lead to complicated chain reactions, generally not measured. The main effects of such policies are often not those originally planned. These indirect secondary consequences of agricultural policies should be shown by the model.

Third, we must describe the secondary consequences (through the expected structural changes) on water resources, energy resources, environment, land conservation, migration patterns, and social structure. The measurement and evaluation of these effects might be the most difficult part of future research.

After adequate description of the national agricultural systems we shall turn to the global level (see Figure 9). Here we will describe the interactions among national policies and among the international and national structures. Through sensitivity analysis we will investigate how the national systems react to policies of other countries, national food aids, changes in the international trade pattern, changes in the international finance situation (e.g. exchange rates, balances of payment), and international technical development and its adaptation.

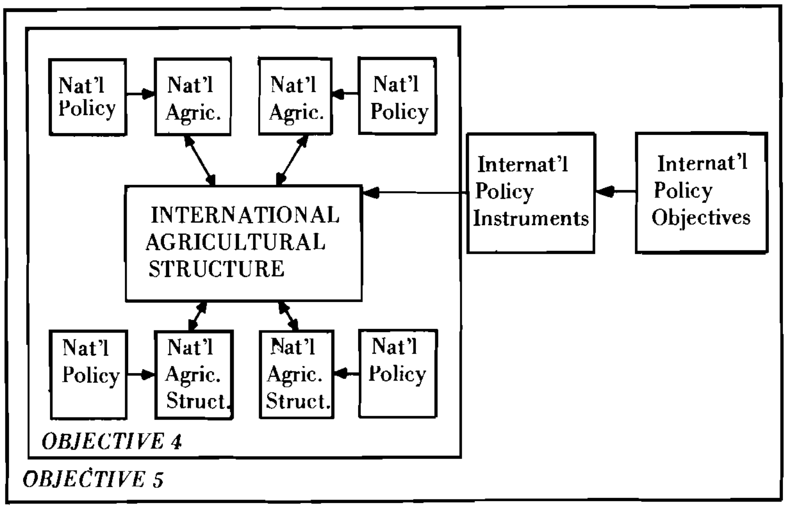


Figure 9. Hierarchy of objectives on the international level.

The primary reactions will induce chain reactions in the internal structure of individual countries. Connecting the national models into an international structure will present one of the most difficult methodological problems of the research. Trade models, econometric methods, game-theoretical approaches, simulation, and heuristic methods will be investigated before a decision is reached.

Having arrived at an adequate representation of the international system, we will describe the international agricultural policy objectives and instruments--especially international food reserves, price policy alternatives, and food aid--and their effects on making the latent demand manifest in single countries, reducing or avoiding temporary hunger, changing income distributions, long-run agricultural development (structure and productivity), and changes in international structure (self-sufficiency versus comparative advantage).

Clearly, not all these objectives can be completely realized in the short term, but they should be kept in mind as a frame of reference.

We are aware that our plan is ambitious. But if there is a time for ambition and optimism, it is at the start of the research, while we are still undisturbed by insufficient methods and annoying facts. Experience has taught us that the time will come soon enough when we will need all our confidence and optimism to overcome the inevitable difficulties.

Panel Discussion

GLOBAL ENERGY SYSTEMS

G.B. Dantzig

What should be the form of a global energy model?

I would recommend the development of a PILOT Energy Model along the lines of the one being built at Stanford for the USA, except in a global setting. This model was started by work of Häfele, Schikorr and Manne at IIASA. Its purpose was to develop a plan for expansion of energy facilities to meet population growth and energy needs. It was a model for a hypothetical country somewhere between the size of the USA and the USSR. Our research at Stanford was influenced by the further work in the USA of Manne and that of Hoffman on the Brookhaven Model. The components of the PILOT Model for the USA are:

- *Reserves*: Detailed description of the energy sector, beginning with a statement of potential reserves of coal, oil, gas, uranium ore;
- *Discovery*: Finding rates as more and more equipment is used to discover new reserves and methods of extraction;
- *Energy technology*: Detailed description of the energy technology in terms of what is needed from the economy to build equipment to discover, extract, and process energy into a useable form;
- *Current status*: Current statements on capacity and production.
- *General economy*: General description of the economy in input-output terms, general description of what is needed to expand capacity; information on current economic status--capacity of industry, production, international trade;
- *Consumer demands*: Description of consumer demands, historical consumption patterns, effects of changes in income and prices on demands; trends; effect of equipment stock (electric stoves, automobiles, etc.) on demands;
- *Objectives*: Statement that the general objectives of the economy is to maximize the increase of the standard of living.

It seems to me useful to build a *world* PILOT Model similar to the Stanford Model for the USA. Some care will have to be exercised that the requirements for transportation between the location of resources, the location of manufacturing facilities and the locations of world populations are reasonably approximated. This will require, probably, a satellite transportation model. A second case: there are great discrepancies between the living standards of different countries as well as between people within countries. There are also differences in consumption patterns. These are not too difficult to represent in the model. Various plans for eliminating the discrepancies among countries and among classes within countries could be studied.

The Stanford PILOT Model is expressed insofar as is possible in terms of physical flows. For a world model, I believe it essential to do the same. Monetary considerations such as balance of payments, block currencies, tax, salary, profit, prices response, investment policies enormously complicate the analysis, and it is better to see how to make the monetary policy serve the ends of maximizing the standard of living by the proper expansion of energy production.

M. Styrikovich

This session includes many interesting topics for discussion in a global energy perspective, but because of the time shortage, I want to concentrate mainly on one question--a global energy model for the transition period. This period will be rather long, and any serious attempt to investigate various ways of going through all the difficulties of this critical period as smoothly as possible needs a really global approach. We must take into account the peculiarities of several typical groups of countries that differ greatly not only in the structure of society, but also in natural conditions, degree of development, and life style. These conditions vary considerably even for developed countries. You will recall a graph in Häfele's presentation* showing the percentage of useful energy in some highly developed countries. Only a small part of that energy was in the form of electricity. A much larger part was in the form of industrial heat and heat for the residential and commercial sector; and the heat supply possibilities are quite different in other countries.

The life styles of the Soviet Union and the United States, for example, are quite different; the possibilities of meeting energy needs, especially by a centralized supply from nuclear power stations, will differ widely. In the United States, the large majority of the population lives in one-family houses,

---

*This volume.

spaced out in large suburbs outside the cities. In the Soviet Union, the majority of people live in flats in multi-storey apartment buildings rather closely grouped in sections of the city. Thus in the United States only one type of supply pattern has so far been needed for residential heat, air conditioning and hot-water supply: small individual boilers based on domestic liquid fuel. In the Soviet Union, the housing areas of cities as a rule have district heating with big hot-water pipeline systems from electrical stations producing, in combination, electricity and low temperature heat.

Specific energy needs for transport are connected with the settlement pattern. In the United States, a large part of the population travels from home to place of work by private car, which means a very large amount of liquid fuel for each man-kilometer. In the Soviet Union, most people use municipal transport: the electrified railway, the underground, and the trolleybus or autobus running on set routes; the latter can be replaced by the electrobus in the near future. So we see that the percentage of consumers relying on either liquid fuel or electricity plus (shortly) district heating from nuclear stations is quite different in the two countries.

But this is not the only difference. You have to take into account, for example, that some countries--mainly well-developed ones--are in moderate or cold climate zones, while many of the developing countries are in tropical zones. Thus the needs for the household sector will be quite different.

For a global model system, I think it might be possible to lump into several blocks countries with almost the same life style, degree of development, and natural conditions. Of course it would be very difficult to combine these blocks in one complex; but that is a question connected with modeling, and it is not my specialty. I leave this to Dantzig and other experts in that field. The greatest difficulty today is to build such a model for developing countries; in well-developed countries, as a rule we already have national models that can be combined into one system. In developing countries, the situation is quite different. There is no possibility of using experience drawn from history for model building. The developed countries evolved slowly, in pace with the growth of new technologies; developing countries, by contrast, must grow from a low level at a time when these technologies already exist. A way must be found to adapt modern technology to the conditions of developing countries with their excess of free labor, lack of skilled labor, and limited number of trained people. If IIASA could organize--perhaps with financial assistance from some international body--a group that includes both well-known modeling specialists and representatives of developing countries who are familiar with the conditions of those countries, I think that such an experiment could be useful.

Discussion (W. Sassin, Rapporteur)

Following the statements of Dantzig and Styrikovich, the panel members emphasized the touch situation arising from cooling-water requirements in densely populated and industrialized regions. It was stated that this specific constraint will increasingly favor large conversion plants sited along the coastline of the oceans. More generally, the panel conceded that for various reasons a properly designed and implemented strategy for deploying the economy of scale will lead neither to a highly vulnerable system nor to a situation where other options that might turn up later are foreclosed. A combination of coal and nuclear energy as primary energy sources and a strong interlinking of grids for secondary energy will both contribute to greater flexibility of future energy systems. Still, it was maintained that possible acts of terrorism require specific precautions, and that the proper size of energy plants will have to be a compromise between the tradeoffs in economy and safety. Whether a large number of smaller units can be safeguarded more easily than one big unit cannot be judged on general considerations, however.

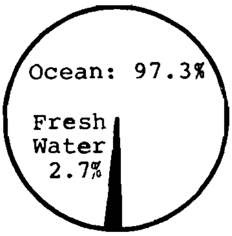
Regarding the importance of the development of energy demand for the formulation of any energy strategy, the question was raised how to improve global economy models. LP models with energy as an endogenous variable were given the largest credit. Two different opinions evolved, however, on which type of objective function would be more useful: the traditional one expressed in terms of monetary units or a new one expressed in terms of life-style components.

GLOBAL RESOURCES

Z. Kaczmarek

Unlike reserves of coal, oil, soil and other similar resources, the global stock of water cannot be depleted. Water resources may, however, be used in a more or less rational way, and, at least partly, may be destroyed by pollution from man's activities. People and nations tend to take water for granted until severe difficulties arise, and then to regard it as a local concern. The current circumstances of population and industrial growth, geographical diversity and technological complexity force a new recognition of the responsibility that nations share in managing the world's water resources.

The total volume of the Earth's water is estimated at about $1.4 \cdot 10^9 km^3$ (see Figure 1). However, more than 97 percent of this total is the salty substance of the oceans. It is also estimated that, at any given time, about 77 percent of the fresh water is stored in ice caps and glaciers, 22 percent in groundwater, and only 0.01 percent in streams. At the same time, man's requirements are met largely by the withdrawal of the water flowing in surface streams. Although groundwater resources have been greatly developed in some parts of the world, their aggregate use on a global scale is much less than that of surface water.



Location of Fresh Water	(in %)
Ice caps and glaciers	77.0
Groundwater	22.0
Lakes	0.35
Atmosphere	0.04
Streams	0.01

Figure 1. World water supply.

The fact that water circulates several times during a year determines its available supply. Driven by the sun's energy, water flows from the oceans to the atmosphere, then to the continents and, in the form of river discharges, back to the oceans. Rough estimates can be made for the river runoff for the world as a whole and by continents. The runoff data presented in Table 1 are based on a monograph by M. I. Lvovitch [1], and are related to estimates of world population. Data on "firm" runoff--i.e., runoff of very high probability of occurrence--are presented in addition to the average or total values, because of the random variability of river discharges. In fact, only the values for firm runoff can be compared with water demands to determine the situation in a given area.

There are tremendous differences among areas, ranging from rocky deserts with virtually no water, to tropical forests with a water surplus throughout the year. Even in the countries of IIASA's National Member Organizations, the average yearly surface water resources available vary from 128,000 m^3/capita in Canada, to about 800 m^3/capita in Hungary (Figure 2). In addition, there are daily and annual variations in the supply of water. Reliable water resources for specific areas and given time periods may therefore be smaller than the estimated average. The rational time redistribution of water resources by means of storage systems and long-distance water transfers may substantially increase the available amount of usable water.

Table 1. River runoff (m^2/capita/year).

Continent	Total Runoff	Firm* Runoff
Africa	12,060	5,430
Asia	6,100	1,850
Australia	121,000	30,860
Europe	4,760	2.020
N. America	22,160	8,920
S. America	41,800	15,730
World	10,490	3,790

*Runoff of very high probability of occurrence.

After: [1]

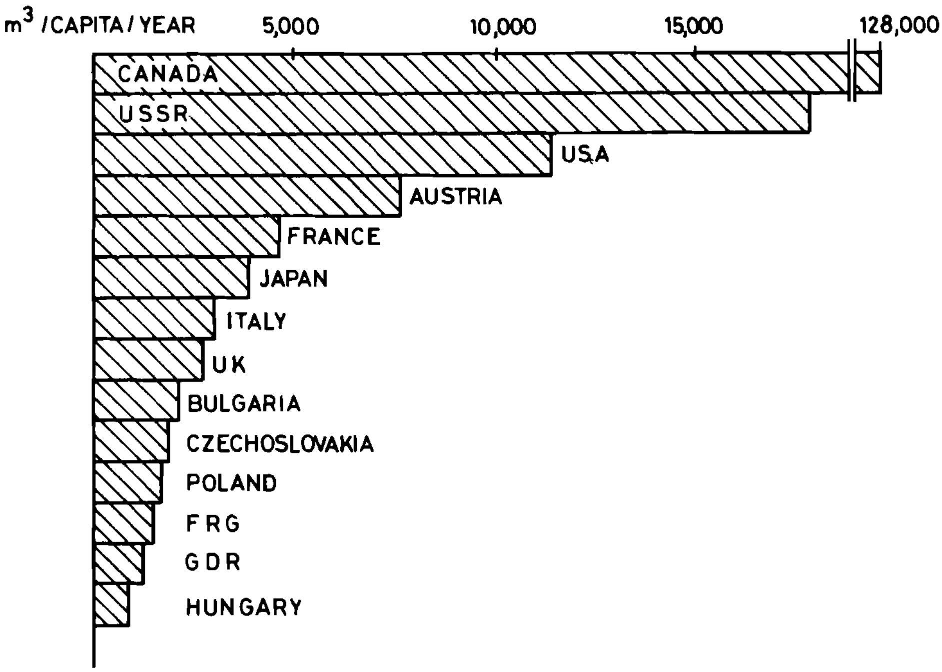


Figure 2. Water resources of IIASA NMO countries.

According to estimates made on the global scale, the consumptive use of water over the next 50 years will be *less* than reliable surface fresh water resources (see Figure 3). In general, an increase in water demand is proportional to an increase in national income or in Gross National Product (GNP). In the USA, for example, the rate of water consumption in 1970 in relation to 1950 was about 2.3, while the GNP of the USA during the same period increased 2.1 times. Similar relationships were observed for socialist countries in Eastern Europe. It is expected that technological progress will lead to the use of less-water-consuming technologies by industry, so that the future relationship between water consumption and national income may change.

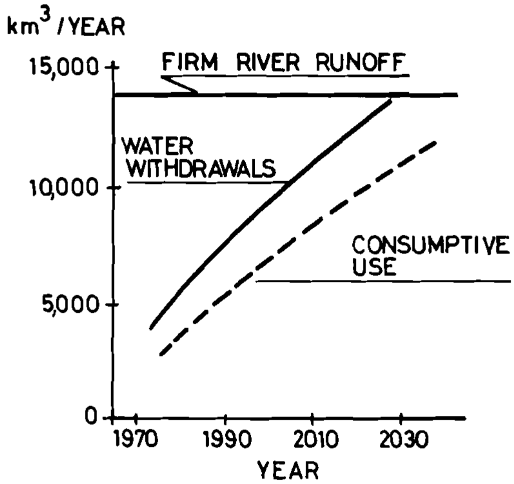
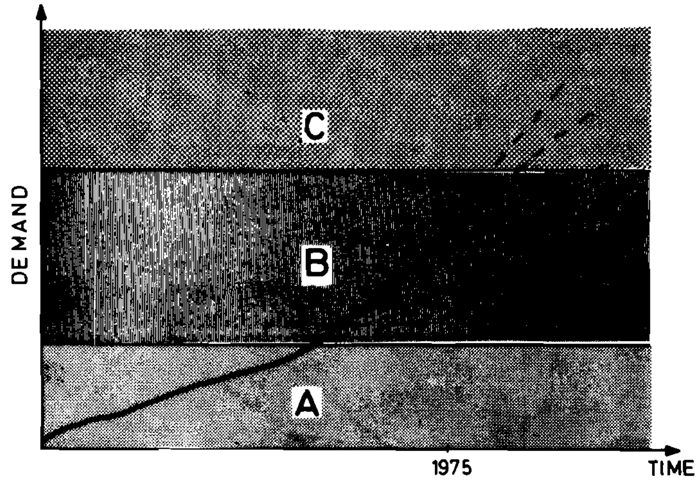


Figure 3. Estimated world water resources versus demand.

After: [1,2,3]

Water problems are usually site-specific and of a regional character. Three characteristic situations arise in the evolving relationships between water demand and supply (Figure 4). At one extreme are the areas with a large natural supply and a relatively low level of demand that can be satisfied without major human interference in the hydrological regime (level A). In the second case, demands can be satisfied only through complete regulation of water resources and the rationalization of demands (level B). Thirdly, in some cases, non-conventional sources of water supply, e.g., desalination, are needed to solve water supply problems (level C). The means for managing water are flexible, including diverse social methods for managing water demand and the improved location of water users, with the continuing growth of population and technology, the complexity of water management also grows. Communities that were accustomed to relatively simple methods of withdrawing water and disposing of waste will, in the future, be faced with many more intricate problems induced by the increased and diversified demand for water.



A - Flood protection, quality control

B - Storage, local transfers, optimal management, flood protection, quality control

C - External supply + **B**

— known demand   --- forecasted demand

Figure 4. Water resources situation.

Although water problems occur in different mixes throughout the world, they are, in most cases, of a regional character. Thus the time is ripe to mobilize the experience and human skills needed for solving global water problems. The following are examples of actions needed:

- A concrete program for reducing the health hazards in drinking water;
- A system for global monitoring of water quality;
- A program for improving water management globally with the view to meeting world food needs;
- Mechanisms for anticipating and reducing international conflicts over water resources.

The forthcoming United Nations World Water Conference, to be held in Argentina in 1977, will undoubtedly discuss these important problems. IIASA should continue to contribute toward the advancement of methods and techniques for their solution.

References

[1] Lvovich, M.E., *Mirovyje vodnyje resursy i ich buduszcze* (Global Water Resources and the Future), Moscow, 1974.

[2] USSR, National Committee for International Hydrologic Decade (V.I. Korzoun, ed.), *Mirovoi vodnyi balans i vodnye resursy zemli* (World Water Balance and Water Resources of the Earth), Girrometeoizdat, Leningrad, 1974.

[3] Baumgartner, A., and E. Reichel, *World Water Balance: Mean Annual, Global, Continental and Maritime Precipitation, Evaporation and Runoff*, Oldenbourg, Munich, 1975.

H. Mottek

However useful the distinction between global and universal problems underlying the structure of this Conference may be, it is difficult to apply it consistently, at least as formulated in IIASA documents such as the Conference invitation extended by IIASA. This becomes obvious with problems of natural resources and the environment. That is because the resources themselves--the soil, the useful plants and animals, the minerals, the lakes and most water systems--usually lie in territories of sovereign States with their own economic policy, laws, and jurisdiction.

If we stress not only the global aspects where they are obvious, as with oceans and the atmosphere, there are three reasons for this:

1. The role played by certain resources in world trade;

2. The export and import of detrimental matter through the media of water and air;

3. The implications of insufficient resources; critical situations or even disasters resulting, for example, from food shortages and environmental pollution are not confined to a single country.

In the scientific treatment of many resource and environmental problems, global effects help us to deal successfully with the interdependence of natural resources, the environment, and the economy on a regional basis. The fact that such problems can be treated within the framework of IIASA was demonstrated by the Conference on the Brastsk-Ilimsk project* (USSR), which produced stimulating suggestions for treating global problems. It is also shown by the successful approach to other topics, called "universal" in the language of IIASA.

By generalizing experiences of this type within IIASA's framework, we promote the expansion of a resource that is vital to the improvement, and even to the maintenance, of living conditions in all nations, of all mankind. This resource is not reduced through use, but rather is sustained and multiplied: the human resource of knowledge, especially scientific knowledge. When the founders of IIASA defined the acquisition of knowledge, and its application to the solution of urgent problems of mankind, as the substance of a common task of different States with different social systems, they imparted to the Institute's research a global character that serves for the enhancement of that global resource, and the cause of peace connected with such cooperation.

The fact that, for the sake of this expansion, great efforts are required in dealing with the critical problems of mankind, which necessitate the interaction and cooperation of different States appears to be trivial to scientists. But outside scientific circles, many believe that in the protection of the natural environment, the main task is to utilize available knowledge rather than gain new knowledge. However--and this should again and again be made clear to the public--experience in the practical solution of environmental problems has proved quite the opposite to the widely held view. One is confronted with the following questions:

1. To what extent will human activities--especially economic--influence the environment as a whole, and its various subsystems; what changes have been provoked, and to what extent are these reversible?

2. To what extent do temporary, long-term, or permanent changes have an impact on society, and especially on the economy?

With these questions we are formulating the age-old question of man addressed to science: the question of the possible effects of his present and future actions, and as a logical consequence, of how to improve his actions and his decisions. But when we ask this question in relation to the natural environment, we meet an obstacle. Not only is there a lack of factual knowledge, but even theoretical knowledge is inadequate for providing answers. Our insights have not kept pace with the so-called direct effects

---

*For details see H. Knop, this volume.

on man and the environment (type 1 knowledge), whose impact has increased super-exponentially, or with the side effects and late-time effects (type 2 knowledge). Let us take as an example the relationship of man to climate, or the implications of pollution for human health. We are hampered by the lack of facts when considering natural resources as elements of the natural environment with a view to protecting them from excessive exploitation and thus from diminishing them unnecessarily. For the development of natural resources that we regard as "usable by society", sufficient knowledge, especially of type 1, assumes decisive relevance.

If, for instance, we consider mineral resources, mere geological knowledge on deposits is not sufficient; we must also know the technologies of mining, processing, and further utilization. It is through such knowledge that components of the Earth's crust become resources in the economic sense. Thus the size of mineral resources and of natural resources as a whole is dependent on knowledge, especially type 1 knowledge. Therefore, it is remarkable that a model built at IIASA is based at the same time on our at present still limited knowledge and on unlimited potential resources. It is lack of knowledge on natural resources, the natural environment, the possibilities of utilization, and the prerequisites of conservation that prevents our eliminating the danger of local, regional, or even global catastrophes. It may even force us to exaggerated measures for their prevention.

On the other hand, the size of the impending danger and of possible detrimental effects determines the criteria for estimating the urgency of global problems. The endeavors of the international scientific community should be directed to these fields, where the costs of ignorance are very high. The systems approach, systems theory, and systems analysis are suitable means for precise determination of these costs, especially in relation to natural resources and the environment. The methods of risk evaluation and decision theory under conditions of limited certainty, or even uncertainty, should be applied in order to diminish uncertainty where the danger potential costs are greatest. Let me therefore, repeat the proposal I put forward at a IIASA Conference in September 1973.

On the basis of a well-founded program listing urgent research projects, IIASA should present an appropriate proposal to the public. The preconditions for such a program should be the development of an adequate methodology, and meetings of experts held in order to analyze the state of knowledge required for solution of such global problems. The platform could be provided by IIASA projects already in progress, where implementation may reveal such dangerous areas of ignorance. Drawing up such a program, or certain sub-programs, would ensure for IIASA activities and methodology a broad effect, and would promote the solution of global problems to which IIASA has been asked to contribute by its founders.

Discussion (E.F. Wood, Rapporteur)

One discussion participant focused on five issues: 1) a long-range view of energy demand, which would require the inclusion of technological change, market movement, etc., as part of the analysis; 2) incorporation of *forecasts* of technology and technological development in analysis; the example given was that of the Green Revolution, which is not really a technological breakthrough but is consistent with past trends in technology; 3) the importance of policy to the development of technology; 4) capital shortage as a significant constraint in resource development (though one can replace capital by knowledge, especially in developing countries where capital must be held to a minimum and local resources become important); and 5) IIASA's role in stimulating work in systems analysis concerned with policy in order to expand knowledge and technological development.

Other discussants tended to explore those issues. On the topic of incorporating technological change, it was pointed out that a number of energy models include this aspect by predicting availability of the technology (example: solar power), often with probabilities of that availability through special constraints on capital expansion.

Also, in analyzing the phasing of technologies, it was felt important to consider the interaction of the various local resources (for example, labor, capital, industry). We can, and do, phase technology differently in different regions.

It was pointed out that through a specific policy, a government can accelerate research and increase the probability of technological changes. Unfortunately it is hard to estimate what the impact of a policy will be, since you cannot extrapolate past trends. Furthermore, there is a significant time constraint in developing and implementing technological changes; thus, in the short run there is virtually no technological change. In the area of food resources there are fears that the rate of technological development cannot keep up with the rate of population increase.

On the topic of technological change, one discussant saw a fundamental problem in developing countries in that the transition from a rural economy to an industrial economy cannot be made smoothly, partly because we do not know the appropriate technology for this. A nomadic society has population densities of about .1 person/km^2; a farming society, 10 people/km^2; and an industrial society, 300 people/km^2. The industrial countries took centuries to make this transition while today developing countries must do it in decades. Thus the economies and the societies are out of step.

A number of panel members expressed in different ways their view that we really do not know the proper technology for helping the developing countries to deal with this problem. The balance between technology, capital, and development in the developed world may not be appropriate for the developing countries. One must consider the technological level in these countries before proposing new technology--especially technology developed for highly capital-intensive, non-labor-intensive societies.

GLOBAL DEVELOPMENT

G. Bruckmann

Let me make a few remarks to lay a base for discussion of IIASA's role in global modeling.

A few weeks ago, after the first day of the Club of Rome meeting in Philadelphia, there was a headline in the *New York Times* that read, "Club of Rome Against Curbing Growth". Of course, the news was wrong. What should be interesting for us is the question why it was wrong. It seems to me that it was wrong essentially because of a lack of understanding of the short but exciting history of what has become known as the global modeling movement.

Let us have a brief look at this development. There are decisive differences between *Limits to Growth* and *Mankind at The Turning Point*, or more precisely, between "World Three" on the one hand and the Pestel-Mesarovic model* on the other; but these first two major global modeling efforts have some common features. They have taught the world scientific community a number of things:

- The impact of the interdependence of economical, social, ecological and technological problems,
- The impact of the time variable upon these problems,
- The finiteness of global aspects; not so much the absolute finiteness of any particular resource, but that of the availability of certain resources or solutions within a given space of time,
- The fact that global developments are the result of national policies in a distinctly sectoral approach.

As all of you are aware, the two books have given rise to numerous publications and to a number of other modeling efforts. Instead of simply listing these chronologically, let me profit from the fact that a retrospective summarizing view allows a

---

*This model is described in *Multilevel Computer Model of World Development System*, M. Mesarovic and E. Pestel, eds., CP-74-1/6, IIASA.

certain classification. As a criterion, I will use what I consider the major message we might have learned from the first five years of the global modeling movement. This is that global developments cannot be understood unless one gets down to the level of national policies, and unless sectoral developments are studied more carefully in their interdependencies--that is, studied in what Dr. Levien has called a comprehensive way. At first glance, this seems to be asking too much; but let us have a look at the extent to which global modeling has hitherto been able to live up to this goal.

Maybe this is the right moment to say a word about the role IIASA has had in this context. From its earliest days, there was earnest debate about the degree to which IIASA itself should indulge in a major global modeling effort. It was decided to proceed in two stages. First IIASA would simply assume a monitoring role, and conduct a series of conferences in this field, with a double purpose: to permit a direct exchange of knowledge and views among the major modeling groups, and to gain sufficient experience and an overview of the field so as to be able to decide upon the kind and extent of any global modeling work IIASA might take up. In this first stage we had three conferences, each focusing on a major model but also devoting time to presentations of the state of development of other models. The first conference, held in the spring of 1974, concentrated on the Pestel-Mesarovic model; the second, in October 1974, on the model developed by the Fundación Bariloche, and the third, in September 1975, on MOIRA, the model developed by a Dutch team headed by Hans Linnemann.

Let me try to evaluate these major models from the point of view of the criterion I mentioned earlier. In a sense, the model developed by Pestel and Mesarovic can be considered the most advanced, inasmuch as it consists of a combination of sectoral approaches and is being explicitly applied on a national level. We are fortunate to have Professor Pestel here to tell us more about it.

If I were to classify the model by the Fundación Bariloche, I should say that it is certainly more crude in its sectoral submodels, and includes national policies only indirectly. Its great merit, however, lies elsewhere; as you know, it is the first major model of explicitly normative kind.

MOIRA concentrates very strongly on national policies, and limits itself, however deliberately, to one major sector, namely food and agriculture, treating all other sectors as exogenous variables. Its main advantages are twofold. First, by limiting itself to just one major sector it can treat that sector in a much more refined way; and second (a result that may not have been anticipated), after discussing this most advanced model in the food and agricultural field for a whole week, the conference participants were frightened to realize how little we know about the interrelations and how much work there is left to be done.

I should also mention here the Japanese model developed by Kaya and his associates: a more restricted model, which, however, also aims at depicting the effect of national policies upon sectoral development.

It may be said that this first IIASA Conference marks the transition from stage one to stage two of IIASA's involvement in global modeling. In deciding on its own activities in this area, IIASA has been able to draw upon a great deal of accumulated experience, both from the models presented at our conferences and from the extensive Energy program*--a model that may be considered a prototype of a sectoral analysis, seen in a comprehensive holistic context. On the basis of this experience, it seemed feasible not to build up an entire global model, but rather to extend the sectoral studies in the energy field to a second major area, food and agriculture.** We hope that in this work we will be able to go one step further toward the goal I tried to sketch.

As a side activity, IIASA will continue its conference series, not only to keep up to date ourselves, but also because--and I say this with pride--these conferences have gained a place in the history of global modeling.

Let me add just a few words on what I should like to call the limits to global modeling. After all that has been said in these last years about modeling from a systems or a philosophical point of view, one very crude formula remains: there can never be a model that fully maps reality. Models must always fall short of depicting certain important aspects of reality. But models are the only way we can deal with reality. Every decision in our everyday lives is based on models we have of reality, so essentially there is nothing wrong in trying to model even global developments. As long as we remain aware of its intrinsic limitations, global modeling will at least help us to study the structure of reality.

There is another aspect that should not frighten us. It has been claimed, and rightly so, that there is no such thing as a value-free model; but I think this is an asset rather than a liability, and in thinking so, I am in good company. Pestel and Mesarovic explicitly recognize, in their norm-formulation stratum, a value-cultural zone. Linnemann stated that the very point of departure of their model was a value decision, namely, resentment of any kind of triage among nations: nations that need no help, those that eventually will be able to help themselves, and those that one will simply have to allow to go to pieces.

---

*See W. Häfele, this volume.

**See F. Rabar, this volume.

When it comes to IIASA's role in global modeling, I think we should just as freely admit that we have similar values, maybe unspoken, that guide our work: the firm conviction that scientific cooperation among nations can prove to be of benefit not only to the participants, but to this fragile globe as a whole.

E. Pestel

When Mesarovic and I decided five years ago to work in this area, we did not regard it as an academic venture. Our intention was not just to enrich science; we had the final goal of influencing governments--not so much with the results as with the procedures which we were going to develop. It was clear that in the first attempt all we could do was to develop a sort of prototype, to explore the feasibility of what we had set out to do. Thus the model and the results that were the basis for our book *Mankind at the Turning Point* provide only broad conceptual guidelines for decision makers in policy and economic matters, and this from a long-range point of view offering little help in their day-to-day political business.

I would like to make one other point. People often confuse the results we presented with the instrument used to produce them. I think there should be a clear distinction. We tried to develop a model of the world, regionalized and in a hierarchical fashion: a neutral, objective model as free from ideology as possible. Now when you use this model you use it by way of the scenario technique. And here I disagree somewhat with Bruckmann: the scenario technique is essentially a normative approach. When I write a scenario I have certain goals, and in order to reach these I define a number of input qualities in their time development. The model then tells you what can and cannot be done, and what finally comes out in view of all the constraints embodied in the model. Of course you can also use the model the other way around: you could write a normative scenario and then find out what resources--material and human--are necessary to reach this if everything develops according to plan. But we thought this approach would not be as fruitful as trying to develop visions of future development and test these against the "reality" as embodied in the model, to the best of our ability.

Now for the past two years we have worked at an increased pace. And since we were not engaged in an academic venture, we tried to get funding from governments. Before that, we had received generous support from the Volkswagen Foundation, but at this stage we had to involve the governments--which means that they pay the bill. And we were successful in that: the Ministry for Research and Technology of the Federal Republic of Germany established a discussion circle--what we first called a "tobacco college" in which we did some brainstorming. This circle supported our ideas and then influenced the government to give us a very well-endowed short-term assignment.

Our first aim was to make what we did more accessible to national policy makers. That forced us to go from the global to the national level. Now you cannot build for the national policy maker a model having only the detail of a regional model. The smaller the area and the time horizon in which he wants to act, the more detail is required. Our model still took a long-range view--up to the year 2000 and beyond--and begins to be meaningful say five years from now, avoiding the short-term fluctuations one cannot capture with this type of model. But much more detail was provided. For example, the German economy is depicted in 19 sectors, and--more important--is described not only in monetary terms for each sector but also by technological quantities. These quantities are, first, the different types of primary and secondary energy used--oil, coal of different qualitites, gas, hydro, nuclear, and even wood--and then the man-hours of unskilled workers, skilled workers, and so forth, up to academics. Other quantities are those of basic materials; here we are just beginning, with steel, lead, and aluminum. We describe the flow of these technological quantities through the economy, from input to final demand--split up in private consumption, government consumption, exports, investments, and imports--and the capital stock development. We succeeded in modeling the historical part from 1950 in such a way that we have splendid agreement, reflecting real fluctuation in sectors not much involved in final demand but necessary for the flow into other sectors. This gives us a chance to investigate a number of topics that are otherwise very hard to tackle. For example, you may decide to change the structure of industry by slowing down or even diminishing the heavy industries, producing only very high-quality steel, and importing half-finished products from the developing countries so as to gain trade partners; the model then permits you to examine the consequences to the labor market, the energy inputs, pollution and so on.

We had to disaggregate the model, which had 10 regions. We now have a data base storing the available data for each nation which of course differ widely. With our model-building equipment we can aggregate them and can call them as we want to, and thereby gain much greater flexibility. We have also disaggregated vertically in order to take various aspects into account. We are aiming at a general-purpose model that can be used to answer any specific question by assembling those parts of the model that are of importance for answering that question. As for our cooperation with IIASA, we are most fortunate that Häfele is part of the discussion circle of the FRG Ministry for Research and Technology, and has been made our supervisor. We have learned a lot from him, and I think our input to IIASA can be also quite useful. Our programs are at the disposition of those teams that can use them; this is quite important because you will recognize that the eggshells of some of the IIASA projects are still present. When IIASA started, there were a number of projects. These have now been joined in a matrix, and inputs that start from a different philosophy can be useful.

GENERAL DISCUSSION

(K. Parikh and W. Sassin, Rapporteurs)

The discussion ranged over the history, purpose, adequacy, usefulness, and dangers of global modeling.

After giving a brief history of global modeling, Bruckmann had concluded that efforts so far have emphasized the interdependence of economic, social, ecological, and technological problems and the limitations of certain resources and solutions within a given time span. He had stressed that global developments can be understood only in the context of national policies and sectoral developments. Pestel had described how the procedures of the Pestel-Mesarovic model were used to develop a national policy model for the FRG, which requires far more detail than regional and global models.

It was generally accepted that the purpose of global modeling is a cognitive one, namely to gain an understanding of the nature of the interdependence of systems, of nations, and of peoples, and that such an understanding is desirable. It was argued, however, that physical and social systems are too complex to be fully modeled and that models can give only partial understanding.

Further discussion questioned applied systems analysis, at least with respect to global systems, and tried to clarify its possibilities and limitations. To start with the limitations, any global system description must be incomplete. This is more a problem as we observe a rapidly growing interdependence of "global subsystems". To reduce the unseizable complexity a simplifying structuring must precede model-building--and here inevitably value judgments enter. It is this point, more than the limited capacity of IIASA, that led to the repeated recommendation for close cooperation with outside institutions and decision makers to ensure proper guidance and critique.

The parallel interaction of energy and food production with the climate was of primary concern. Meteorology cannot fully explain the phenomenon "climate" and predict the consequences of large amounts of waste-heat releases. Other factors beyond the scope of traditional meteorology--e.g., CO_2 releases, dust, and chemical pollutants originating from agricultural activities--are even more important: they interfere with large natural energy flow mechanisms or disturb highly sensitive equilibria, e.g., the ozone layer of the stratosphere. Applied systems analysis will not answer, but will formulate more precisely, meteorological and climatological questions important for deploying energy strategies or agricultural development programs. Moreover, systems analysts may be able to contribute to the development of methodology for calculating global circulation. Even with inadequate methods, by pushing the methods to their limits useful results may be obtained.

Thus all one can safely conclude from global circulation studies--for example of effects of point sources of heat, or of the CO_2 problem--is that these questions need to be studied. Despite this uncertainty, however, the need for climatological predictions to evaluate the shadow prices of different strategies (for energy, food, development) in terms of climatological quality was emphasized. It was argued that even a partial understanding of our interaction with the world and the Universe would be worth the effort.

It was further argued that applied systems analysis is in a position to trace the influence of possible climatological risks on pending technological decisions--a prominent example being the development of alternative primary energy sources. The fact that, owing to insufficient knowledge of the effects of atmospheric pollutants on the climate, possible consequences of a decision in the energy sector cannot be excluded is attributable to the lack of knowledge at a given point in time. Climatological studies can be evaluated and priorities established in this light.

An important point of the discussion was the statement that in a quite subtle way, values are introduced into our models. The values implicit in defining the boundary of the problem to be studied may not be obvious. By not elaborating on that point, one may create an impression of the inevitability of certain assumptions. Concern was expressed about the assumption, in both the Energy and the Food and Agriculture models, of 12 billion people. The resources required to meet, e.g., the energy needs of such a large population could be devoted to other areas, and possibly to stabilizing the population at a lower figure. When brilliant technical systems analysis show that it is possible to meet the energy needs of 12 billion people, those less brilliant might conclude that a population of 12 billion is inevitable. The question was asked whether a world with so many people can live stably, or whether we would all be psychological wrecks.

In response to that statement, it was pointed out that 12 billion people are by no means considered as a target; but it is uncertain whether the figure, projected by the UN Population Conference in 1974, can be avoided. Several panel members agreed that if such a menacing development is to be limited, one has to argue the other way round: we must not rely on the impossibility of exploiting global resources such as to feed and supply the basic energy needs of 12 billion or even more people. It is by demonstrating the actual possibilities that the basis for a rational policy including a population policy is provided. Applied systems analysis, and especially IIASA, should be as clear as it can be in working out the real constraints and the consequences of the foreseeable alternatives for global development.

Invited Comment

P. Handler

It is a little distressing to recognize that you've come to the time of life when you're used for ceremonial purposes--as I suspect is the case, for I certainly cannot pose as an expert on applied systems analysis or on any of the problems IIASA is dealing with. But it was an invaluable experience to participate in IIASA's creation. I thoroughly enjoyed the amicable, straightforward tenor of the meetings with Gvishiani that were required to negotiate what evolved into IIASA. Vienna turned out to be the logical place for the Institute, and I am happy this came about.

We are pleased that the number of National Member Organizations that adhere to IIASA has expanded and probably will continue to do so. My own reasons for believing in this project were initially political: it seemed a remarkable opportunity to have people from East and West work cheek by jowl. It was this more than anything else that provided the drive behind IIASA.

What sort of work did we think IIASA would do? I was somewhat fuzzy, but it seemed to me imperative that IIASA deal not only with methodology but with real problems in a real world; otherwise it was sure to founder. I am delighted that both these aspects appear to be flourishing.

When we started all this, it was before the rise in oil prices and the oil embargo, before the acute international awareness of energy problems, before the crop failures of 1972. There was no sense at that time of an impending food crisis anywhere in the world. What have come to be two central themes of IIASA were not at that time thought of as topics of urgency for the world. We did know that IIASA must deal with problems of significance to all nations. I have listened to what has been said in this hall in the last few days, and it is clear that there are people working at Schloss Laxenburg with determination and clarity and insight.

Your courage in addressing these immense problems is extraordinary. What troubles me a little bit is that the systems you deal with, the mechanisms of thought in an analytical approach, are fraught with error, and that the hazards of making a blunder are tremendous. But if you have the courage and the intellectual honesty to be sure you know what you have said and done and what its limitations are, then the work can be rational and useful.

Most of my life I have believed that informed intervention can improve the lot of mankind; that if you knew enough, you could find the critical element of a large system and improve the circumstances of human beings. When I had just entered science, the disease pellagra had been the leading cause of death in the southeastern United States for 30 years. My first independent research was on the nature of that disease--how it developed as a consequence of a niacin deficiency in diet. And at that time I listened to endless conversations about what it would take to change the social structure of the American South, to improve its economy so that people would stop eating the traditional diet that caused pellagra. One day it occurred to me that if one made it mandatory to put nicotinic acid into cornmeal, then you could wager anything you pleased that we would stop the disease. And so my first political effort was to sell this notion to the legislatures of eight southeastern States; and after one year, all eight had ruled that cornmeal sold on the open market must be fortified with nicotinic acid. The following spring, when pellagra should have appeared again, the incidence rate was down to 10 percent of the preceding year; and two years later, the last case of pellagra was seen in the American South. And that is what I mean about informed intervention in a complex system: had we been waiting for the cultural upheaval that was required, we probably would still be waiting. I believe in informed intervention when one knows how to do it; but clearly the systems you are dealing with are of such character, and so large, that you must be very sure of your ground before you are willing to intervene at all.

I listened with particular attention to the description of the food program.* It was stated that this is not a local but an international problem. My view is rather the opposite, I confess. Historically, national barriers have by and large been impervious to the passage of food; each nation has fed itself. The amount of food going across national frontiers has been very very small. The idea of a major fraction of the world's food moving across national boundaries is relatively new. And the food sold by the countries that have it is often sold to countries that aren't hungry but just have money and want to eat better. So for the benefit of the Food study group, here are some of Handler's laws about food, invented while I listened. First, it is a truism that world food production far exceeds the amount necessary to feed the world population; the problem is how to get it from where it is to where it is needed. Second, to the best of my knowledge there are no hungry people in the world who have money. Third, nowhere in the world are farmers happy about growing more food than their families can eat, unless somebody gives them something they want for the extra food they produce.

These rules guide the behavior of the agricultural economy today as they have in the past. The problem of starving nations

---

*See F. Rabar, this volume.

can be stated in any unit you please: energy, per capita income, water resources, food--it is the same problem. I cannot imagine that over time, the rest of the world is going to grow enough food to solve the problem of the poorer nations; we must assist *them* to grow more food.

So I am a little worried about the structure of the food model and its assumptions. Food is the most burning problem on the planet, and it will get worse unless the affluent nations find some way to help those nations who need it; but merely to give food to the poor countries cannot be a permanent solution.

UNIVERSAL PERSPECTIVES

Introduction

H. Raiffa

Roger Levien has described IIASA's approach to universal problems in some detail. As you will recall, we have classified as universal those issues that confront many nations within their own borders. The management of an urban complex is a good example of a universal issue. It does not require international action; and the externalities resulting from policy are felt mainly within one nation, and to a much lesser extent by neighboring nations. Each universal problem is bounded geographically but replicated universally.

Many of IIASA's early activities dealt with universal issues. This was true in our Ecology, Integrated Industrial, Biomedical, Urban, Water, and Large Organizations projects. Today, we will focus on three examples of that work: examples that highlight IIASA's role and approach to issues of universal importance.

These three examples are: forest/pest management, energy/environment systems, and large-scale planning projects. I would like to say a few words about why each was chosen for IIASA, about its unique characteristics, and about the common conceptual basis that ties the three studies together.

The pest management case study was chosen early in IIASA's history. It was a concrete problem that a young applied institute needed to face. The study was highly analytical, and its objective was to develop descriptive mathematical models that can be used to test alternative policies for ecological management. As a result, it had in its early stages a relatively narrow regional focus--the forests of New Brunswick, Canada. But because of its geographical bounds, the pest management study has enabled us to experiment with methodological techniques that we can generalize not only to other questions of forest or pest management, but to other questions of ecological management as well.

The energy/environment study was begun in early 1975 and draws strongly on IIASA's international, interdisciplinary nature. In this study, we concentrate on three regions: the Rhône-Alpes Region in France, the German Democratic Republic, and the State of Wisconsin in the United States. Our objective has been to develop, with analysts and policy makers in each region, methodologies and approaches for integrated planning of energy and environmental development. Whereas our approach to pest management was analytical, this study mixes analytical and conceptual elements. Whereas we focused on building effective sectoral models in the forest management case, in this study we are concerned with approaches that integrate environment and energy factors into a single planning context.

We began our work on large-scale planning projects just over a year ago with an international conference based on the development of the Tennessee Valley in the United States. As a second case study we are looking at the development of the Bratsk-Ilimsk Territorial Production Complex in the Soviet Union. We are also considering additional case studies in Poland, Japan, and Iran. In each of these regions, we are examining approaches to regional development, concepts of planning and management at a regional level, and organizational alternatives for dealing with regional issues. Our objective is to formulate a broad common conceptual framework for approaching regional planning and mangement.

Despite their differences, there are critical links between these studies. Each of them addresses an important aspect of research into regional issues. The pest management study is concerned with methodologies for sectoral analysis. The energy/environment study looks beyond single sectors to the interactions among sectors. Finally, the study on planning projects looks at the overall analytic framework in which the many factors affecting regional decision-making can be examined.

I would be the first to admit that when each of the studies was chosen, it was selected on its individual merit. Each has brought to IIASA benefits of its own. It is only after we have begun them that their interrelationship is becoming clear. As we progress further with each of them, we expect these interrelationships to become clearer still. But we should not be overconfident. The integration of sectoral models into comprehensive approaches to regional issues is extremely difficult. We may not achieve success at IIASA; but because IIASA is interdisciplinary and international, it is a good place to try to forge these links. As Academician Aganbegyan will discuss in more detail, the need for such an attempt, and IIASA's potential to meet it, have prompted our decision to create a cross-cutting program in Integrated Regional Development.

Ecological Policy Design: A Case Study of Forest and Pest Management†

C.S. Holling, D.D. Jones, and W.C. Clark

At this Conference we heard eloquent expressions of the ideals and principles of IIASA; we heard descriptions of major global problems that threaten the very destiny of mankind. Now I am forced to go from the sublime to the ridiculous. I shall be speaking of a worm--worm's-eye view of systems analysis.

It seems scarcely logical that IIASA, whose goal is to address global and universal problems, should be concerned with an insect. But the reason for this choice is that the budworm/forest ecological system provides an admirable prototypical case study for the development, enrichment, and expansion of methodology and concepts that in a very real sense do seem to provide the ingredients for a new kind of ecological policy design. It is the development of those concepts and methodology that relates to IIASA's goal to address universal problems and to transfer the lessons learned to different situations, different problems, and different nations.

In the short time available for this presentation, I can only touch on this larger objective, using the budworm/forest case study as an example. In that, I will briefly review our efforts to capture an abstraction of the real world in a model that can then be used as a kind of laboratory to develop policy prescriptions. Given those policies, I will comment upon the techniques of evaluation, and conclude by discussing the central issue that has concerned us for the last year: that of transfer into the hands of those who make policy and those who endure those policies.

I am frustrated that there is insufficient time to talk about the concept that illuminates our work. It is a concept that addresses what we believe is *the* central issue of renewable resource management: how to design explicitly in the face of the unknown. The domain of our knowledge will always be less than that of our ignorance; and even the best of methodologies for treating the known can, if we ignore the unknown, lead to larger and larger disasters achieved more and more efficiently. The

---

†Presented by C.S. Holling.

way systems cope with unexpected events--the unexpected events that lie in every system's future--relates to their stability properties. We have drawn heavily on stability theory, concentrating on those aspects that relate to the resilience of systems. By resilience we mean the capacity of systems to absorb unexpected events and still survive--not necessarily efficiently but persistently. And, equally important, the resilience focus identifies a positive benefit to those erratic intrusions that we normally design out of our systems. It is those unexpected events that make for a system that continually renews and enriches its flexibility. Beyond that, all I can do is refer to the Conference presentation of Hans-Richard Grümm* who has collaborated with us closely. He describes some of the topological approaches that were applied to give numerical definitions for resilience. I would also emphasize that Alexander Bazykin of the USSR and John Casti of the USA have been collaborators in this work. And of course, Wolf Häfele has carried the torch in an admirable way in his energy study; so much so that I can even excuse his translation of resilience into "Schlagabsorptionsfähigkeit".

A conceptual framework for policy design, however, is meaningless unless there also exists a cohesive methodology linking it with the constraints and realities of actual management practice. To develop such a methodology and to test the applicability and practical relevance of the resilience concept, we have chosen to analyze specific case studies typical of large classes of ecological problems. Three case studies have engaged our attention. One involved an examination of development in high alpine regions of Austria--a microcosm of the global problems of population, resources, land, and environment. Another, still in progress, concerns national and international aspects of management of world fisheries, particularly Pacific salmon, conducted by my colleagues, Carl Walters and Ray Hilborn. The third was the budworm/forest management problem.

A careful cross-comparison has recently been made of these case studies and the IIASA energy study. These four cover a broad range of problems--global versus regional, ecological and social versus physical and economic, and national versus international. Earlier comparison had already established commonality in the identification of the primary issue (coping with the unknown) and the central concept (resilience topology). But, surprisingly and significantly, this commonality of concepts was matched by a commonality of analytical element. These are summarized in Table 1 and Figure 1. Rather than review that schema in detail, I will use it to organize the description of the budworm problem.

---

*See Volume 2.

Table 1. Elements of ecological policy design.

Systems Level	Analytical Element	Function
N + 1	Hypothetical Overview (Embedding)	Consequence check for larger societal implications
N	System Description	Specification and dynamic description of causal structure for the system studied
N	Policy Prescription	Specification of a strategic range of alternative objectives for the system and development of corresponding policies
N	Policy Evaluation	Comparison of alternatives through an array of indicators, focusing on the unknown, the uncertain, and missing components of the descriptive analysis
N – 1	Implementation	Consequence check for detailed practicality and operational feasibility.

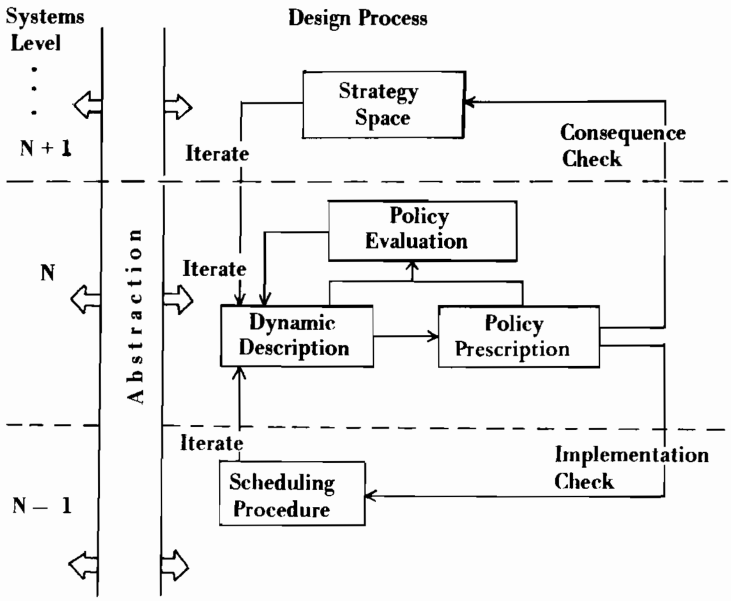


Figure 1. The process of ecological policy design.

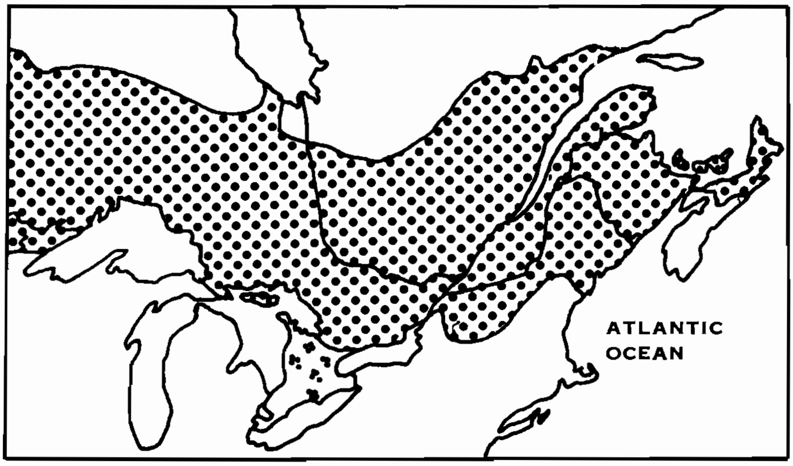


Figure 2. Spruce budworm infestations in eastern Canada from 1909 to 1966.

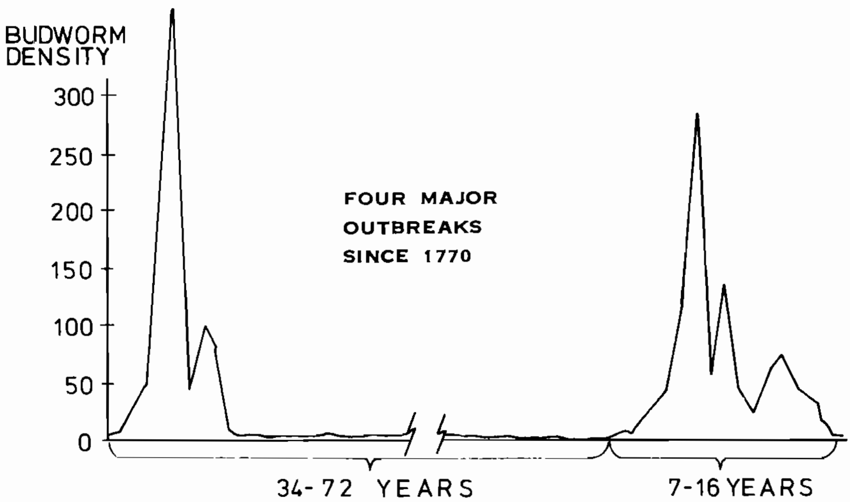


Figure 3. Historical pattern of spruce budworm outbreak.

SYSTEM DESCRIPTION

What is the budworm problem? It covers a huge geographical region encompassing the whole eastern central area of North America covered by boreal forests (Figure 2). It is characterized by a dramatic boom-and-bust cycle, with periods between outbreaks typically of 30 to 45 years' duration but occasionally slipping into 70 or more years (Figure 3). Between outbreaks, the insect is present but extremely scarce, increasing by three to four orders of magnitude during outbreak. At this time the balsam forests of this region are subjected to major mortality with many stands being totally destroyed.

Although this cycle has existed for centuries, before 1930 the budworm was not a "problem". It was, in a sense, a natural curiosity, but more directly was beneficial in that it was an important part of the renewal and maintenance of diversity of that particular forest ecosystem. In the 1930s, however, the forest industry began to mobilize its technology to utilize balsam trees for the pulp and paper industry. And suddenly what was a natural curiosity became a major social and economic problem, since a major part of the economy and employment of some of the regions affected became dependent upon the forest industry.

The geographical scale of this problem, its long-term time behavior, and its economic importance are classic features of the major pest problems of the world. It was for this reason that the budworm problem was chosen. Because of our larger interest in that class of universal problems, our emphasis was on generality and transferability of techniques and approaches.

The first step in attempting to develop a viable and succinct dynamic description is to bound the problem. Something will always have to be left out of an analysis, and those first stages of bounding have to proceed in a highly organized way because they profoundly affect the usefulness, if any, of the subsequent analysis. In our case we chose a region in the Canadian province of New Brunswick not because we were specifically interested in New Brunswick, but because it provided a convenient vehicle by which we could focus on our central issue of development and transfer of methodology (Figure 4).

Within New Brunswick, we had to decide on the area size, emphasizing the minimum size necessary for just capturing the essential behavior. Because of certain features of the dispersal properties of this moth, it developed that the absolute minimum area required was approximately 15,000 square miles. The region we finally chose was about 17,000 square miles covering most of the forested regions of New Brunswick (Figure 5).

One of the key features of ecological problems is a high degree of spatial heterogeneity, and that presents a significant challenge to methodology. In this example, there is a distribution of industrial activity, recreational opportunities, and species diversity over space that demanded a disaggregation of

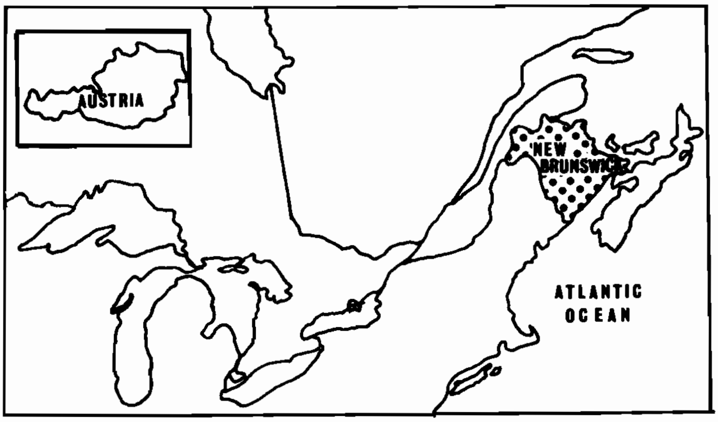


Figure 4. The province of New Brunswick in eastern Canada (inset of Austria to scale).

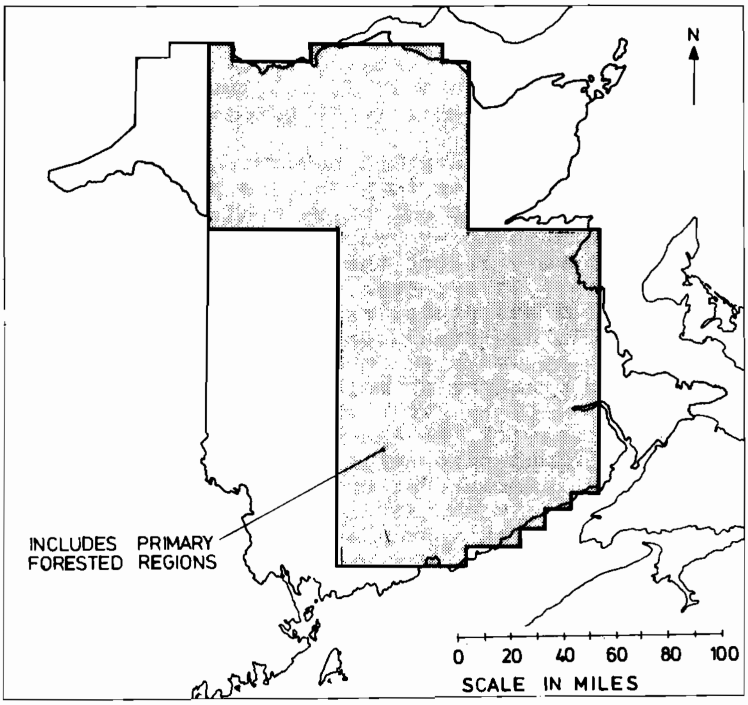


Figure 5. Study area within the Canadian province of New Brunswick.

the region into subregions of approximately 66 square miles each. It is at that scale of resolution that the system operates. There are 265 such subregions or sites within the overall area (Figure 6).

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	
01	1				2	3	4	5	6							2
02	7	8	9	10	11	12	13	14	15	16						3
03	17	18	19	20	21	22	23	24	25	26						4
04	27	28	29	30	31	32	33	34	35	36						5
05	37	38	39	40	41	42	43	44	45	46						6
06	47	48	49	50	51	52	53	54	55	56						7
07	57	58	59	60	61	62	63	64	65	66						8
08	67	68	69	70	71	72	73	74	75	76						9
09	77	78	79	80	81	82	83	84	85	86						10
10	87	88	89	90	91	92	93	94	95	96						11
11						97	98	99	100	101	102	103	104	105	106	12
12						107	108	109	110	111	112	113	114	115	116	13
13						117	118	119	120	121	122	123	124	125	126	14
14						127	128	129	130	131	132	133	134	135	136	15
15						137	138	139	140	141	142	143	144	145	146	16
16						147	148	149	150	151	152	153	154	155	156	17
17						157	158	159	160	161	162	163	164	165	166	18
18						167	168	169	170	171	172	173	174	175	176	19
19						177	178	179	180	181	182	183	184	185	186	20
20						187	188	189	190	191	192	193	194	195	196	21
21						197	198	199	200	201	202	203	204	205	206	22
22						207	208	209	210	211	212	213	214	215	216	23
23						217	218	219	220	221	222	223	224	225	226	24
24						227	228	229	230	231	232	233	234	235	236	25
25						237	238	239	240	241	242	243	244	245		26
26						246	247	248	249	250	251	252	253			27
27						254	255	256	257	258	259	260				28
28						261	262	263	264	265						29
	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	

Figure 6. Numbering and indexing system for the 265 subregions, or "sites", in the study area.

Of the thousands of species and variables in that forest ecosystem, the essential time and space behavior can be captured by the set of variables suggested in Figure 7.

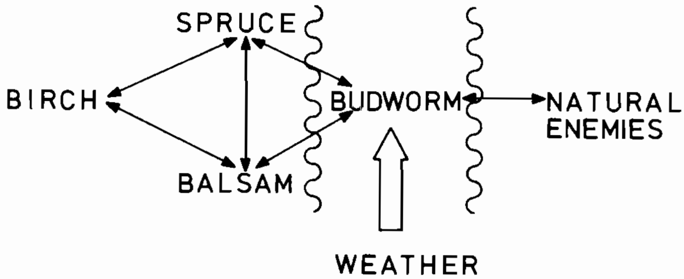


Figure 7. The key roles or variables and their interrelations in the natural ecosystem.

There is, among the tree species, a specific interaction such that balsam tends to outcompete the other species. The budworm, however, periodically shifts that competitive edge since balsam is preferentially attacked. Hence the budworm generates a dynamic shifting rhythm of competition that in part contributes to the maintenance of the particular species diversity of that ecosystem. Weather must be considered, since it has been established that outbreaks are often triggered by a sequence of warm, dry summers if the forest conditions are suitable. Finally, natural enemies, particularly parasites and birds, have a central role to play during the inter-outbreak periods. In fact, the qualitative time and space behavior of this system is determined by the interaction of natural enemies, dispersal, and the generation time of trees. This small set of variables, therefore, represents the minimum variables that must be considered in order to capture the essential behavior.

We must equally concentrate on bounding our problem in time. As suggested by Figure 3, the time horizon has to be 100 to 150 years, not because any manager has that kind of time horizon, but because the time constants of this natural system demand it. The evaluation of any policies on a shorter time scale can identify, perhaps, short-term benefits, but at the price of long-term disasters. The time resolution had to be one year, in part because of certain biological mechanisms, but more important because that mapped more closely into the time perceptions of the management agencies.

At the same time as space, variables, and time are bounded, policies must also be bounded. The core of the descriptive analysis focuses on the forest ecosystem, but it must, from the outset, be responsive to realistic alternative policies. The specific policies, or actions, that have been or could be applied are almost infinite: the use of insecticides, biological control agents, genetic manipulation, tree harvesting and planting schemes. Moreover, the actions that now seem to be economically impractical might, with future developments, become highly feasible. The whole range of actions feasible now and in the future, however, falls into essentially three classes: control of the insect, harvest of the trees, and manipulation of the forest through planting. A descriptive model must allow intervention by any of these classes of action at any moment in time and any point in space.

The results of that bounding exercise are summarized below. Although it might sound like a fairly ruthless and parsimonious effort, considerable complexity emerges.

Policies	Budworm control and forest management
Key Variables	Host tree species (with age structure), foliage condition, budworm and weather
Time Horizon	100 - 150 years
Time Resolution	1 year with seasonal causation
Spatial Area	17,500 square miles
Spatial Resolution	265 subregions of 66 square miles each.

Ignoring the control variables, there are 20,935 state variables in this description of the system. Moreover, the relationships are highly nonlinear. This, in fact, was one of the reasons why the Methodology group at IIASA developed an interest in the budworm: because it represented a level of complexity beyond the state of the art of optimization and yet, perhaps, not quite so far beyond that something couldn't be done. It therefore offered the potential for a major methodological advance in optimization.

The basic form of the model structure is shown in Figure 8.

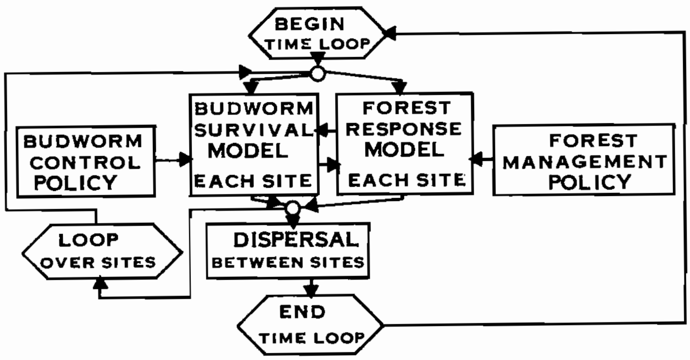


Figure 8. Budworm forest simulation model: basic model structure.

Budworm reproduction and survival, forest response, and control policies are independent for each of the 265 sites. Once each year, dispersal occurs among the sites, and the process is then repeated for the next simulated year. The budworm and forest response models were developed from the extensive set of data collected by Environment Canada over the past 30 years. But there are three critical processes that are not clearly understood at present and for which there is, at best, qualitative information. These three semi-knowns are the effect of natural enemies at low densities of the insect, the detailed response of trees to defoliation, and the specifics of dispersal. Since this problem of grappling effectively with substantive unknowns is central to any successful analysis of ecological problems, considerable effort was spent in developing a formal procedure to cope with such uncertainties. Moreover, these three areas of uncertainty are typical of many situations. Rarely, for example, is there much detailed information about events when the number of organisms is very small. Nor is there often much knowledge concerning very slow processes such as those involved in tree responses. Finally, dispersal occurs over such large areas that only the very recent application of radar technology has made it possible to define and quantify the form and magnitude of spatial contagion. And yet we know each of these three sources of uncertainty to be critical in determining aspects of renewable resource systems behavior that have been particularly troublesome in past efforts of environmental management.

The ecological literature contains a rich body of experimental and theoretical analyses of key ecological processes. These have led to the identification of classes of interactions, each characterized by a specific family of mathematical equations. For example, predators display a set of responses to prey or host species that fall into nine primary classes. Not only is each class defined by a specific family of functional relations, but the biological attributes for each have also been sufficiently well identified that quite qualitative information usually makes it possible to assign a specific example to the appropriate general class.

This work provides a theoretical framework allowing us to mobilize the existing information, however sparse, in a way that lets us proceed by steps to define a narrower and narrower range of possible relations. Having identified in this manner the classes of responses characterizing specific situations, it remains necessary to parameterize them. Even in the worst circumstances, information usually exists to permit rough specifications of the parameters, leading to the definition of a maximum possible range for each response class.

The final step is to cycle these possible relationships through the full simulation model in order to define a "feasible range" of forms that retain the known qualitative behavior of the system. At that point, informed judgment can informally select a "standard" relationship for use. Alternatively, an organized application of decision theory can assign subjective probabilities and so generate a range of possible outcomes.

The key point of this exercise is to directly face the reality of unknowns and to recognize that an organized approach in dealing with them can provide not only reasonable solutions that will allow the policy design process to proceed, but at the same time very clear and specific priorities for future research.

A dynamic descriptive model of the sort outlined here is useless for prescription unless it presents opportunities for meaningful management intervention by policy actions. There are two main classes of possible policy action, one relating to control of the budworm and the other to management of the forest. These are structured in broad terms, allowing for the exploration of both insecticide control of budworm and biological and other methods of control. Similarly, the forest management policy can indlude specific actions of cutting by age or condition of trees, and also a variety of silvicultural and tree-breeding actions. Although the model is structured to accommodate a wide range of possible actions, for the purpose of this case study attention was directed largely towards budworm control using insecticides or bacterial agents, and forest management using different techniques of scheduling cutting in space and time and by tree age and condition.

Figure 9 shows output from the full simulation model under conditions of no management or harvesting. To a remarkable degree the qualitative patterns match the real-world behaviors as summarized earlier in Figure 3.

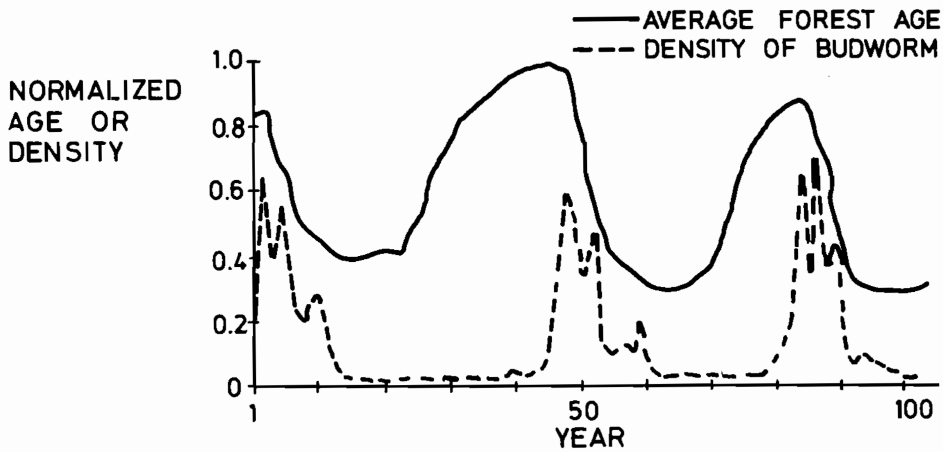


Figure 9. Typical outbreak pattern generated by the model, with no management or harvesting imposed.

The inter-outbreak periods generated by the model are typically 35 to 40 years, and occasionally the model slips into an inter-outbreak period of 74 years. The amount of tree mortality imposed and the order-of-magnitude changes of the budworm are close to those that occur in nature, and even some of the subsidiary peaks in density of budworm shown in Figure 9 have in fact been known to exist.

Because of the spatial disaggregation we can analyze not only time behavior but space behavior as well. Figure 10 shows some examples of spatial output from the model, viewing the province of New Brunswick as if the observer were above the state of Maine looking northeast. In the example shown, the x and y coordinates are spatial and the z coordinates are density of budworm. These are just selected examples at various stages in the time sequence; the basic message is that again, in the spatial as in the temporal sense, there was a remarkable congruence between the simulated world and the real world.

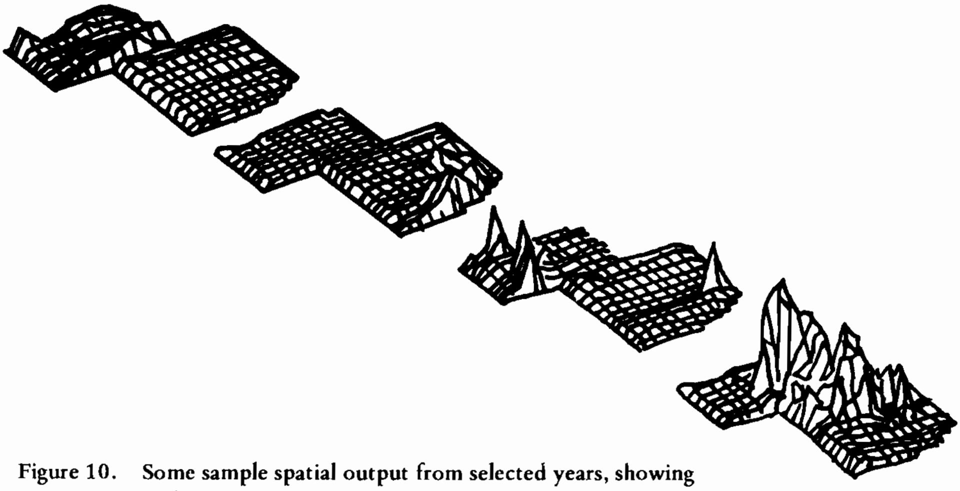


Figure 10. Some sample spatial output from selected years, showing budworm density as the height over the 265 grid area.

Although simulation models of this sort are admirable devices to capture explanation, they do not capture understanding, because of the complexity. As a consequence, a major effort was made to apply other kinds of modeling techniques--differential equations, topological analyses, and Markoff processes--to determine whether these techniques could be used to encapsulate understanding in a succinct manner. As only one example, Figure 11 shows the equilibrium manifold for budworm, for different amounts of foliage and different forest ages, under conditions of no management. The particular trajectory shown on that manifold is that of the boom-and-bust cycle of the unmanaged world. When further transforms are introduced as a consequence of proposed policies, we find that

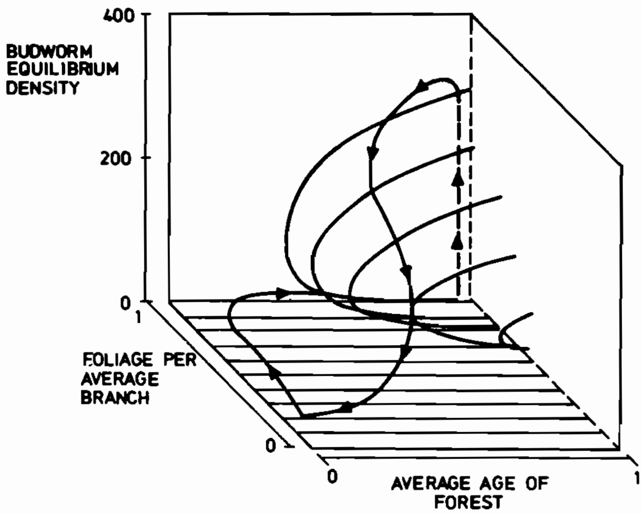


Figure 11. Budworm manifold.

such representations provide a powerful device for scientists and managers to grasp and encapsulate an understanding of systems dynamics and of the central importance of key processes that affect stability conditions.

But of course the world has not always been an unmanaged one. Since 1953 it has been subjected to historical management through a combination of harvesting of older trees and an insecticide spraying program that concentrated not on eliminating the budworm, but on preserving the trees in order to maintain a viable forest industry. The results when these historical management policies are introduced into the model, initializing to conditions in 1953, are shown in Figure 12.

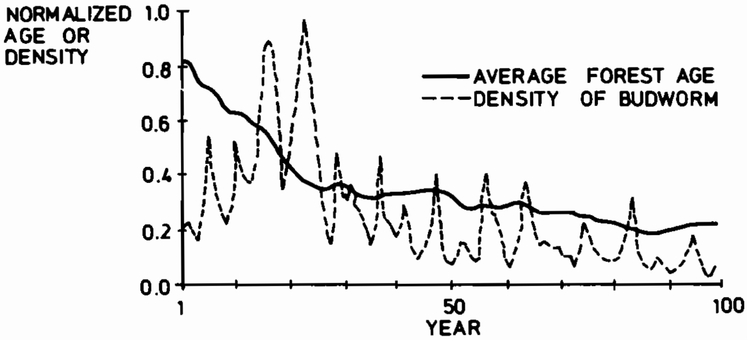


Figure 12. Simulation of the effects of historical management policies.

For the first 23 years, i.e. to the present, the rate of erosion of the forest was indeed significantly slowed down, thus guaranteeing continued employment during that period when otherwise the industry would have collapsed. But that short-term benefit was bought at a high price. This policy, in a sense, represents almost a caricature of a non-resilient, non-robust policy. It is bought at the expense of a spreading of semi-outbreak conditions and a gradual but persistent erosion of the forest. If at any point there is a policy failure--because of unexpected increases in cost of insecticide or an unexpected health hazard--then an outbreak of such severity and geographical extent would be generated as has never occurred before. And yet there seem to be no options, for the social consequences of that failure and the geographical extent of the impact flooding into Maine, Ontario, and Quebec would be beyond the capacity of the management agency to absorb.

POLICY PRESCRIPTION

But are all options closed? With this development of a well-tested model, the opportunity presents itself to use it as a means to develop and evaluate alternative policies.

To do that, the first requirement is the definition of objectives. Because we are interested in the objectives not simply of New Brunswick but of other regions with similar problems, we chose to define a strategic range of objectives with eight specific objectives along that range. At the one extreme the objectives represent the narrowest kind of profit maximization, and at the other, maintenance of the biological and ecological variability while still providing social and economic benefits. The point of this strategic range is not that any touchstone on it is realistic, but that the real objectives of Ontario, Quebec, New Brunswick, Maine, Europe, Japan, can be found somewhere along that range.

Given these eight objectives, we can then apply a variety of optimization techniques--dynamic programming, fixed-form control optimization--to develop optimal policies that identify interesting starting points in a very complex policy space. But such optimization techniques as exist cannot cope with the high dimensionality and nonlinearity of this system. As a consequence, simplified versions of the model had to be designed to make it feasible to develop such appropriate starting points in policy space.

In the time available I can give only one example, concerning an optimization policy developed by Dantzig and Winkler using an objective of simple unconstrained profit maximization. The results of that policy can be summarized in policy charts of which examples are shown in Figure 13. A separate table is provided for each age of tree (or, in practice, average age of stand).

For any tree age, under any conditions of foliage and budworm density, the tables indicate whether to leave the stand alone, harvest it, or spray it with insecticide. The particular rules developed by this optimization happen to be almost diametrically opposed to the historical management policies that had been developed through the intuition and informed judgments of scientists and managers.

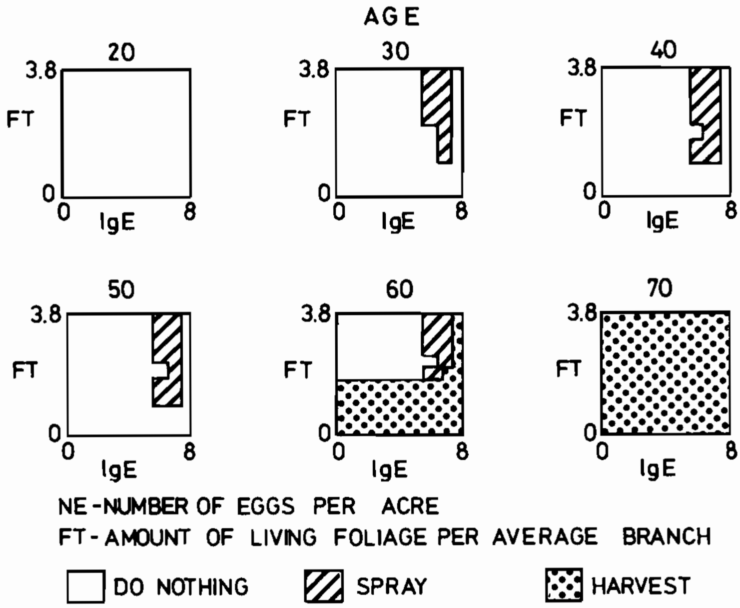


Figure 13. Representative policy tables generated by the Winkler-Dantzig optimization.

But because the optimization had to be developed using a simplified variant of the model, it is essential to evaluate its full consequences. This is done by cycling the rules back through the full simulation model, evaluating the policies in terms of the elements left out of the objective function or the dynamic programming model. The results of applying those rules to the full simulation model are shown in Figure 14. Again the simulation starts with conditions in 1953, but unlike the historical management policies, the budwork outbreak is rapidly brought under control, the budworm remains rare, and the forest is not subject to significant budworm-induced mortality. The changes in forest condition occur because of harvesting activities, and the cycle indicated is a consequence of past budworm outbreaks establishing a narrow age distribution.

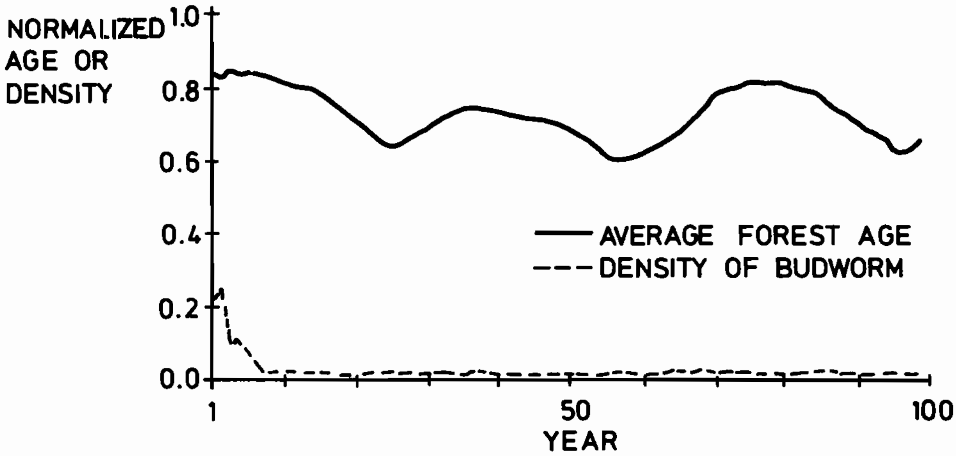


Figure 14. Simulation of the effects of applying the Winkler-Dantzig optimization rules, starting with 1953 conditions.

POLICY EVALUATION

But we do not live by state variables alone. Many things are left out of the analysis, and the way we have handled this is by generating a host of indicators--resource indicators, environmental indicators, socio-economic indicators, and indicators of resilience and robustness. It is these indicators that are of relevance to decisions, and that are designed to map into the mental or mathematical models covering areas not included in the analysis.

Figure 15 shows the effects of applying the Winkler-Dantzig optimization rules on five indicators, drawn from a menu of 45, that happened to be of interest to a particular manager. These should be compared to Figure 16, which shows the time stream of these indicators for the historical management policies. Clearly the Winkler-Dantzig rules dominated the historical ones in nearly every attribute considered. In particular, the objective function included only profit, and yet, despite that, indicators of environmental impact--such as proportion of area sprayed or of recreational quality--were significantly enhanced. This is an illustration of a policy that is robust to alternative objectives.

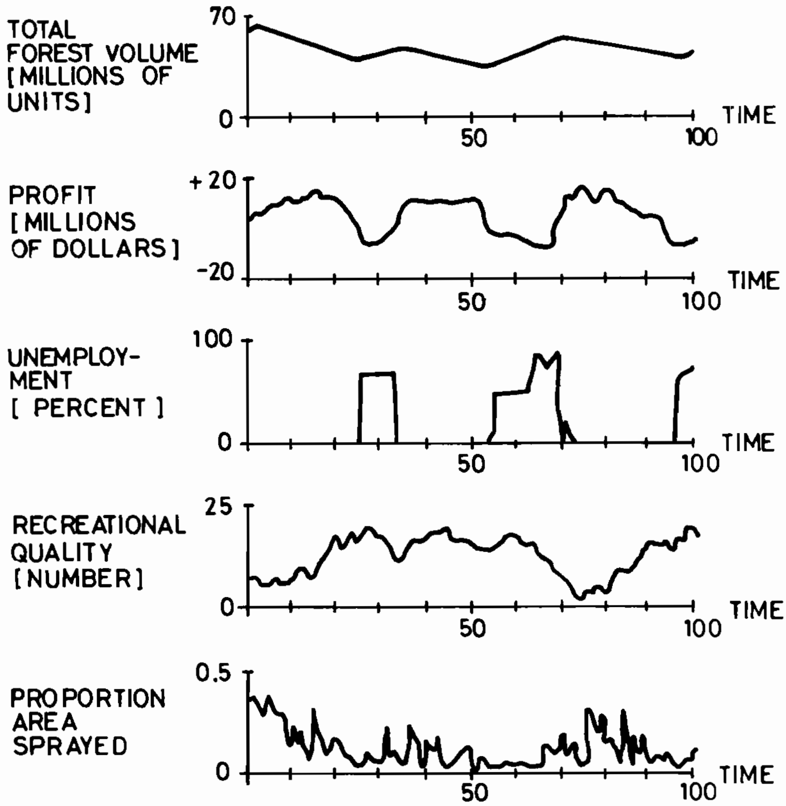


Figure 15. Indicators generated by the constrained Winkler-Dantzig rules.

IMPLEMENTATION

We have emphasized throughout the necessity of policy design transferable to a wide variety of situations. This has been our prime motivation and justification for focusing on generality at all stages of the analysis. This emphasis has numerous advantages, but it has serious shortcomings with respect to implementation.

For implementation decisions are made in specific circumstances, not general ones. Decisions are shaped by regional constraints, by particular institutional structures, and by unique personalities. The focus on generality sets the stage for implementation, but unless followed by effective application to specific situations, the analysis can become simply an academic curiosity.

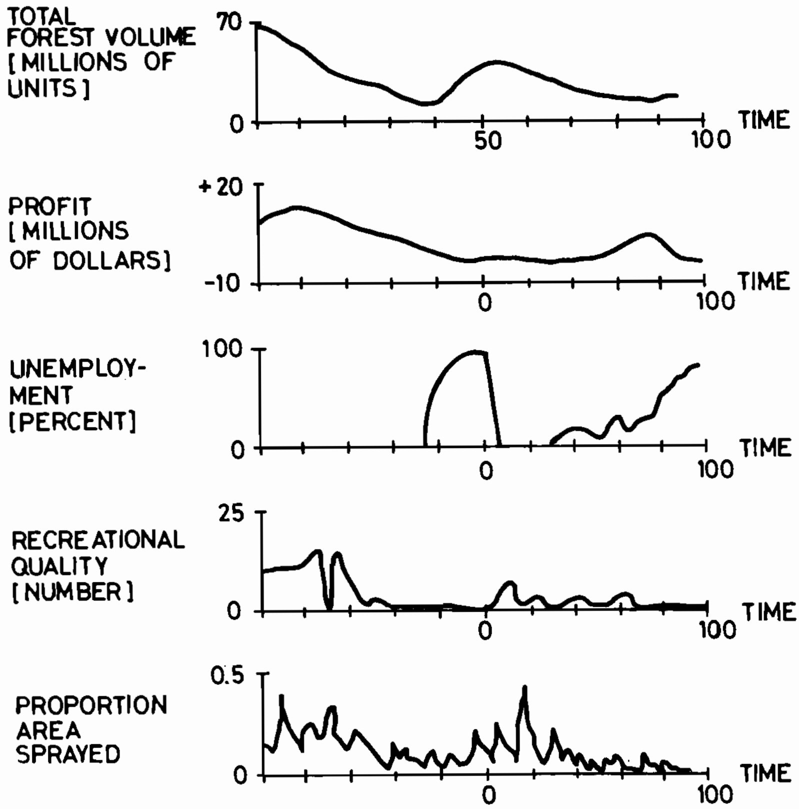


Figure 16. Indicators generated by historical management policies.

Hence, close working ties have been maintained with the potential policy makers throughout the design process. At present, transfer and implementation take place at three levels: one involving federal and provincial agencies in New Brunswick, one involving key institutions within the larger group of provinces and states affected--particularly Ontario, Quebec, New Brunswick, and Newfoundland, and Maine in the USA--and one involving other countries in Europe and Japan faced with similar problems. In each case the goal is not to recommend a unique policy, but rather to transfer the concepts, modeling, and evaluation techniques together with a menu of alternative policy touchstones into the hands of those responsible for and affected by decisions.

To facilitate this transfer process, we have designed a carefully orchestrated series of workshops for scientists, managers, and policy people in the regions affected. These emphasize interactive computer displays so that participants can ask their own questions and receive their own responses. The consequence of that effort is that a short time ago the New Brunswick government announced the establishment of a task force charged with developing policies for 1977. The techniques they are using are those described herein. The state of Maine and the US Forest Service have also expressed interest, as has the Canadian province of Quebec. In late October another workshop will be held--under the auspices of the International Institute for Applied Systems Analysis--for groups in Europe and Japan faced with similar agricultural or forest pest problems.

If our purpose had been to develop an analysis destined for academic journals, we could have completed the exercise within months. But because we have continually emphasized the need for test and transfer of these new techniques of ecological policy design, the problem has demanded a much more extensive effort to communicate, modify, and adapt to users in a variety of situations. With this, a rare opportunity has emerged to develop a cross-comparison of institutional and decision environments in different situations. Howard Raiffa and his colleagues at Harvard have undertaken just such a cross-comparison between New Brunswick and Maine, with the potential of expanding it to other regions of North America and Europe. That in itself is a long-term project, but one that is a minimum requirement if we are to capitalize on the full potential of the study to date. Only by adding those key concerns for institutional arrangements can we gain the experience and confidence necessary for a science of ecological policy design.

Acknowledgments

In one sense it is presumptuous to thank those directly involved in this study since they were all equal partners in a strange inter-institutional and interdisciplinary experiment. Nevertheless, they deserve the recognition of being as much part of this creation as the authors of this paper. The policy people and scientists of Canada's Department of the Environment gave remarkable and consistent support throughout. In particular Gordon Baskerville, Charles Miller, and their colleagues of the Maritimes Forest Research Centre were committed partners in the team, with their flanks admirably protected by Evan Armstrong, Dick Belyea, Murray Nielson, Dick Prentice and John Tener.

At IIASA, in its pioneering first year, an astonishing group of outstanding people gave their all to something as silly as a budworm--David Bell, George Dantzig, Myron B. Fiering, and Carlos Winkler.

The third institution involved was the Institute of Resource Ecology, University of British Columbia. Our friends and colleagues, Carl Walters, Ray Hilborn, Randall Peterman, Pille Bunnell, Nick Sonntag, and Zafar Rashid carved off pieces and solved them at times when they saw we were faltering.

Finally, and of supreme significance: Howard Raiffa, then Director of IIASA, made it all happen.

Management of Regional Energy/Environment Systems

W.K. Foell

INTRODUCTION

Late in 1974, a research study on Management of Regional Energy/Environment Systems was initiated by the IIASA Ecology project. The study was so structured to take advantage of IIASA's international and multidisciplinary character. In addition, during 1975 and early 1976, it served as a rich source of case studies for what has been the dominant aim of IIASA's Ecology project since its inception--the development of a coherent science of ecological management that could be applied to similar problems throughout the world. The research was founded upon the following four key presumptions.

- Energy-use limitations will result from unacceptable costs and consequences, not from resource depletion;

- Strong relationships exist between energy systems and economic development. Energy and its environmental corollaries will exert increasing influence on technological, economic, and environmental decision-making bodies throughout the world;

- Many significant social and environmental consequences of energy systems arise from embedding the system in a specific region or human environment;

- There is a need to study alternative human patterns and life styles in connection with energy/environment systems.

The study, designed to integrate energy and environmental management considerations from a system perspective, has four primary objectives:

- To describe and analyze existing patterns of regional energy use and supply, and to gain an insight into their relationships to socio-economic patterns;

- To analyze and compare alternative methodologies for regional energy and environmental forecasting, planning, and policy design;

- To develop new concepts and methodologies for energy/environment system management and policy design;

- To use these methodologies to examine alternative energy policies and strategies for test regions, to explore their implications from various perspectives using sets of indicators related to environmental impacts, energy-use efficiencies, etc., and to investigate whether these strategies represent a viable choice for the society in which they are being considered.

In this report on the way this study has developed over the past 16 months, emphasis is placed upon the conceptual framework within which it has been conducted. Detailed results are described in current or forthcoming IIASA publications.

THE RESEARCH FORMAT

The Comparative Case Study Approach

One of IIASA's strengths is its access to research institutions and scientists throughout the world and its mandate to interact with them in applied and policy-oriented research. To take advantage of this capability and as a vehicle to sharpen the research, the Energy/Environment study was organized on a comparative basis, three distinct geographical regions being chosen as the first case studies: the German Democratic Republic (GDR), the Rhône-Alpes region in southern France, and the state of Wisconsin in the USA. The regions were chosen in part because of their greatly differing characteristics--socio-economic and political structure, technological base, geographic and ecological properties, and institutional approaches to environmental and energy planning management--and partly because of the presence in each region of an institution with policy-oriented research program, examining energy/environment systems from a broad resource-management perspective.

A Research Network

A small core team of IIASA scientists, cutting across several research projects, conducted the in-house research in collaboration with research institutions in the three regions under study, namely:

- The Energy Systems and Policy Research Group of the Institute for Environmental Studies and the College of Engineering, University of Wisconsin-Madison, USA;

- The Institut für Energetik, Leipzig, GDR;

- The Institut Economique et Juridique de l'Énergie (Centre National de la Recherche Scientifique - CNRS), Grenoble, France.

Each of these institutions plays an active role in its country or region in conducting applied policy-oriented energy research and in advising decision and policy makers.

The interaction between IIASA and the collaborating institutions is shown in Figure 1. As indicated, there was a flow of models, data and personnel. The vigor of this flow reflected positively upon IIASA's potential coordinating role in the international scientific community. Planning for a follow-up phase was begun in 1975, with preparations for participation by an additional country or countries.

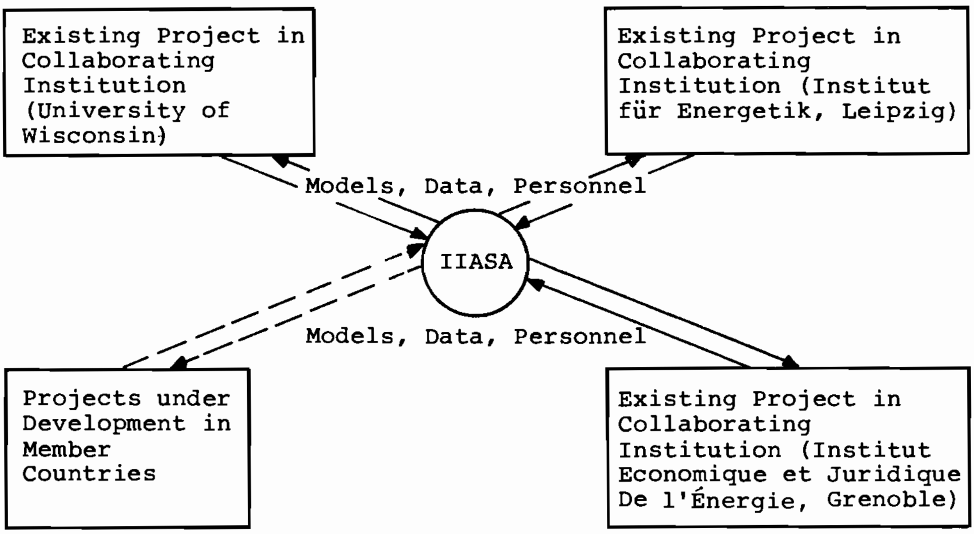


Figure 1. Interinstitutional relations within the energy/environment system study.

Research Components

The research activities can be broken down into five components:

- Description of the energy/environment systems of each region: past and current energy use, energy supply models and flows, environmental quality indices (air, land, water, etc.), economic activity, demography, human settlement patterns, and so on;

- Description and comparison of regional institutional and organizational structures within which energy and environmental planning, management, and policy design are conducted;

- Comparison of energy/environment modeling tools used in each region, according to methodology, domains of policy and planning applications, relation to the decision-making structure, transferability to other regions, etc.;

- Development of alternative futures (scenarios) for each region as a tool to examine alternate energy and environmental policies and strategies;

- Development of methods and concepts for communicating and evaluating energy/environment strategies and options.

DESCRIPTION OF REGIONAL ENERGY/ENVIRONMENT SYSTEMS

A detailed comparative descriptive analysis was developed for the three regions. It focused on relating differences in energy use, supply, and environmental conditions to socio-economic activity and geographic properties. There are dozens of ways to aggregate and display the characteristics of the energy/environment system of a region: from an economic perspective, on an energy-flow basis, with material-economic flows (input-output), and so forth. For the purposes of this study, the system structure shown schematically in Figure 2 was used. The major components are socio-economic activities, energy demand, energy conversion and supply, primary energy, and environment.

The hierarchical structure within each component is complex; details are given in a forthcoming work [1], and only an overview is presented here. Most of the data are for 1972, chosen as a reference year.

Socio-Economic Activities

Table 1 provides a comparison of the size, population and the population density of the three regions. The contrast

Table 1. Comparison of population and area, 1972.

	Population (10^6 people)	Area (km^2)	Density (people/km^2)
GDR	17.0	108,178	157
Rhône-Alpes	4.7	43,634	108
Wisconsin	4.5	145,370	31

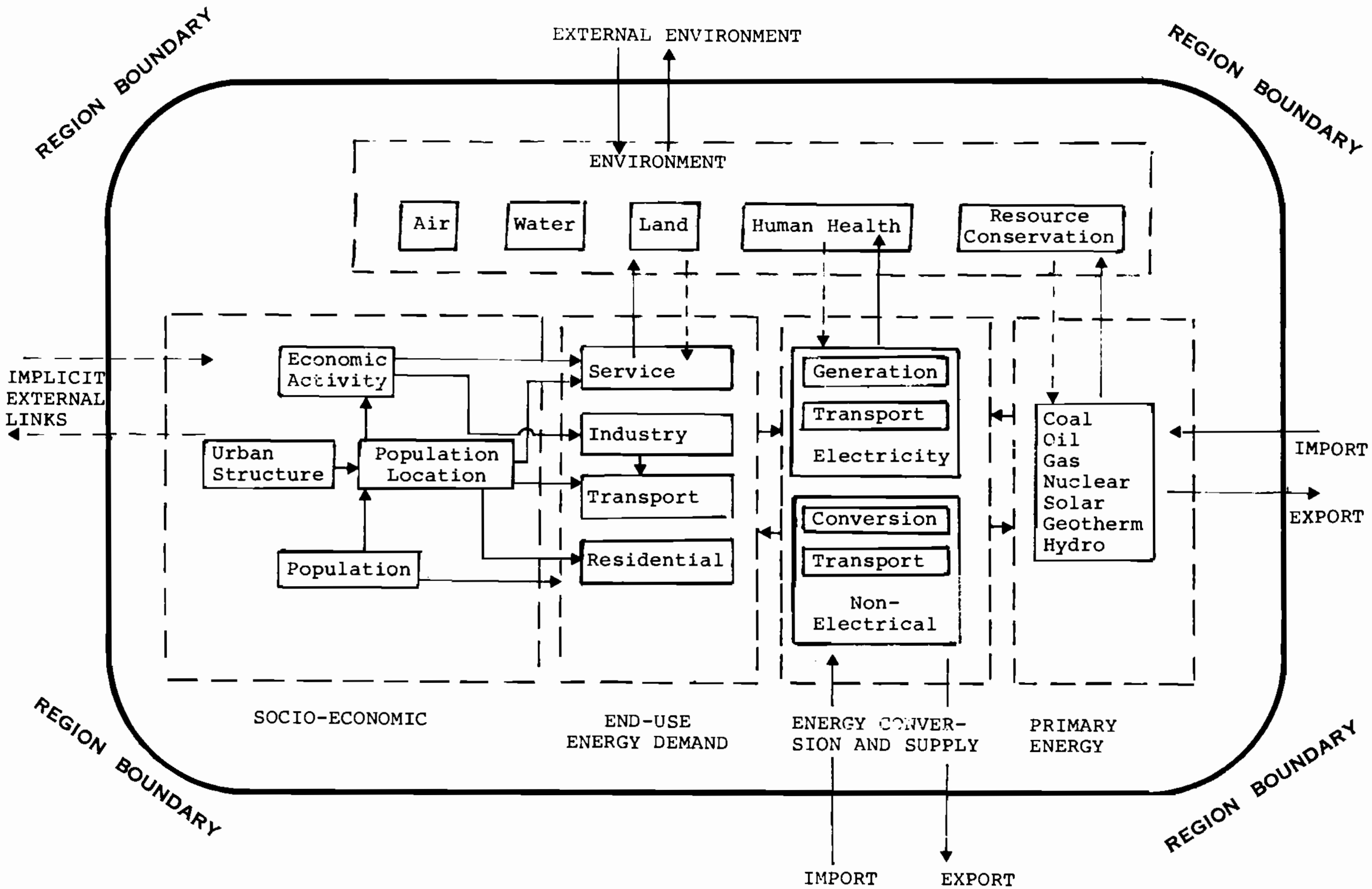


Figure 2. Structure of energy/environment system for scenario development.

between the overall density of Wisconsin and the heavily populated GDR is striking. Figure 3 shows the current zero population growth behavior of the GDR, in contrast to continuing though modest growth rates in Rhône-Alpes and Wisconsin (currently approximately 1% and 0.8%, respectively). The contrasting population dynamics had a strong influence on the scenarios written for the regions. Both the GDR and Rhône-Alpes are more industrialized than Wisconsin. Wisconsin relies heavily on the automobile; however, time-series studies show that auto ownership in the GDR is increasing at an annual rate of 12% in comparison with a 4% growth in Wisconsin. Also striking is the heavy GDR reliance on mass transit.

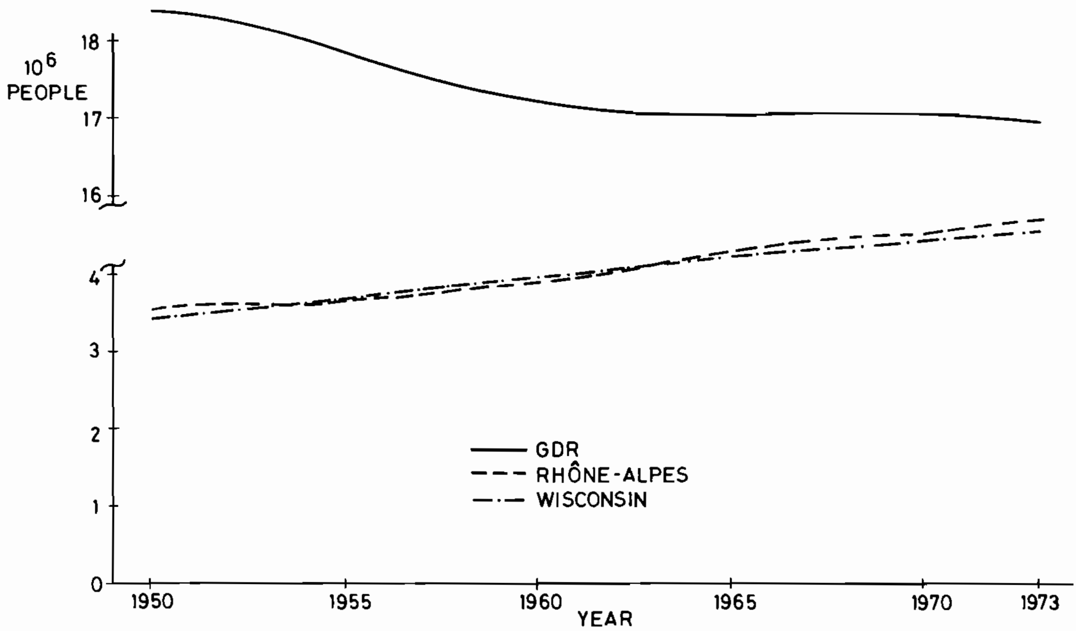


Figure 3. Cross-regional comparison of population (1950-1973).

Energy Use and Supply

The comparison of primary energy use in Table 2 shows that, although the per capita energy use is greatest in Wisconsin, the density of use is by far the greatest in the GDR. The primary energy sources for the three regions differ significantly. The GDR relies heavily on coal (mainly domestic strip-mined lignite), whereas Rhône-Alpes is dependent on petroleum and hydropower (Figure 4). Wisconsin, although having no naturally occurring fuel resources, has a diverse supply mix comprised mainly of petroleum, natural gas, and coal; nuclear is providing a rapidly growing portion of its energy.

Table 2. A cross-regional comparison of primary energy use (1972-73 data).

	Annual Energy Use (10^{15} cal/yr)	Annual Energy Use per Capita (10^{9} cal/p/yr)	Density of Annual Energy Use (10^{12} cal/km^{2})
GDR	749	44	6.9
Rhône-Alpes	168	35.7	3.8
Wisconsin	319	70.9	2.2

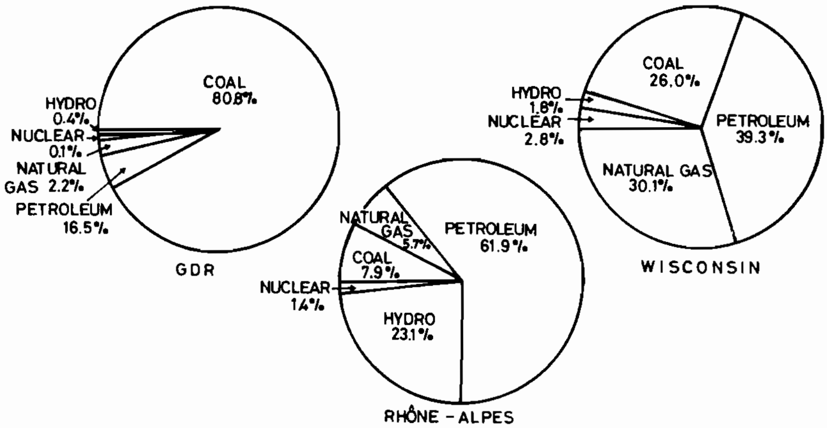


Figure 4. Cross-regional comparison of primary energy by source (1972).

This brief description provides only a glimpse of the three energy systems, but gives an indication of the diversity of the three regions. The natural and environmental characteristics are discussed in some detail in a forthcoming publication [1].

Institutional Structures

As indicated earlier, one component of the research program was to describe the institutional and organizational structures associated with planning and policy analysis in the energy and environmental areas in each region. Although this was one of the smaller parts of the research effort, it was a significant one.

As work progressed, it became apparent that there was a strong relationship between the institutional and decision structures of a region and the formal models and planning tools that were used. This was demonstrated quite vividly by the contrasts in the structures of the three regions. These structures, and the models and planning tools, are described in several papers by regional energy experts and policy makers [2].

APPRAISAL OF ENERGY/ENVIRONMENT MODELS

A major objective of the project was to appraise and compare the energy and environmental models of the three regions studied. This appraisal would be valuable to each region in assessing its potential use of models from other regions, and would reveal how the models are tied to the policy objectives and characteristics of the region.

In order to emphasize the transferability of the models, the appraisal was divided into two parts. Each collaborating institution described its own system of energy/environment models; and each appraised the models of the two other groups from the perspective of its own system and methodological requirements for planning and policy analysis. For example, the Wisconsin group identified the types of information it desires and examined whether the French models treat these areas adequately.

The Models

Although each region uses a large variety of models, only the major planning models were appraised [1].

The GDR models appear to be aimed at long-term planning activities, with emphasis on the economy/energy (as opposed to the energy/environment) relationship [2]. They combine demand projections, technological development estimations, and investment planning in a system that allows for analysis of alternative growth strategies. Although energy-related environmental modeling activities are apparently going on in various institutions and planning organizations in the GDR, these models have not been integrated into the central energy-planning models. The highly integrated GDR energy model appears to be quite advanced in its capability to examine and model the significant interrelations of the various economic sectors. An economic objective function, the minimization of social expenditures, forms the basis of the optimization procedure used.

In Wisconsin, the multiplicity of decision-making units means that it is impossible to construct a single model with a unique objective function, or even with a common constraint set, since not all the various agents in the system are constrained by the same array of factors [2]. The need is for a comprehensive well-integrated system model, but one that explicitly recognizes the fragmentation of decision-making. For Wisconsin, one must talk in terms of a *set* of energy/environmental models and the means by which they can be integrated. The modeling activity comprises efforts in both the public and private sectors, only some of them coordinated. One exception is the work of the Energy Systems and Policy Research Group at the University of Wisconsin, which has resulted in the development of a computerized dynamic simulation model of the entire Wisconsin environment system.

Although there is considerable centralization in energy planning in France, the private sector plays a significant role, and hence the energy modeling activities are more akin to those in Wisconsin. However, as has been mentioned earlier, since the institutional and economic structure of France is highly centralized, the economic and energy activities of the Rhône-Alpes region comprise no autonomous economic system, and thus no energy modeling exists exclusively for the region. Model evaluation therefore dealt with models for the nation. Particular attention was given to the linear programming model developed at the Grenoble Energy Institute. It provides for an optimization of the total energy system, subject to constraints on availability of particular primary energy fuels, and for the inclusion of environmental constraints, although not at a level of complexity that makes them amenable to regional analysis.

SCENARIO BUILDING

The writing of alternative futures, often referred to as scenario building, was chosen as a methodological device in this research because of its value in the studying and evaluating of the interaction of complex and uncertain factors. Broadly described, scenario building is a detailed examination of the likelihood and consequences of alternative assumptions about the future. This set of futures may provide a better view of what is to be avoided or facilitated, the types of decisions that are important, and the points in time after which various decision branches will have been passed.

The technique used assumed that the region under study could be described as a system comprised of socio-economic, technological, and environmental components coupled to each other with various degrees of strength. The system description used for our work is shown schematically in Figure 2. The scenario-building process was one of imposing given policies on the systems within the framework of the initial conditions and constraints characteristic of the region, and then evaluating the resulting development and evolution of the region.

The Policy Issues

The policy issues were chosen on the basis of two criteria. They had to be of special interest to at least one region and of general interest to the other two; and they had to have sufficient focus and data that they could be approached in at least a semi-quantitative manner with methods available to the IIASA team. They also had to be relevant to mid- and long-term planning and policy analysis (5-50 years).

The procedure for choosing policy issues satisfying the above criteria was an iterative one, beginning with discussions with the collaborating institutes. After several issues were identified, they were explored by the IIASA team to see whether they could be approached within the time frame of the project and with the expertise available at IIASA. After general decisions were made on these policy issues and on the types of scenarios that would help illuminate important policy questions, some months were spent gathering data and developing relationships with which to describe the alternative futures. Several of the major issues are listed below.

Urban Settlements: How are energy use and environmental impact related to urban density, urban size, types of housing, and energy supply technology and type? In all three regions the answers to these questions are useful for policy analysis related to land use, building standards, district heating strategies, and the like.

Transportation Systems: What are the energy and environmental implications of continuing present trends and policies for inter- and intra-city passenger transportation?

Energy Supply: What are the consequences and implications of satisfying future energy demand through alternative energy supply options and strategies?

Structure of Economic Growth: How would energy demand and environmental quality be affected by alternative patterns of economic growth?

Environmental Protection and Resource Conservation: Are there environmental limits associated with various patterns of energy demand and supply? What are the environmental effects of various pollution control policies associated with alternative energy system strategies? What are the major environmental tradeoffs associated with alternative fuels for the production of electricity? How will a policy encouraging expansion of district heating influence air quality?

In order to specify a "policy set" within which a scenario was built, it was necessary to develop a notation for expressing a policy in terms of a number of characteristics. In a functional form, the framework for a given scenario is described in the following terms:

- Population,

- Economic Growth and Structure,

- Human (Urban) Settlement Location and Form,
- Technologies of Energy Use,
- Transport Systems for People and Goods,
- Heat Supply Systems,
- Primary Energy Conversion and Supply Technology (Including Electricity Generation),
- Environmental Control and Protection.

This framework then is used to provide the exogenous functions, boundary conditions, and constraints for the models used to build the scenarios.

The policy issues listed above were addressed by two specific paths. First, three alternative policy sets were developed, and each applied to each of the three regions. In selecting a limited number of scenarios for study, we tried to choose rationales that were meaningful in all three regions, combined the majority of the policy issues described, and could conveniently be compared. Second, sensitivity studies were developed to evaluate the effects of variations in one policy variable while holding the others constant.

Models and Methodology

The main quantitative tool used for scenario building is a large-scale simulation model, originally developed at the University of Wisconsin and extended at IIASA to treat regional energy/environment systems with characteristics differing from Wisconsin. In addition, some new models or quantitative approaches are being developed at IIASA during the course of this research, e.g. energy/environment preference models [3,4] and air pollution methodology [5,6]. The Institut für Energetik in Leipzig also provided considerable quantitative input based upon extensive calculations in the preparation of the GDR long-term energy plan.

The WIsconsin Regional Energy Model (WISE) is a computerized simulation model designed to describe the technological-economic-environmental interactions in a regional energy system. It is built of a hierarchy of submodels. Its simulation structure provides considerable flexibility in both the modeling process and the application; it makes possible the modification of selected system components without the necessity to rework the entire model, and the focusing of attention on specific system areas as well as on the entire system. Although there are numerous ways to describe the overall structure of the WISE model, one of the more revealing is by component subsystems (Figure 5). The flow of information in the model begins with the exogenous specification of population, human settlement pattern, and economic activity. These variables provide a basis for calculating end-use energy

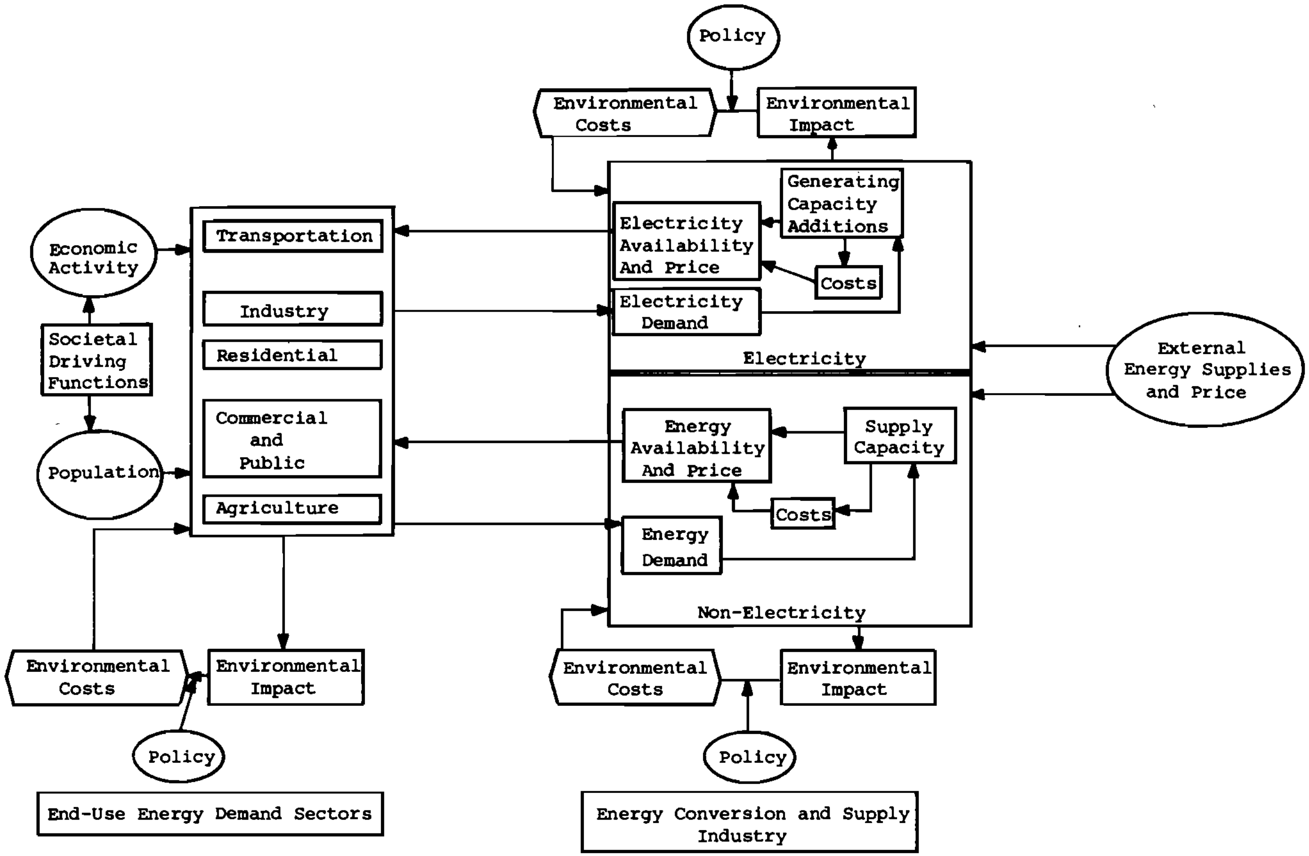


Figure 5. The WISconsin regional Energy model (WISE).

demand. A second group of models calculates characteristics of supply systems necessary to meet that demand, including supply capacities, primary energy, etc. The environmental impact models use population and human settlement data, as well as outputs of the energy demand and supply models, to calculate environmental impacts (indicators), including human health and safety. A growing literature exists on the structure and applications of the WISE model [7] and on the IIASA extensions. The use of the model in scenario building is described in more detail in Reference [8].

When a submodel or set of submodels was not applicable to a particular region, other alternatives were used. Since in the GDR a plan for energy use through 1990 exists, some end-use demand scenarios were obtained from the Leipzig Institut für Energetik rather than calculated with the WISE model. In addition, because the Rhône-Alpes region is not a distinct political unit, some types of data were difficult to obtain; here the models had to be simplified accordingly.

The Scenarios

The three scenarios can be briefly characterized as follows. S1, the base case, represents a continuation of current socio-economic trends and policies (the "Plan" in the GDR). S2 results from policies encouraging a high-energy future, based on a presumed low or moderate energy costs and placing little or no emphasis on improving efficiencies of energy use. Low environmental controls are also assumed. S3 is low-energy future, resulting from policies encouraging energy-saving technologies of transport, heating, and industry, and promoting increased environmental quality through conservation and stricter pollution controls.

Other scenarios could have been chosen for the initial study, perhaps for equally good reasons. However, these three could be applied consistently across the three regions and seem to focus attention on many important issues. They were built at IIASA for Wisconsin, Rhône-Alpes and a composite region ("Bezirk X") typical of the heavily industrialized southeastern GDR. They were discussed in November 1975 by energy and environmental experts and decision makers from the three regions at the IIASA Workshop on Management of Regional Energy/Environment Systems. The final step of the scenario-writing process is still under way: examination of the internal consistency of the dynamic evolution of the energy/environment system. As an example of the methodology, some Wisconsin results are presented below.

An overview of the three Wisconsin scenarios is shown in Table 3. For purposes of comparison, total population growth and economic activity are not varied among the scenarios; the focus is on alternative urban forms and spatial distribution, energy supplies, energy efficiency, and environmental controls.

Table 3. Overview of the three Wisconsin scenarios for the period 1970 to 2025

	Scenario Number		
	S1	S2	S3
Population	Declining growth rate	Same as S1	Same as S1
Economic	Continued expansion of service in relation to industry	Same as S1	Same as S1
Urban Form	Suburban extension 25% apartments	Exurban dispersal 50% apartments	Small compact cities 50% apartments
Technology	Almost constant energy use per unit value-added in service and industry	Increasing energy use per unit of value-added Emphasis on electricity	Declining energy use per unit of value-added Conservation measures
Transportation	Auto efficiency gain	No auto efficiency gain	Large auto efficiency gain
Heating	Mostly gas	Emphasis on electricity	Solar Conservation measures
Energy Supply	Synthetic fuel from coal Mix of coal and nuclear for electricity	Synthetic fuel from coal Mostly nuclear for electricity	Solar for electricity No new nuclear Synthetic fuel from coal
Environmental	Present trends of increasing controls for SO_2 and particulates	Low controls of SO_2 and particulates	Stringent controls of SO_2 and particulates

Spatial population distribution affects virtually all parts of the system; e.g., the average trip length for personal transportation is related to city size. Population distribution also affects environmental impacts of energy use in ways other than by modifying energy use. For example, the location of pollution sources relative to population is an important consideration in the estimation of associated health impacts.

The percentage of total end-use energy in each demand sector for Scenario S1 is displayed as a function of time in Figure 6. The end-use energy includes only energy consumed in end-use processes; conversion losses, such as in electricity generation, are excluded. The service sector increased its share of end-use energy from 13 to 31 percent over the 55-year period, while the residential sector's share dropped from 30 to 15 percent. Transportation maintains approximately the same fraction of the total only because freight energy increases in relation to economic activity; personal transportation energy grows at a much lower rate than freight energy in Scenario S1.

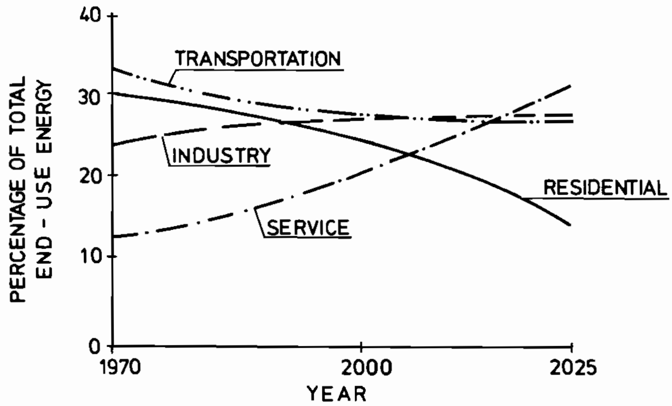


Figure 6. Percentage of total end-use energy by sector for Wisconsin (Scenario S1).

The total emissions of sulfur dioxide, expressed in metric tons of SO_2, for eight districts in Wisconsin are shown in Figure 7 for the years 1970 and 2025 for Scenario S1. Sulfur emission controls and use of low-sulfur coal in coal-fired electrical plants are assumed to reduce by more than a factor of three the quantity of SO_2 emitted per unit of electrical generation from coal. The emissions indicated in Figure 7 show a spatial dependence that is based on location of power plants, industries, and population centers. The calculation of expected health impacts depends not on emissions but rather on ground-level concentrations. The release characteristics, e.g. stack height, of the different sources of SO_2 result in ground-level concentrations that are not directly proportional to the emissions shown.

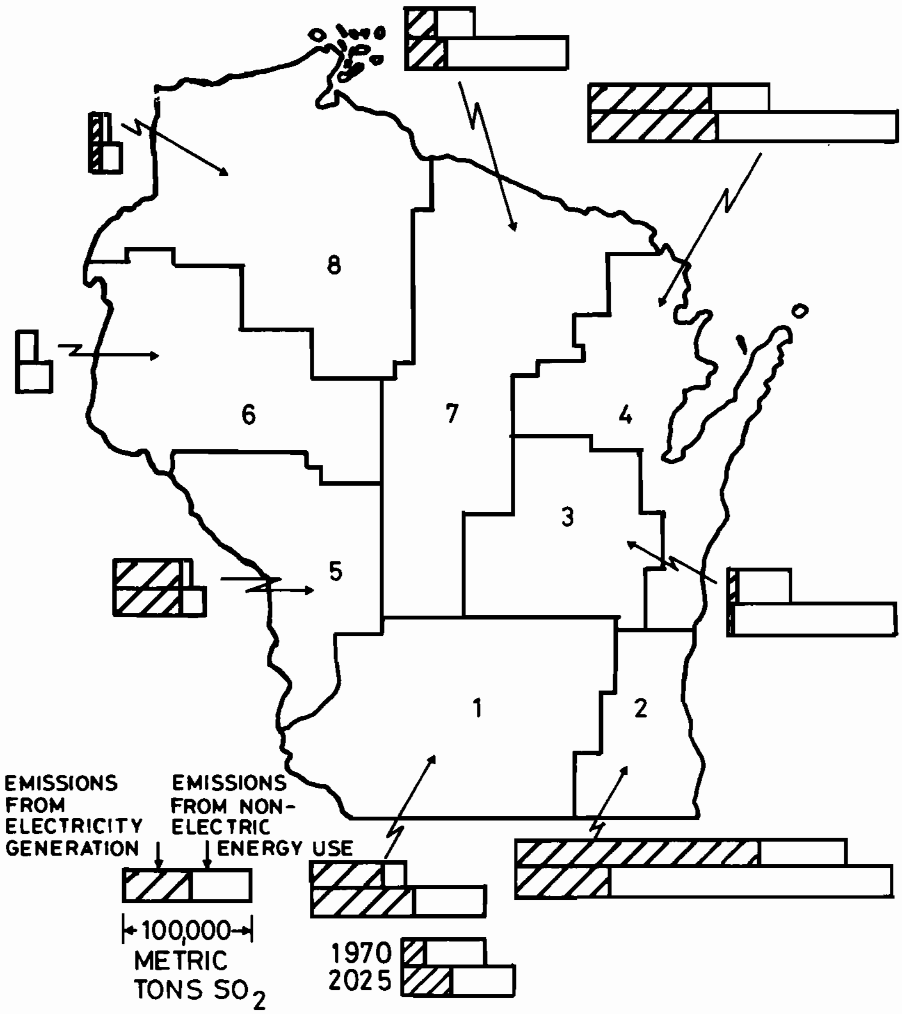


Figure 7. Total emissions of sulfur dioxide in Wisconsin by district for 1970 and 2025 (Scenario S1).

Environmental consequences were one of the major objectives of scenario building. The SO_2 emissions shown in Figure 7 re-resent only one of a wide range of indicators used to characterize environmental implications. Broadly defined, these indicators include effects on land, air, water, structures, and human beings, including the health and safety of people employed in the energy system and of the general public. Some indicators were associated with "quantified" human health and safety impacts--those *explicitly* included in the Environmental Impact Model (EIM) used in this research. The choice of this set of impacts is clearly to some extent subjective; in addition, some degree of uncertainty (and perhaps controversy) is associated with some of the calculated impact factors. There are also many impacts that are recognized, but remain unquantified; there are others that are unrecognized, or considered unimportant, and hence unquantified. Some initial attempts to cope with uncertainty and subjectivity are described in References [4] and [9].

One of these "quantified" indicators of impact associated with energy use in each scenario is shown in Figure 8. Person-days lost (PDL) are used to combine the effects of mortality and morbidity; each fatality is associated with 6000 PDL. The quantified totals shown include health and accident impacts on the public, and on people employed throughout the energy system, from resource extraction through waste disposal. The quantified health effects of air pollution from non-electric energy use represent 68, 54, and 18 percent of the PDL in the year 2025 in scenarios S1, S2, and S3, respectively. One reason the base case (S1) has more PDL than the high-energy case (S2) is that residential and service sector air pollution is high in areas of high population in S1. Electricity is used to a large extent in S2, and power-plant emissions are well away from population centers and have different dispersion characteristics than low-level releases, such as from residences. The results shown in Figure 8 can be expressed in terms of other indicators--for example on the basis of per capita, per unit land area, per unit energy use.

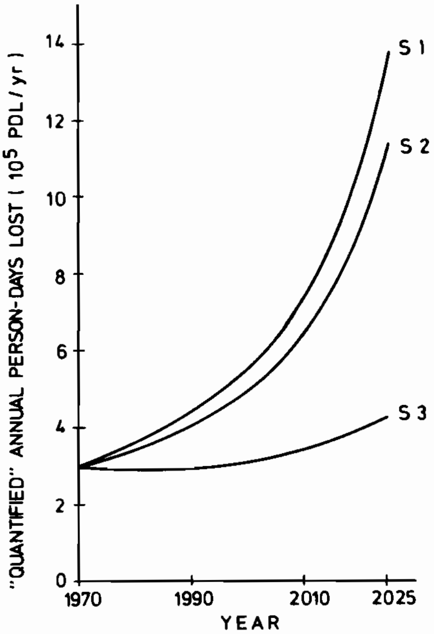


Figure 8. "Quantified" human health and safety impact associated with energy use for the Wisconsin scenarios.

The comparison of the three regions is proving useful in evaluating the potential of a range of indicators in policy analysis. For example, Figure 9 displays the total quantified human health and safety impact, in terms of person-days lost, for Scenario S1 for each region. It should be noted again that Bezirk X is a highly industrialized composite region in the GDR. The quantified human impact in the figure is divided into impacts that occur within and outside the region. The impacts are divided according to the energy sector with which they are associated, namely, non-electrical energy consumption within the region; electrical energy consumption within the region; exported non-electrical energy; and exported electrical energy. Energy export did not have a major effect on quantified impacts in these scenarios, except in the early years for Bezirk X. An example of an impact associated with electricity use within the region that occurs outside the region, in the case of Wisconsin, is the health and safety impact on coal miners. Wisconsin produces none of the coal consumed there. An example of an impact that is associated with non-electrical energy export and occurs within the region, in the case of Bezirk X, is that of air pollution near the coal-briquette factories in the Bezirk that export some or all of their production. One apparent conclusion from Figure 9 is that for Scenario S1, Wisconsin suffers the greatest quantified human health and safety impact per capita in the year 2025. However, as mentioned earlier, such results can be viewed from different perspectives--e.g. impacts per unit of energy consumed--that lead to different impressions.

A preference model, based on multiattribute decision analysis, has been developed to provide help to the decision maker in the complex task of sorting out the important and unimportant information. It is essential that effective communication and evaluation techniques be used to convey results such as shown in Figures 8 and 9. Clearly, the characteristics shown there represent only one small aspect of the total impact and should not be used in isolation; this is discussed further in the following section.

EVALUATION OF OPTIONS AND STRATEGIES: IMPLEMENTATION OF RESULTS

It has been pointed out that scenario writing in no way represents a forecasting or prediction. The scenarios are meant to stimulate discussion and to provide a better basis for evaluating alternative futures. The success of their use in design or management depends on feedback between the scenario builders and the managers and designers of the energy/environment systems. Feedback in scenario writing is similar to the mechanism by which man's knowledge grows. In that sense, the cycling is a process that rarely stops for long; new knowledge evolves continuously, and scenario writing is never finished. Time also affects feedback, to the extent that hypothetical future events as laid out in the scenarios either do or do not occur.

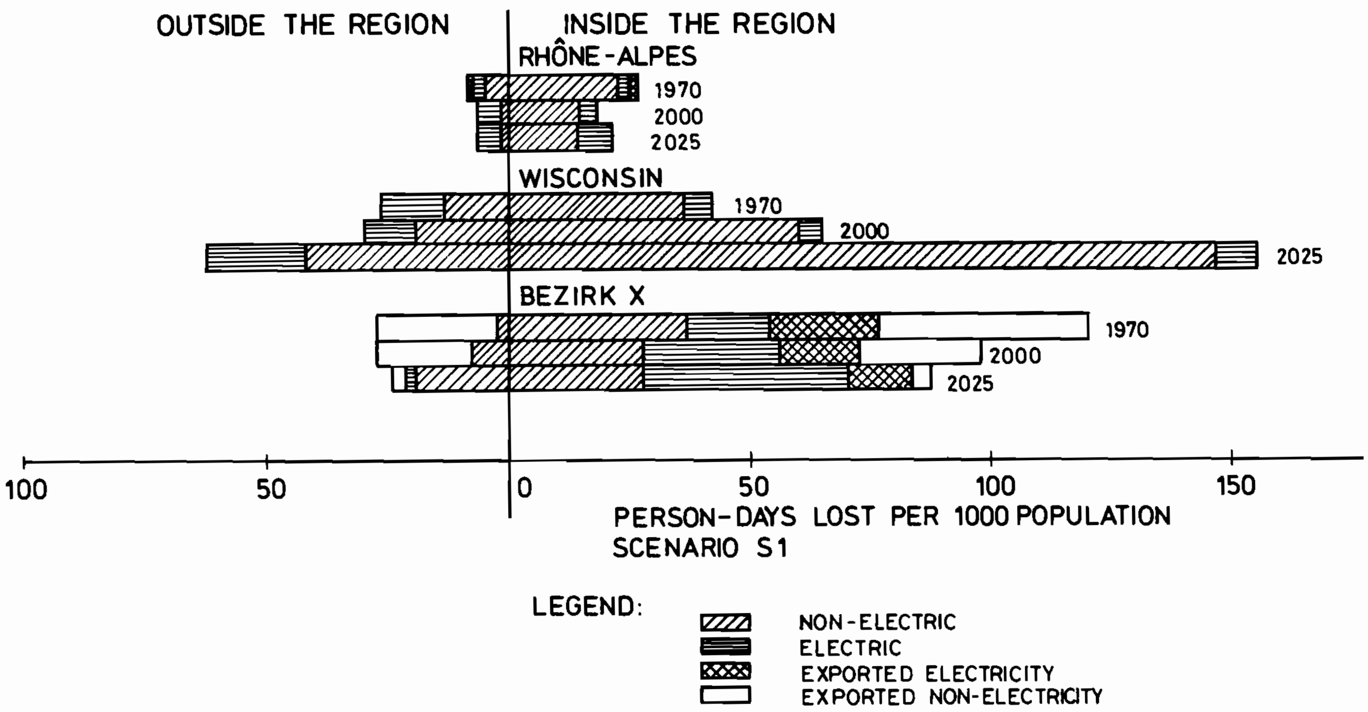


Figure 9. Cross-regional comparison of health effects of energy use.

From the methodological description in this paper, it is obvious that no formal method has been applied for including uncertainty in the procedure. Rather, the uncertainties must be judged subjectively by scrutinizing the scenarios and the sensitivity studies. Clearly there is ample opportunity to exclude major components and events that can completely change the evolution of the energy/environment system. This is a well-known hazard of scenario writing.

The scenario writing process is *descriptive*. To explicitly transform the scenario output into *prescriptive* forms, additional steps are obviously required. One of these is the embedding of the scenarios into an institutional and decision framework where *preferences* and *values* must be applied to the results. This is a complex task that would differ considerably across the three regions studied because of their very different social and institutional structures.

Decision Analysis - An Evaluation and Communication Tool

It has been a major task simply to describe these systems and their possible evolution. Each region studied provides a wealth of examples of the complexity of the management problem. Decision analysis has been applied in this study as one approach to the evaluation and communication of alternative policy designs. The method used was based upon multiattribute utility theory [10]. In this approach, a so-called preference model is introduced into the evaluation process. The relationship between the energy/environment impact model and the preference model is illustrated in Figure 10. The outputs of the impact model are impact levels of the "attributes", i.e. the altered system states. Examples are the sets of environmental impacts associated with the various regional scenarios. To the extent possible, the impact models are meant to be objective and to exclude value-judgement content. The construction of the preference model for a decision maker requires the assessment of a utility function for each attribute.

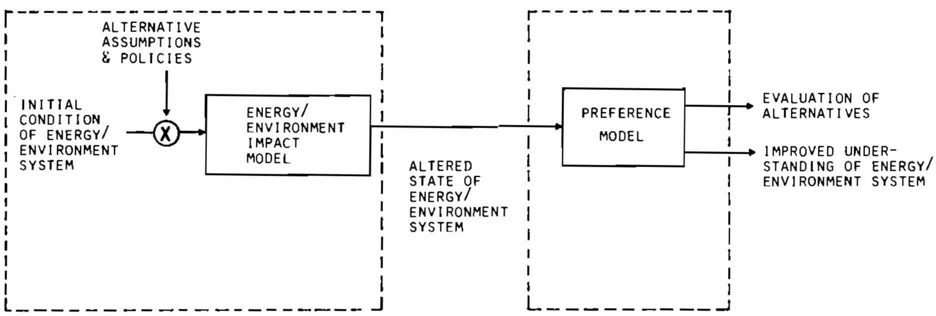


Figure 10. Relationship between impact model and preference model.

Assessment requires personal interaction with the decision maker, since his utility function is a formalization of his subjective preferences for the attributes (impacts). One of the advantages of this evaluation framework is that recognized but unquantified impacts can be identified and included in the analysis by determining an appropriate proxy variable that can be measured. The overall preference model, based on the measured utility function for a particular individual, allows the calculation of the individual's expected utility associated with the combined impacts of a given policy (scenario). The expected utility calculated for an alternative is a measure of the relative desirability of that alternative for the assessed individual.

Our first application of that method to regional energy/environment systems was based upon a set of policies related to the choice of electricity generation systems for Wisconsin. The EIM [9] was used to generate the following 11 attributes of a set of scenarios based upon alternative policies:

X_1 = Total quantified fatalities,

X_2 = Permanent land use,

X_3 = Temporary land use,

X_4 = Water evaporated,

X_5 = SO_2 emissions,

X_6 = Particulate emissions,

X_7 = Thermal energy needed,

X_8 = Radioactive waste,

X_9 = Nuclear safeguards,

X_{10} = Health effects of chronic air pollution exposure,

X_{11} = Electricity generated.

Utility functions for two individuals from Wisconsin were determined and used to evaluate the set of scenarios [11].

In a follow-up study [4], preliminary utility assessments were completed for five individuals from Rhône-Alpes, the GDR, and Wisconsin over a set of four attributes selected from the above set. The group included decision makers and energy/environment specialists. The utility function u_i over attribute X_i is set equal to zero at the least desirable level of X_i, and equal to one at the most desirable level of X_i; the shape of the function is determined by the assessment procedure. Some representative results are shown in Figure 11 for one of the individuals assessed. The utility functions for the five individuals were used to evaluate their preferences for several hypothetical supply and environmental policies.

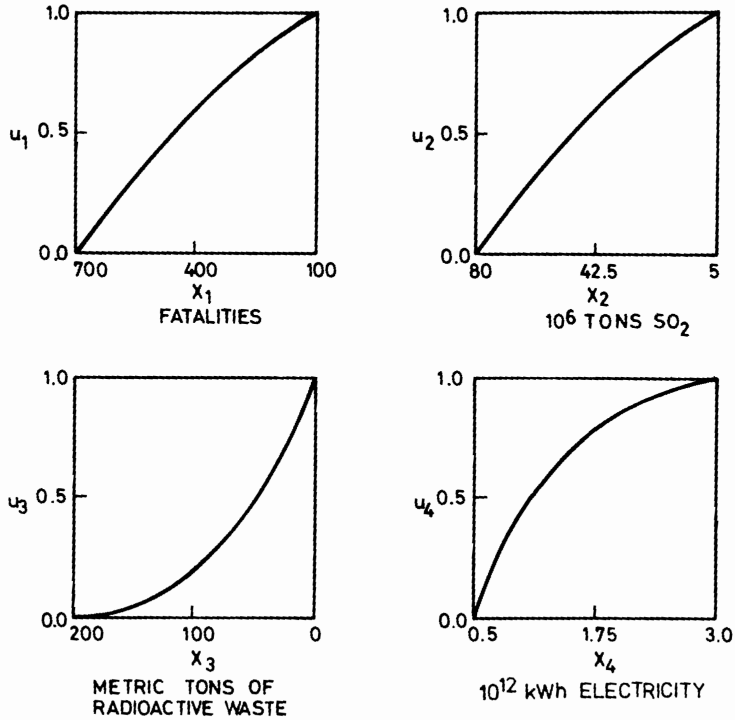


Figure 11. Utility functions for one individual.

What have we learned from these initial applications of this approach? First of all, we must emphasize that we agree with Holling et al. [12] who, in their forest pest management studies, bemoaned the unsatisfied need for an adequate framework to interpret and use social, economic, and environmental indicators. Our approach does not eliminate the difficulties of meaningfully aggregating across kind, time, and space so that rational preferences can be expressed for alternative futures. Second, we do recognize some of the practical difficulties in implementing this procedure within many types of decision-making and policy-analysis structures. However, we have discovered that the process itself can have benefits; that is, building a preference model can assist in evaluating policy. Included among these benefits are:

- Aid in the understanding and communication of the value tradeoff alternatives,
- Aid in identifying important issues and sensitizing individuals to them,
- Isolating and resolving conflicts of judgment and preference among groups,
- Making modelers aware of additional areas of concern, in general leading to improvements of the impact models.

These and other benefits have made it apparent that more effort should be devoted to this component of the research program. An interinstitutional task force has been formed to continue the development of this appraoch and to generate procedures for integrating it with more traditional computational procedures.

Implementation and Transfer of Research Results

Although each research component described in the preceding sections has the potential to contribute to improved management of regional energy/environment systems, none of them should stand alone. It is essential that each be used as a complement to the others and, more important, that they all be linked in a coherent research format that promotes *frequent interaction with the institutional and decision clients for which it is intended.*

The need for interaction with the client is vital and was thus given primary emphasis in our research. From inception of the program, information was solicited from the appropriate users; and at the conclusion of the first phase, they were asked to evaluate the scenario-building results. Frequent workshops encouraged this interaction. This process, shown schematically in Figure 12, was perhaps the key element in integrating the several components of the research program and in providing a communication interface between the modelers in the three regions.

The research program reached a milestone in late 1975, when a workshop held at IIASA brought together 25 scientific experts, policy makers, and members of the public from the three regions. Figure 12 is also representative of that workshop. Apart from the socio-technical interaction of specialists and policy makers from the GDR, France, and the USA, the workshop provided an opportunity to introduce the comparative scenarios and alternative models into planning and policy design procedures in these countries.

Papers presented by the collaborating institutions included appraisals of the others' modeling procedures and comparisons of some of the energy and environmental planning practices in the region, e.g. pricing, environmental standards, and building practices. These papers are being prepared for publication.

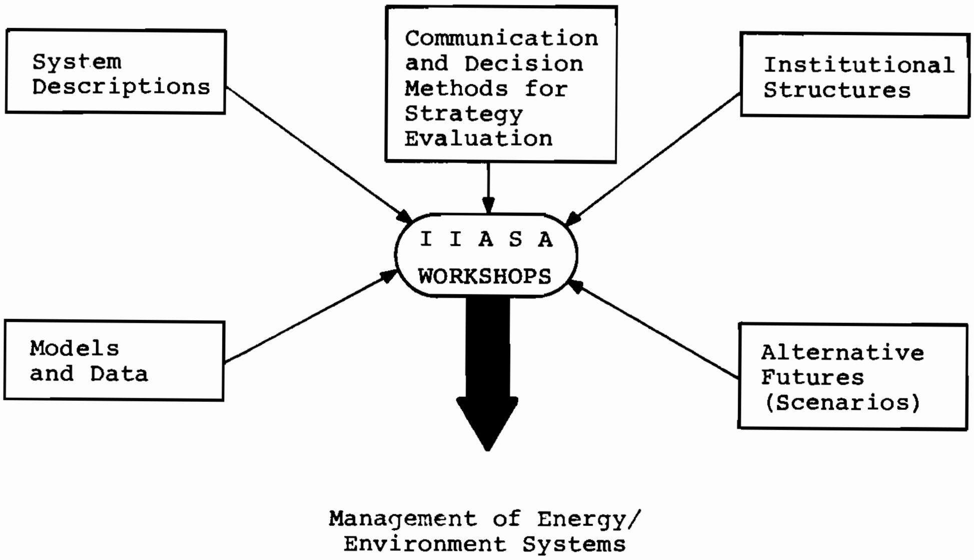


Figure 12. Management of energy/environment systems.

A research transfer process tacked onto the tail end of a research program has almost no chance of success. It is essential that the transfer process be given high priority at the very beginning of a study whose ultimate objective is improved policy design and that this priority be preserved through the entire process. The objective of this transfer is not specific policy recommendations, but rather the transfer of concepts, models and methodologies, evaluation procedures, and a range of policy analyses. Our efforts to do this, perhaps only partially successful, have been terribly demanding of time and energy and, occasionally, even frustrating. At times, they may seem to distract us from the substantive research activities which have traditionally been the domain of specialists in each of our fields. But without exception, there is agreement among the research team that even a partial success in embedding the research outputs into the actual policy-design processes would be more than adequate justification of our efforts.

Future Work

One of the most important outputs of the 1975 research has been the creation of a network of research institutions, coordi ated by IIASA. This has provided IIASA with encouragement in its role as a catalyst and coordinator of policy-oriented research in the international scientific community. The three collaborating institutions will continue to pursue research during 1976, and in addition IIASA will extend the studies to other regions, again with very different socio-economic, geographic, and institutional characteristics. Specifically, one of them will be located in a less industrialized country, to allow the IIASA team to further generalize their models and methodologies. Although we realize that there can never be a universal energy/environment model, our long-range goal is generalization of the approaches into a coherent and sound process for resource management in all regions of the world.

CONCLUSIONS AND SUMMARY

This presentation gives an overview of the framework and initial results of a research program on long-term policy assessment of regional energy/environment systems. Some major results and conclusions of the study to date are the following

- A quantitative description and comparison of energy/environment systems has been developed for the three regions; the comparative descriptions have provided insight into the relationships between energy and the regional socio-economic patterns.
- Alternative energy/environment scenarios were written for the three regions as a vehicle for analysis of selected long-term policy issues. There are indications that these scenarios are playing a role in energy/environment planning in the regions.
- A significant socio-technical interaction of specialists and decision makers took place at a IIASA workshop in 1975 during which the energy/environment scenarios were discussed and analyzed.
- A set of energy/environment models were tested for their relevance and validity by application to the greatly differing regions.
- A decision analysis approach was developed and applied to energy/environment policy analysis.
- A significant transfer of models and analytic methodology occurred among the collaborating institutions in the three-region study.

References

[1] *Proceedings of a Workshop on Integrated Management of Regional Energy/Environment Systems* held November 10-14, 1975. International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

[2] Born, S., C. Cicchetti, R. Cudahy, and J. Pappas (Wisconsin); P. Hedrich, K. Lindner, and D. Ufer (GDR); J.-M. Martin and D. Finon (France), *Energy/Environment Models and their Relationship to Planning in Wisconsin (USA), the German Democratic Republic, and Rhône-Alpes (France)*, RM-76-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[3] Keeney, R., *Energy Policy and Value Tradeoffs*, RM-75-65, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[4] Buehring, W.A., W.K. Foell, and R.L. Keeney, *Energy and Environment Management: Application of Decision Analysis*, RR-76-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[5] Dennis, R.L., *Regional Air Pollution Impact: A Dispersion Methodology Developed and Applied to Energy Systems*, RM-76-22, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[6] Buehring, W.A., R.L. Dennis, and A. Hölzl, *Evaluation of Health Effects from Sulfur Dioxide Emission for a Reference Coal-Fired Power Plant*, RM-76-23, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[7] Foell, W.K., J.W. Mitchell, and J.L. Pappas, *The WIScons in Regional Energy Model: A Systems Approach to Regional Energy Analysis*, University of Wisconsin-Madison, Institute for Environmental Studies, Report 56, Sept. 1975.

[8] Foell, W.K., *Scenario Writing: One Component of a Systems Approach to Energy/Environment Management*, RM-76-20, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[9] Buehring, W.A., and W.K. Foell, *Environmental Impact of Electrical Generation: A System-Wide Approach*, RM-76-13, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[10] Keeney, R.L., and H. Raiffa, *Decision Analysis with Multiple Conflicting Objectives: Preferences and Value Trade-offs*, Wiley, New York (in press).

[11] Buehring, W.A., *A Model of Environmental Impact from Electrical Generation*, unpublished Ph.D. dissertation, Dept. of Nuclear Engineering, University of Wisconsin-Madison, 1975.

[12] Holling, C.S., et al., A Case Study of Forest Ecosystem/Pest Management, in *The IIASA Ecology Project: A Status Report*, RR-76-2, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Large-Scale Planning Projects: the Tennessee Valley Authority and the Bratsk-Ilimsk Complex

H. Knop

INTRODUCTION

The IIASA project on Planning and Management of Large Organizations had as its objective the systems analysis of decision-making processes in socio-economic systems. It started later than most other projects, in September 1974. It was staffed mainly by visiting scientists for the first year and began operating fully only in September 1975. Since March 1976, its activities fall within the research area Management and Technology.

During this period, the Large Organizations group focused on case studies of large-scale planning projects embracing the interaction of socio-economic systems and their management (see Figure 1). In the first stage of our research, we asked: how is systems analysis used as a tool of management? To answer this question, we investigated methodological experience in planning, management, and organization of several large-scale planning projects, with the aim of making it available to all those who deal with similar problems. On the basis of these case studies and the present state of the art in this field in general, we will be able to answer the second question: how can systems analysis be applied to the management of a given socio-economic system? That is, we will extend the transfer of experience by elaborating our own recommendations for improving managerial methodologies.

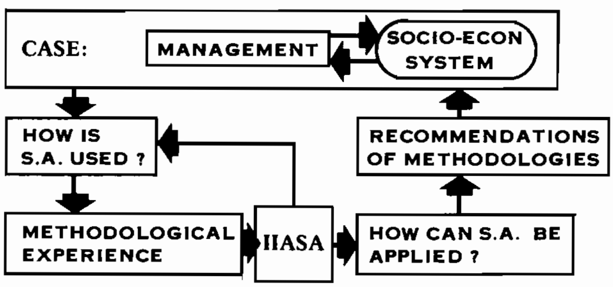


Figure 1. Systems-analysis approach of the Management and Technology area.

The first two cases we chose were regional development programs: the Tennessee Valley Authority (TVA) in the United States, and the Bratsk-Ilimsk Territorial Production Complex (BITPC) in the Soviet Union. Both began with large international conferences at IIASA: the TVA Conference in October 1974, and the Bratsk-Ilimsk Conference in March 1976. The former was followed by a field study of a group of IIASA scientists in June 1975, and a field study will follow the Bratsk-Ilimsk Conference in June-July 1976.

Why did we choose regional programs for our case studies? We did this mainly for the following reasons:

- Managing the social, economic, technological, and ecological complexity of regional development programs is a universal problem common to many countries, and is of practical interest to all the National Member Organizations of IIASA;

- In order to comprehend the complex nature of socio-economic systems, reconcile conflicting interests, and find, evaluate, and choose feasible and consistent strategies for regional development, one must apply systems analysis;

- The overlapping of social, economic, technological, and ecological problems in regional programs is a suitable topic for integrated research by scientists from various disciplines;

- Last but not least, IIASA has easier access to information on regional programs than national plans or the strategies of big companies.

IIASA is a unique institute for pursuing such studies. Its East-West character gives us the opportunity to make the experience of the cases universally applicable. IIASA is dedicated to studying the application of systems analysis in real-life situations, and to applying systems analysis to the studies themselves. The required variety of skills and expertise in various disciplines is available at IIASA; and during the past two years several opportunities arose for shared research by IIASA groups dealing in a regional context with energy, water, ecology, human settlements, and biomedical and methodological problems.

Let me now present the two case studies we worked on.

THE CASES

The TVA was established in 1933 as a part of President Roosevelt's New Deal policy. Its activities are concentrated in an area of about 100,000 km2 within the Tennessee Valley watershed boundary (see Figure 2). The main goals of the project were to stop out-migration, stabilize agricultural production and modernize agriculture, prevent catastrophic floods, stimulate industrial development, develop navigation systems, and raise the general economic level.

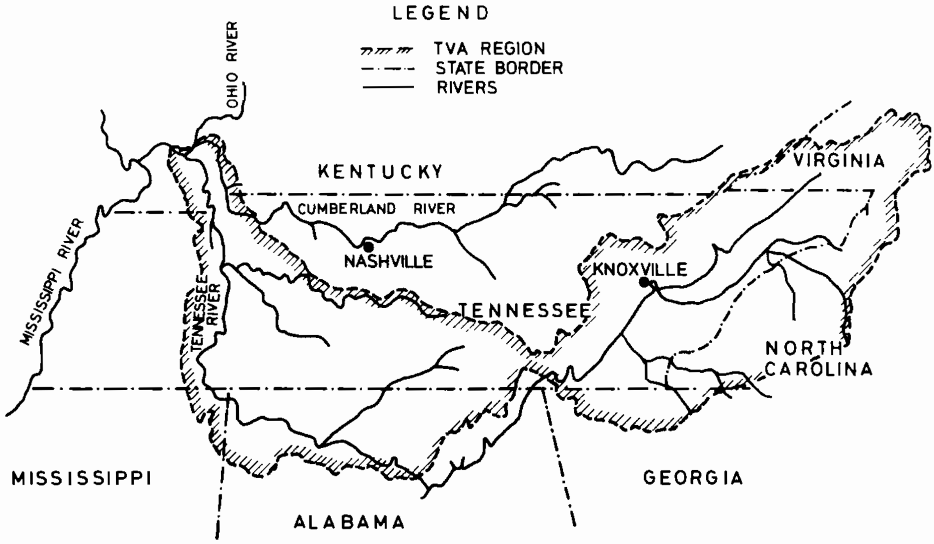


Figure 2. Tennessee Valley Authority Region.

After 40 years we can see that these goals have been achieved. The population increased slightly and then became stable. The standard of living and the per capita income increased significantly and, though still lower, approached the national average. Floods are under control. There has been a rocketing in power generation; all water-power resources are used for power generation and for the supply of very cheap power. At present, power is also generated by steam, gas turbine, and nuclear plants. A highly efficient navigation system was created, and production and productivity in agriculture and industry were significantly increased, due to cheap power, fertilizer supply, and scientific advances in agriculture. Recreational centers were created around the new water reservoirs, and the TVA initiated several federal laws on environmental protection.

The BITPC is located in the Irkutsk region of eastern Siberia (Figure 3) and directly influences an area of about 100,000 km^2. Construction of the first dam started in 1954 as one of the major activities of the fifth five-year plan of the USSR. The main goals were to develop water-power generation by utilizing the inexhaustible water resources of eastern Siberia;

to provide cheap power as an incentive for exploiting and processing the rich natural resources of this region, such as iron ore and timber; to build up an efficient transport system; to develop for this program a powerful construction industry that could also be used for development programs in adjacent territories; and to create settlements, services, and supply industries so as to attract in-migration despite the severe climatic conditions.

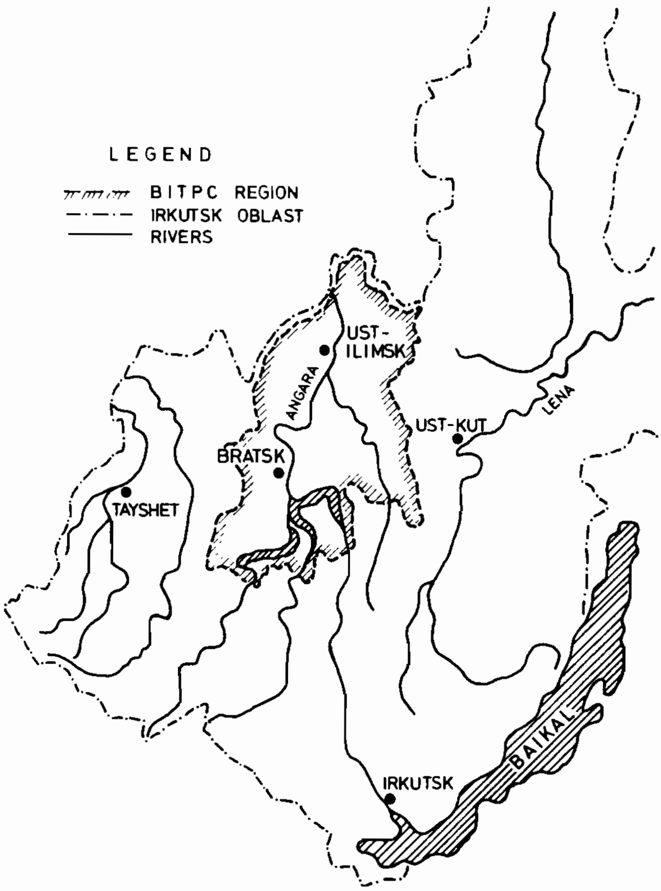


Figure 3. Bratsk-Ilimsk Territorial Production Complex.

What are the most impressive achievements after 20 years? The population increased threefold and has a low fluctuation rate. The standard of living has significantly increased and is higher than the national average. A system of dams has been constructed, big water reservoirs have been built, power generation increased rapidly and is still rising. There was, and is, a rapid development of roads and railroads, and navigation has been improved. A construction industry was established, and energy-intensive industries using cheap power were developed to process natural resources. New cities have been constructed in proportion to manpower requirements. Recreation and environmental protection were closely tied to development of the new water reservoirs.

THE CASE STUDIES

Case studies of complex real-life socio-economic systems offer several advantages. They provide a large volume of basic facts and data on the past and present situation and the direction of development. They allow us, at conferences and in field studies, to communicate with the politicians, managers, farmers, and workers involved in elaborating and implementing regional programs, and to study the human influence on decision-making processes. Studies of existing socio-economic systems guarantee that we are dealing with the full complexity of real life, and not only with a simplified and perhaps faulty model of reality. And finally, such studies enable us to compare managerial methods and tools used for solving similar problems elsewhere.

On the other hand, case studies also have some disadvantages. Significant differences exist in the socio-economic and political environment and internal structure of the regions studied. Also, different starting times and conditions, and the different roles programs play in different countries, result in the lack of a common framework for comparison and generalization. This limits the opportunities for synthesizing a generalized methodology for managing regional development. Although our case studies are not only retrospective, we are not involved in the actual decision process but are confined to post-decision analysis. It can be difficult to get information on the factors and motivations that led to a certain decision. And, as we found during our field study in Tennessee, case studies are relatively time-consuming and expensive.

But despite these drawbacks, we became convinced that this is an appropriate way to deal with systems analysis of socio-economic decision-making, and that IIASA is the right place to do it.

Let me return to the question I raised earlier: in these two cases, how is systems analysis used as a tool of management in regional decision-making (Figure 4)? This general question, which characterizes our research approach in the first stage, can be subdivided into three questions. The first--what is to be decided?--concerns the content of the decision-making process and is directed toward gathering information on the goals and strategies of the program at issue. The second question--who decides?--concerns organizational problems, changes over time, and solutions. The third--how are decisions substantiated?--addresses the content and role of the calculations and models used in decision-making.

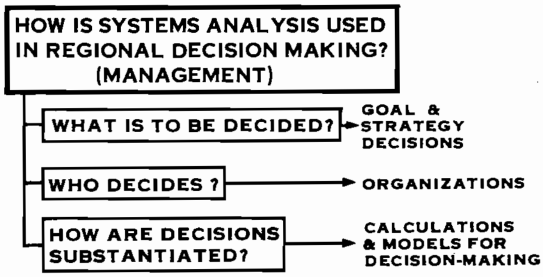


Figure 4. Systems analysis as a management tool.

WHAT IS TO BE DECIDED?

Let me now deal with the first of these three questions: what is to be decided?

A significant part of our efforts in both the TVA and the Bratsk-Ilimsk case has been concentrated on identifying the program goals and their change over time. This was necessary for a complete understanding of the forms, methods, and tools of management used. There is no model and no organizational solution that can be adapted, or even understood, outside the context of the program goals and subgoals. A logical step of this part of the analysis is to find the interdependencies of the goals and subgoals and arrange them in a kind of goal tree in a logical order. We learned during our study in Tennessee, and while preparing for the Bratsk-Ilimsk Conference, that this is practically and methodologically very difficult. The limited information about the past, and the dependence of the goal tree on the viewpoint one chooses and the purpose one has in mind, strongly influence the result. Although this study was helpful for our understanding of the programs, it remained in a rather descriptive stage.

The next part of our studies on the contents of regional decisions dealt with the different variants or strategies for regional development and their division into substrategies at different levels. The interrelations of the variants and strategies are combined into a decision tree. I will explain our methodological approach, taking as an example the simplified decision tree of the BITPC (Figure 5). Of course, the starting point was the basic decision, taken in the early fifties, to allocate part of the investment and manpower resources of the USSR to the development of eastern Siberia, beginning with construction of the Bratsk dam. The next logical step is to determine for what purpose the available energy and local natural resources should be used, and where the local production levels should be set, taking into account the severe climatic conditions and the high specific settlement costs. It was decided to develop energy-intensive production from local resources and encourage settlements, and not to transfer energy and raw materials to regions with more temperate climates and lower settlement costs (an alternative transport strategy).

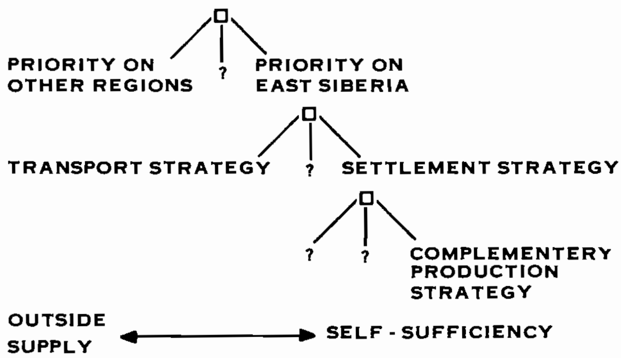


Figure 5. Tentative decision tree of the BITPC.

The next step is to ask what complementary production should be developed in the region. In Bratsk-Ilimsk, the construction industry--which, to a large extent, is always locally bound--and certain food-supplying industries were chosen. Other decisions, now under way, are related to the next stages of the manufacturing process, which in turn lead to the choice between additional, complementary production strategies or other transport strategies. All the Bratsk-Ilimsk substrategies are characterized either by a high degree of regional self-sufficiency or by a strong orientation of the region toward supplying to other regions.

During development of a regional program, many of these strategic decisions recur, and often the answers will differ at different development stages of regional production, infrastructure, and technological development. Our studies in this area are discussed elsewhere.*

---

*See J. Owsinski and D. v. Winterfeldt, Volume 2.

WHO DECIDES?

I now want to deal with the organizational studies related to our second question: who decides? (see Figure 4). In both the TVA and the Bratsk-Ilimsk case, the borders that define the area of influence of different authorities responsible for regional development are not congruent. The TVA is responsible for major development activities in the area of the Tennessee Valley (see Figure 1), and for a somewhat larger overlapping power supply area. The state of Tennessee (lines) only partly overlaps the TVA area. The same applies to the subregions. There are counties, as governmental units, within larger tributary areas, which are subunits of responsibility of the TVA, and still larger development districts.

In terms of managerial structure, in each administrative echelon there are at least two types of managerial units responsible for regional development (Figure 6). For the Tennessee Valley region, these are the TVA, a federal agency, and the state governments of Tennessee, Kentucky, Alabama, Georgia, North Carolina, and Virginia. On the regional subsystems level these are mainly the county and city administrations and the tributary-area agencies of the TVA. Regional development must be coordinated among these units and with many private enterprises that are not under the direct supervision of the regional management units. The regional coordination links are shown by the dotted lines.

The BITPC exhibits some similar organizational features and some differences (see Figure 3). The production complex is located in a part of the Irkutsk oblast, and divided into the districts of Bratsk, Ust-Ilimsk, and Shelesnogorsk. Figure 7 illustrates some important features of the managerial structure in relation to the territorial production complex. There is no special unit for managing operation of the complex. The TPC approach was used mainly for planning purposes; operational management is in the hands of the Irkutsk Soviet and its departments, and of the region and city soviets responsible for parts of the TPC area. Bratskgesstroi, a construction enterprise with 70,000 employees, also played an important role in coordinating the early activities. This is similar to regional development management in the Tennessee Valley, and results in the need for strong regional coordination among managerial units.

This need is emphasized because many activities in the complex are influenced by managerial units outside the region, owing to the fact that the major enterprises are centrally planned and supervised. In the case of the Ust-Ilimsk Cellulose Combinate, there is some international influence as well; it is a joint activity of several socialist countries, and was initiated and organized by the Council of Mutual Economic Assistance (CMEA, in Western countries often called COMECON) and its Commission for the Chemical Industry.

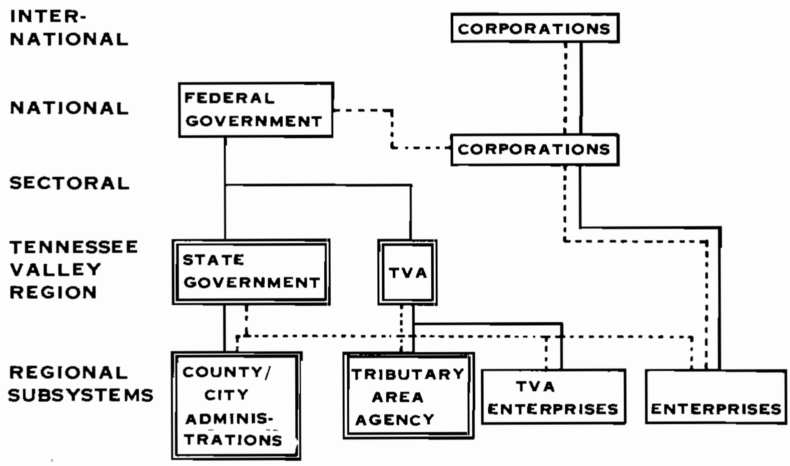


Figure 6. TVA.

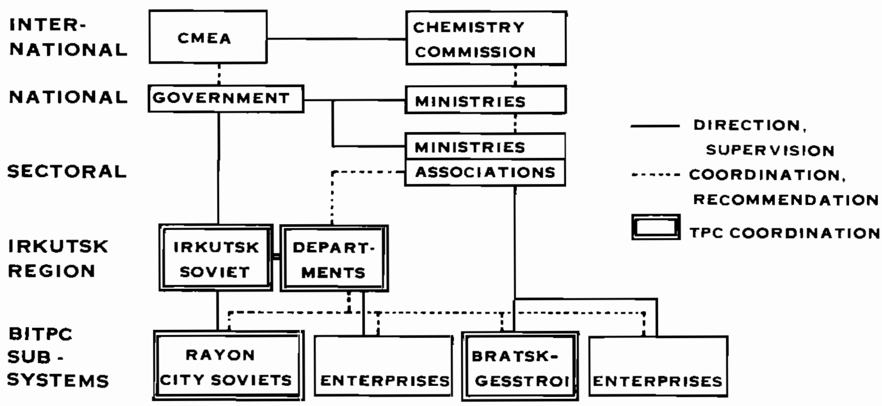


Figure 7. BITPC.

Figures 6 and 7. Management of the Tennessee Valley region and the BITPC, respectively.

With regard to coordinating TPC development efforts, it is interesting that at present there is a discussion in the Soviet Union on establishing special units for the operational management of territorial production complexes. We hope to get further information on this topic during our field study in Bratsk-Ilimsk, which serves as an example and standard solution for other TPCs in the Soviet Union. Other organizational questions are discussed in a presentation dealing with three further regional development cases.*

An interesting aspect of our case studies is the interaction of the regional organization with the social groups affected by regional development. While we are not able to study this area in detail, we will briefly discuss two examples of this interaction. The first concerns the impact of the TVA on agricultural development. Fertilizer research and production were stimulated, and significant efforts made to develop new fertilizers, share know-how with interested firms and industries, test and evaluate the efficiency of fertilizers, and organize a wide network of training courses, conferences, model farms, and the like.

An agricultural development method applied by the TVA is of particular interest: the demonstration method. On demonstration farms, the TVA, in collaboration with universities, worked out recommendations for increasing economic efficiency and supplied low-price fertilizers to the farms. As a result, the net income of 50 model farms increased threefold, whereas the cultivated land increased by less than one-tenth during a five-year period. Our discussions with farmers showed us how greatly successful implementation of a regional development program depends on trust and close cooperation between decision makers and those to whom the decisions apply.

Another example of the interaction between regional development and the social groups concerned was given at the Bratsk-Ilimsk Conference. Development of the BITPC caused a rapid increase in the number of inhabitants of this area, although in this region of severe climatic conditions the strategy is a labor-saving policy of intensive economic development. The city of Bratsk itself grew from 100,000 to 200,000 in ten years. Despite the climate, there was a very low fluctuation rate. We learned that the following factors attracted and held people there:

- Modern enterprises and challenging work;
- Intensive civil construction;
- The good prospects offered by the region, combined with a high degree of confidence in the future;

---

*See C. Davies, A. Demb, R. Espejo and R. Ostrowski, Volume 2.

- Good opportunities for acquiring medium and higher education;

- Reliable air transport to other parts of the country;

- Higher salaries and better terms of employment (i.e., longer annual leave than the national average).

This is combined with a certain spirit of enthusiasm and pride in belonging to the pioneer generation of the region. It is interesting to note that higher salaries and longer vacations, which of course play an important role, are mentioned as the last factor; we have been told by a number of people that this factor would alone not be sufficient inducement.

These two examples illustrate very well our general standpoint, that the influence of the individuals and groups concerned (managers, workers, farmers, consumers) on the way the system acts is an important characteristic of socio-economic systems. Each individual has a certain understanding and evaluation of the system in which he lives and works, and relates it to his interests. This affects to a great extent the decision process and the mode of operation of the whole system. The human factor in a socio-economic system differentiates it from a technical system, where a change in target function or constraints usually causes a direct change in system and output parameters.

HOW ARE DECISIONS SUBSTANTIATED?

Let me turn now to our third question, how decisions are substantiated by means of calculations and models during the decision-making process. I shall deal with three aspects of the balances, models, and model systems used by the TVA (Figure 8) and for preparation of the BITPC (Figure 9): the mathematical type of models and their stage of development, sophistication, and complexity; the economic categories described in the balances and models; and the degree of comprehensiveness of models related to the national economy or its sectors.

All balances and models are based on facts and data describing the initial state and the development tendencies. All the calculations, balances, and models used for decision preparation require a certain input of objectives, values, and needs, formulated by the decision maker and adjusted in the iterative process of decision preparation. When we look at the present stage of development of models that are actually used in the decision-making process, we can easily follow some lines of development. One line starts with the simplest and most widely used tool of decision preparation, the balance. When we combine balance equations we arrive at input-output models of the static and multi-period type, which then lead to static or multi-period optimization models. The other lines show the development of statistical models, mainly econometric, and of network models describing the time sequence of actions for changing an economic system. Simulation models are developed to build model systems with statistical functions and other socio-economic models.

On the one hand, balances and models describe different economic categories such as natural resources, products, construction activities, and so on (shown in the lower part of Figures 8 and 9) on the other hand, models differ in the degree of comprehensiveness. Some of them describe the national economic process as a whole, others the regional or sectoral processes.

Using the modules of this scheme we tried to analyze the models used for the TVA and Bratsk-Ilimsk. Starting from the same points--data and objectives--we find in TVA a relatively low degree of development of regional balances. They serve mainly for land-use and financial calculations. Network models are used for preparing construction activities. Statistical models play a major role in forecasting the development of population and manpower, prices, and production, mainly related to the national economy. Some optimization models are used for sector calculations.

The TVA's modeling efforts started with the elaboration and utilization of several single models dealing with separate managerial questions. These have now been successively combined into a recently elaborated regional model system.

Preparation of the basic decisions for creation and design of the BITPC was based from the outset on a relatively complex regional model system. Using the same modules as before, we can see that the starting point is the same: data and objectives. In contrast to the TVA, normatives play an important role in the planning process. A strong emphasis on modeling physical relations within the regional program leads to the extensive use of balances and balance-based input-output and linear optimization models. The first steps of elaboration and use of multi-period or dynamic optimization models have been taken, with interesting attempts to combine linear multi-period models with network models. The modeling system used includes national models reflecting the commodity flows between branches and regions, as well as regional and sectoral submodels. This model system was used mainly for long-range calculations.

To summarize, there are several similarities between the model systems of the TVA and the BITPC, particularly in the specialized submodels used, for example, for water management, load forecasting, and so on. On the other hand, the differences in the major model types used, the different emphasis on physical relations, the different time horizons, and the different role normatives play in decision preparation reflect the different basic functions of the models and model systems in the two cases,

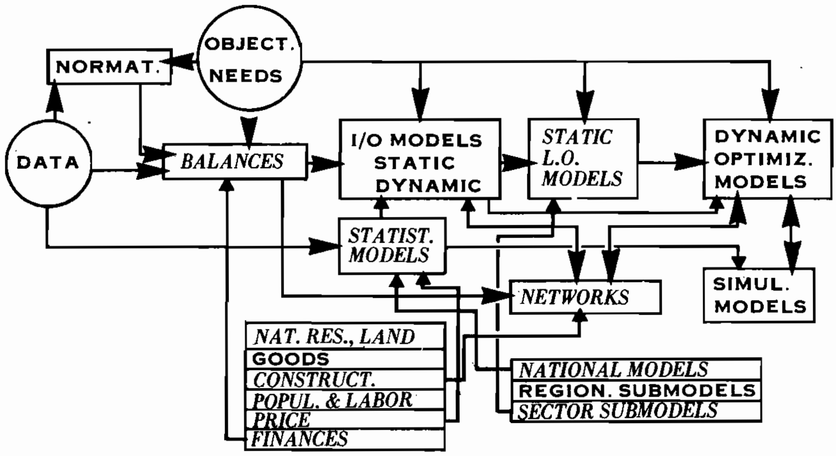


Figure 8. TVA.

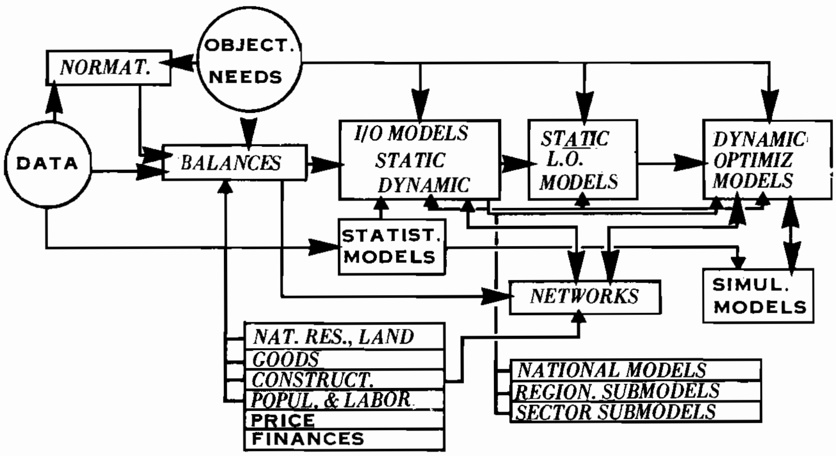


Figure 9. BITPC.

Figures 8 and 9. Regional normatives, balances, and models of the TVA and BITPC. (Italics indicate present development stage of the models.)

which are derived from the different roles of planning and forecasting in the two socio-economic systems. Another presentation deals with some additional facets of the two model systems.*

Let me return to the role of normatives in modeling and decision preparation. I mentioned earlier that normatives play a much bigger role in Bratsk-Ilimsk than in the TVA. But in one respect the TVA's use of normatives or standards is very interesting. It relates to the integration of environmental factors in the planning and decision-making process. This aspect of our study was supported by a contract from the United Nations Environmental Programme (UNEP). The present environmental management system of the TVA can be considered to be in a developing mode, but one fact emerged clearly: TVA has had a remarkable influence on the establishment and review of environmental standards in the United States. This is especially evident in the air-quality program that was started in the early 1950s. Through data accumulated by the TVA and demonstration programs dealing with air quality considerations, the TVA helped to establish ambient standards--as opposed to emission standards--in the USA. Ambient standards are directly related to human health, and indicate the maximum individual dosage allowable at ground level; emission standards are related to source emissions of pollutants. Obviously the former more directly reflect the goals of environmental protection.

The TVA currently has in operation a systemwide sulfur dioxide limitation program, the first of its kind in the USA, which has proved effective and economical in meeting ambient air quality standards. It is also conducting a demonstration program on the emission standards of SO_2: the sulfur content of stack gases is chemically reduced before release into the atmosphere. The purpose is to determine the effectiveness, economic costs, and environmental benefit of this procedure.

It will be interesting to study comparable activities in the BITPC, particularly since their program serves as an example and guide for similar TPCs in the Soviet Union.

FUTURE STUDIES

These are some of the many points of interest in our first two case studies. The third in the series of IIASA conferences and field studies on large-scale planning projects will be the Shinkansen case, a large construction program for the northern super-express railway in Japan. As with our other two case studies, our investigation of the Shinkansen Program will begin

---

*See J. Owsinski and D. v. Winterfeldt, Volume 2.

with a conference, to be held in 1977, followed by a field study.

We have also started analyzing all available information on large-scale planning projects in other parts of the world, under way or already completed; for example, the Guyana program in Venezuela and the Scottish development program. Three other cases, already agreed upon or under negotiation, will be examined in cooperation with scientific institutes in the countries concerned. One is the Lublin Coal Region Development Program in Poland, for which a working agreement already exists. Another is the Computer-Assisted Regional Management System Project of the Kinki Region in Japan; the first workshop took place in March 1976, and the proceedings will be published soon. Subsequent activities are the subject of a working agreement with a group from Kyoto and Osaka Universities and IBM, Japan. Third, details are being worked out for cooperation on the Isfahan Regional Program in Iran.

For all these cases, IIASA research deals with the generalization of methodological experience, the comparison of methodological approaches, and the elaboration of methodological tools, with the aim of contributing to application of systems analysis to other large-scale planning projects. This type of in-house research can be managed with our relatively limited scientific staff, but it can be effective only in combination with a network of international scientific cooperation, which we have begun to establish (Figure 10).

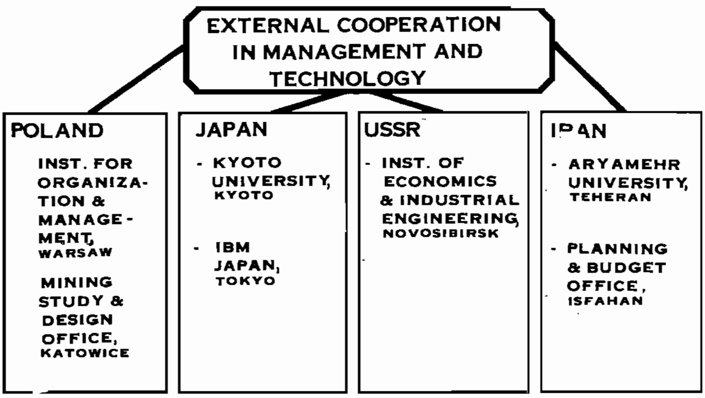


Figure 10. A network of scientific collaboration.

There will never be an ideal model or model system that can be used for regional planning in all cases and under all circumstances; but we hope that, in collaboration with these and many other institutions, we can make the best use of all possibilities for exchange and transfer of successful methods, and perhaps produce some recommendations. These may, for example, relate to the optimal time span of regional programs, the ways and methods of reflecting the real complexity and the proportionality of regional programs, the application of decision analysis to strategy formulation and evaluation, the interaction of regional programs with the national planning and decision process, the transfer of successful models and model systems, and successful modes for regional organization and for the integration of the sciences in the elaboration of regional programs.

Future Research Directions

A. Aganbegyan

The last three very interesting presentations take us back to the key question posed many times at this Conference: what is applied systems analysis? Of course it is easier to ask questions than to answer them. Try, for instance, to explain to someone who has never eaten a pie what it is and what it tastes like: The only way he can know is to be given a pie to taste. Today we have had a delicious pie of applied systems analysis.

Now to the question of what applied systems analysis is. It is a science that is being developed, among others, through IIASA's projects. As I see it, each of the three reports I mentioned can serve as a classical example of applied systems analysis as the science of how to give poor advice--poor, since all other ways and means are even worse.

I enjoyed the brilliant presentation by Holling. Departing for a moment from the specifics of the Canadian forests and the budworm, we can say that this study illustrates how modern methods can be applied to solve concrete problems. It is an example of work that could be published in IIASA's Handbook on systems analysis. The important point here is that the study integrates the professional ecological approach with mathematical modeling and computerization.

I also enjoyed listening to Foell's discourse on the work of his group, which is very interesting from the methodological point of view--in particular, the attempt to portray various scenarios, present a situation analysis, and assess decision alternatives.

In its studies on the future development of Siberia, our Institute is using an approach similar to that developed by the Hudson Institute. I would like to be considered the co-author of Knop's presentation. While that is of course an exaggeration, I simply cannot separate myself from this research project, having participated in the case studies of the TVA and Bratsk-Ilimsk. The scale and quality of these studies are unprecedented in regional science, and I am grateful to Professor Knop for his leadership.

My presentation is called *Future Research Directions*, but it is impossible for one man to define these; at best, I can only give some of my conclusions. To begin with, we should accept the integration of various projects. This idea has been put forward by the leaders of IIASA in the context of making integrated regional development one of the cross-cutting areas in the research structure. For systems analysis of regional development we can identify two approaches. The first of these is well developed. It involves hierarchical models--a national economic model, a model for a large region, one for a territorial production complex in that region, and finally models for smaller territorial nodes, industrial nodes, or centers. Figure 1 illustrates this approach in relation to the region of eastern Siberia. At the top is the entire region, including Krasnoyarsk and the Irkutsk area up to Baikal. Below it is the Sayansk territorial production complex south of the Krasnoyarsk region. The lower part represents the Abakan industrial node within the Sayansk territorial production complex. Figure 2 shows the structure of territorial industrial complexes (small squares) in the region of eastern Siberia (top level in Figure 1). For each level we have developed detailed optimization models that have been experimentally tested in formulating five-year plans for the economic development of Siberia.

The advantages of such an approach are obvious; its disadvantages are equally obvious. Individual subsystems of regional development--such as energy, water, environment, human settlements--are not fully reflected. It is impossible to represent each subsystem in detail. The words of Bellman in his famous book *Dynamic Programming* come to mind. He says that in modeling, one has to go along a narrow and dangerous path between the swamps of overcomplication and the traps of oversimplification.

In contrast to the first approach to systems analysis of regional development, the second approach involves creation of a system of interrelated models, each representing an individual subsystem--energy, ecology, water, etc. These submodels are combined into one integrated system of coordinated models for the entire region.

It is easy to preach such an approach, but in a traditional institute one cannot even cherish the hope that it can be realized. I know of no such institute where highly qualified specialists in the fields of energy, environment, ecology, agriculture, water resources, management, geography, economy, sociology, and mathematics work together under one roof. But IIASA is an institute where an interdisciplinary approach could be applied. With the cooperation of scientists from different countries, a system of models for regional development can be created. France has accumulated interesting experience in constructing the REGINA model (Courbis); the Soviet Union uses a chain of optimal territorial-production planning models; in the USA, the National Bureau of Economic Research (Smith) and Pennsylvania University (Izard) have elaborated regional models; vast experience has likewise been gathered in environmental modeling (environmental research centers in the USA and Japan), human settlements, water systems, etc. Integration of these activities within the framework of the

Integrated Regional Development program will undoubtedly make it possible to obtain significant scientific and practical results.

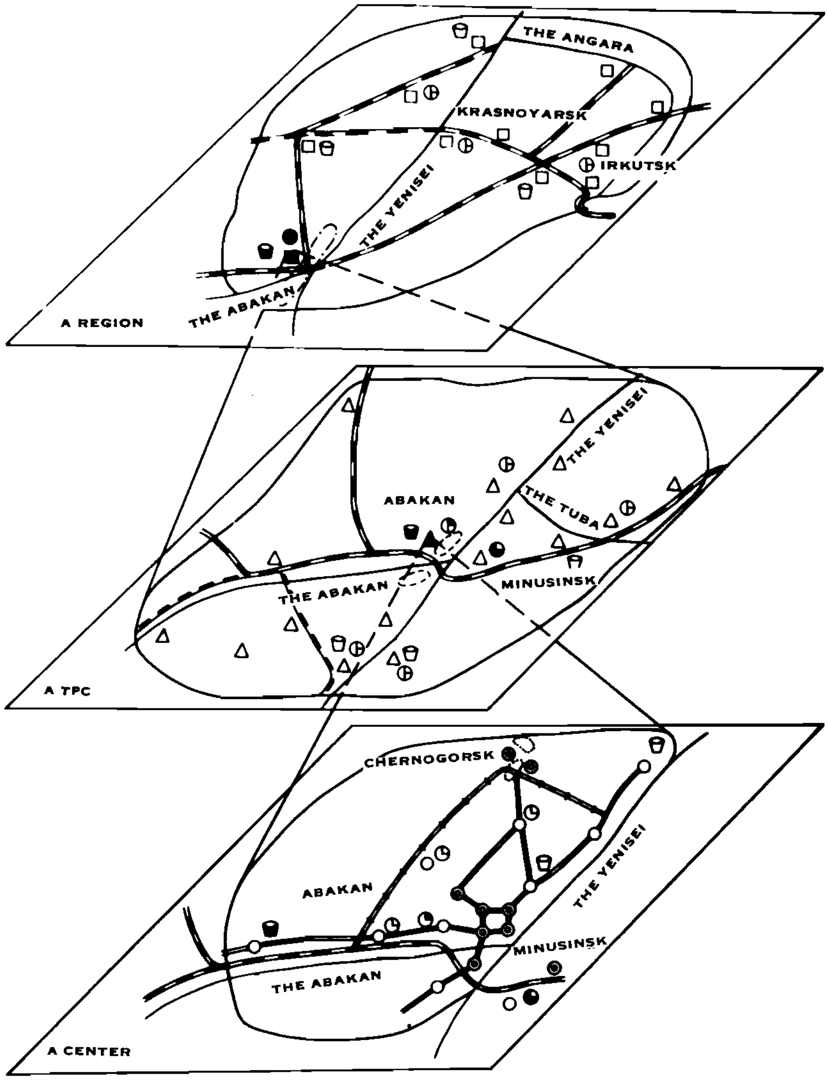
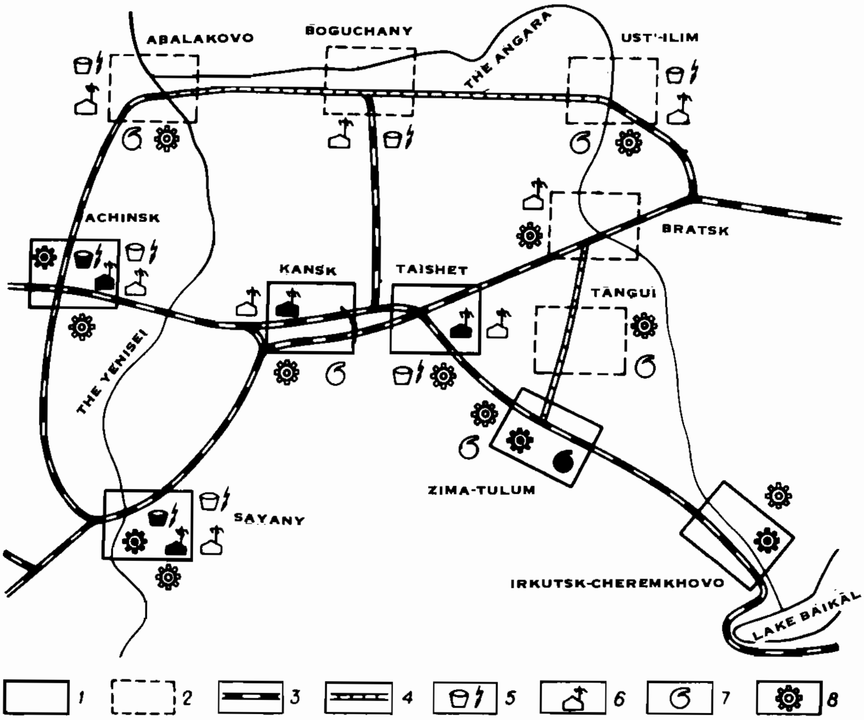


Figure 1. Complex formation in eastern Siberia.



1 AREAS CHOSEN FOR PRODUCTION ACTIVITIES
2 AREAS CONSIDERED BUT NOT CHOSEN
3 EXISTING RAILWAY SECTIONS
4 ADDITIONAL RAILWAY SECTIONS CHOSEN

5 FERROUS METALLURGY	}	LOCATION VARIANTS FOR PRODUCTION ACTIVITIES
6 NONFERROUS METALLURGY		
7 CHEMICAL INDUSTRY		
6 MACHINE-BUILDING		

Figure 2. Different territorial levels of modeling. (The symbols indicate various industries.)

Let us draw an idealized picture of the future (Figure 3). Each research area, in accordance with the cross-cutting theme of its research plan, elaborates its own subsystem. These are then supported by research on management and decision sciences. The regional development work can be focused on three problems (Figure 4). The first, which Knop stressed in his presentation, is the generalization of experience in regional development programs. Great progress has been made in this direction through the case studies on the TVA and the Bratsk-Ilimsk Territorial Production Complex. The second is developing relevant models and working out the tools of applied systems analysis; and the third, applying a developed systems analysis approach to the solution of regional development problems.

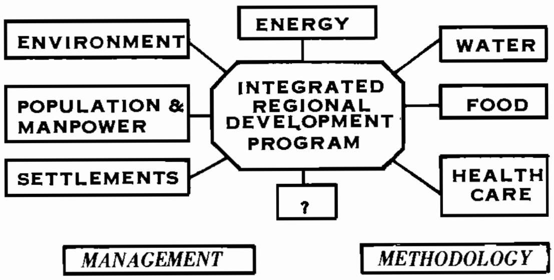


Figure 3. Possible structure of IIASA Integrated Regional Development program.

	GENERALIZATION OF EXPERIENCE IN REGIONAL DEVELOPMENT (CASE STUDIES)	SYSTEMS ANALYSIS APPROACHES, SYSTEM OF MODELS	APPLICATIONS (CASE STUDIES)
ENERGY			
WATER			
FOOD			
ENVIRONMENT			
POPULATION & MANPOWER			
SETTLEMENTS			
HEALTH CARE			
MANAGEMENT			
METHODOLOGY			

Figure 4. Three major problems in integrated regional development.

So far, each IIASA project has carried out research on a particular geographic region. The Ecology project concentrated on the forests of Canada. Foell's group chose a region of France, the German Democratic Republic, and the State of Wisconsin in the USA. Knop's project dealt with the Tennessee Valley region and the Bratsk-Ilimsk territory, and is planning to investigate certain regions in Poland, Japan, and Iran.

If integration is to be more than a word, if it is to be translated into action and is to demonstrate the advantages of an interdisciplinary approach, we may have to concentrate our research efforts on the various projects of a region. One can only hope that at our next Conference the reports of the different research areas, under the title *Universal Perspectives*, will in fact be interlinked and will not just represent an arithmetic sum.

As Karl Marx used to say, any beginning is difficult. IIASA has succeeded in overcoming its initial problems. We are in the ocean of systems analysis and we have no choice but to swim in this ocean.

Discussion

(W.A. Buehring and A.B. Demb, Rapporteurs)

The discussion centered on the IIASA program on Integrated Regional Development. One set of comments related to directions for the study of organizational structures for regional development. Suggestions included three main research foci:

- Effectiveness criteria for management systems in regional development, e.g. comprehensiveness of management functions represented in the region;
- Classification of regional programs and various management approaches, e.g. the nature of the impetus for the program;
- Mechanisms for coordination and integration of activities among regional organizations, e.g. activities of sectoral and territorial units.

Other comments indicated a more general issue to be treated in studies of regional development. Concern was expressed about the degree of comprehensiveness that can be achieved in programs for integrated regional development. The use of indicators was addressed, in particular methods for developing indicators, such as for "quality of life", and the role they might play in shaping choices among objectives. An additional point was raised concerning the difficulty of defining indicators consistently in different national and cultural settings.

Finally, four main areas were suggested for cooperative regional development studies by Poland and IIASA: comprehensive planning and management for regional programs, human settlements, water resources, and health care.

SYSTEMS ANALYSIS AND POLICY-MAKING

Analytical Aspects of Policy Studies

T.C. Koopmans

IIASA is both international and interdisciplinary. The privilege I have had of taking part in its work for a full year, and then from time to time after that, has given me the definite impression that the international communication difficulties are much less serious than the interdisciplinary difficulties. That in a way is a measure of success in the type of activity in which IIASA is unique: to bring people from different countries, different languages, different social systems together. In this regard IIASA has in my estimate been very successful. That the interdisciplinary difficulties still exist is not surprising; they have existed for a much longer time than IIASA has.

I will therefore address myself primarily to those difficulties. A suitable subtitle of my talk would be: "An Attempt at Interdisciplinary Communication in Systems Analysis". I will be speaking as an economist and econometrician to fellow systems analysts who have their roots in other professions. My remarks are challenges and appeals rather than complaints. They are based on interdisciplinary experiences and interactions in many activities in several countries, and are in no way limited to my highly treasured IIASA experiences.

Some of my references are mostly for purposes of information, and some of these will go back to the fifties and even earlier. So I also have a sub-subtitle: "An Attempt at Intergeneration Transfer of Information".

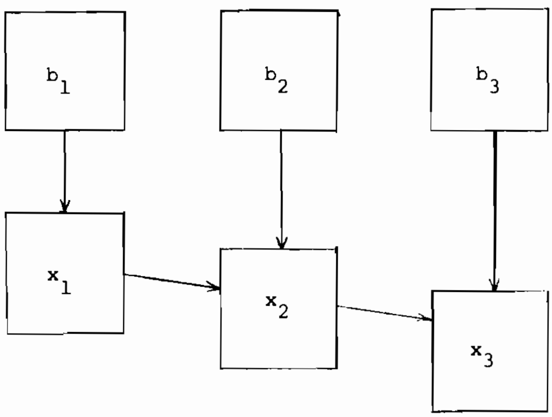
I will use a small number of topics, "modules" I will call them, and concentrate on those in my discussion, shifting from one to the other without much continuity in some cases. They are the following:

- Causal ordering of variables,
- Identifiability of parameters,
- Measures of resilience,
- Judgmental probabilities,
- Allocation of resources:

  "Energy analysis"
  "Shadow prices".

All these "modules" deal with one aspect or another of modeling as a preparation for policy studies. A list of references is appended, so that I will not give detailed references in the text; I will just state the names of authors. Also, I think that the communication difficulties and lack of mutual confidence between the disciplines do not arise from the technicalities of the models. They concern the explicit or implicit underlying concepts. Therefore I will concentrate on the concepts and skip the technicalities.

My first item is that of causal ordering of variables. I am referring to the work of Herbert Simon of the Carnegie Institute of Technology, who is several things: a political scientist, an organization theorist, an economist, a psychologist, a computer scientist--and by that definition, a systems analyst. I follow his exposition, which is reprinted in *Models of Man*, his collection of papers. Figure 1 shows the names of the variables that occur in his simple example of a small linear model: rainfall, wheat yield, and wheat price. Next it shows the equation system that expresses the mathematical structure of the model. Simon's discussion is concerned with defining what one means by causal ordering of variables. He points out that causal ordering is a distinction in terms of the model. Whether it is also a distinction in terms of nature or society depends on how good the model is.



x_1 rainfall

x_2 wheat yield

x_3 wheat price

$$\begin{aligned} a_{11}x_1 &&= b_1 \\ a_{21}x_1 + a_{22}x_2 &&= b_2 \\ a_{32}x_2 + a_{33}x_3 &&= b_3 \end{aligned}$$

Figure 1. Simon's example of causal ordering of variables.

In the first equation of Figure 1 the rainfall is determined by causes denoted b_1 that are not made explicit in the model. The second equation indicates that the rainfall, then already determined, in turn has its influence on the wheat yield, along with the influence of other external factors (b_2). The third equation says that the wheat yield again has its influence on the wheat price, along with b_3. So there is in this model a definite causal ordering.

Note that in taking you through that sequence I have made use of a particular way of writing the system of equations. I could have given the same mathematical information, for instance, by writing down the equation you get by subtracting the first equation from the second, next the one you get by subtracting the second from the third, and finally what you get by writing down the sum of all three. Mathematically that would be an equivalent way of writing the system of three equations, but it would not reveal the chain of causation. This may seem to make the causal ordering an arbitrary concept. However, it ceases to be arbitrary if one has reasons for adopting that particular way of writing the equations--reasons based on knowledge of the phenomena that the relations represent. In the example at hand, there are possibilities for either influencing the behavior of that small system ourselves or of watching nature influence it in particular ways. For instance, if cloud seeding can produce rainfall then the cloud-seeding possibility would here be hidden in the b_1, and would therefore act directly on the rainfall and thereby indirectly on wheat yield and price. Likewise, fertilizer application, hidden in the b_2, will affect yield x_2 and price x_3, but not rainfall, because in the first equation rainfall is already determined. Finally, if rationing of bread affects the price, x_3, it does not act back and affect either yield or rainfall. By associating various ways of intervention with the exogenous variables b_1, b_2, b_3, you obtain an interpretation of the model as written that gives you the causal ordering.

Summing up, the model consists of three parts. First, the set of equations as written; second, the verbal definitions of the jointly dependent variables, the three x's (shown at the top of the figure); third, the interpretation of the exogenous variables (b_i) which includes the descriptions of levers of influence that exist on the part of either nature or a decision maker. The diagram at the bottom is Simon's procedure for indicating the causal ordering. You can read it backwards in this way: that the third variable has arrows of causal influence pointing to it from all previous variables--exogenous and endogenous. The second is influenced by x_1 and b_1 and b_2, but not by b_3 or x_3; the first is influenced only by b_1.

Figures 2 and 3* show a case where the causal ordering lumps four of the five endogenous variables together into one class,

---

*In the *incidence matrix* of Figure 2, an entry 1 refers to a non-zero coefficient, a blank to a zero coefficient.

	Endogenous		Exogenous
y_1	food consumption	z_6	last year's price received by farmers
y_2	food price level		
y_3	real income	z_7	net investment
y_4	food production	z_8	time
y_5	price received by farmers	z_9	last year's income

Incidence Matrix

	z_9	z_7	z_8	z_6	y_3	y_1	y_2	y_4	y_5	
	$\boxed{1}$									b_9
		$\boxed{1}$								b_7
			$\boxed{1}$							b_8
				$\boxed{1}$						b_6
Income formation (multiplier theory)	1	1			$\boxed{1}$					b_3
Consumers' demand for food			1		1	1	1			b_1
Supply of food at retail			1			1	1	1		b_2
Supply of food by farmers			1	1				1	1	b_4
Demand by food processers and dealers			1				1			b_5

Figure 2.

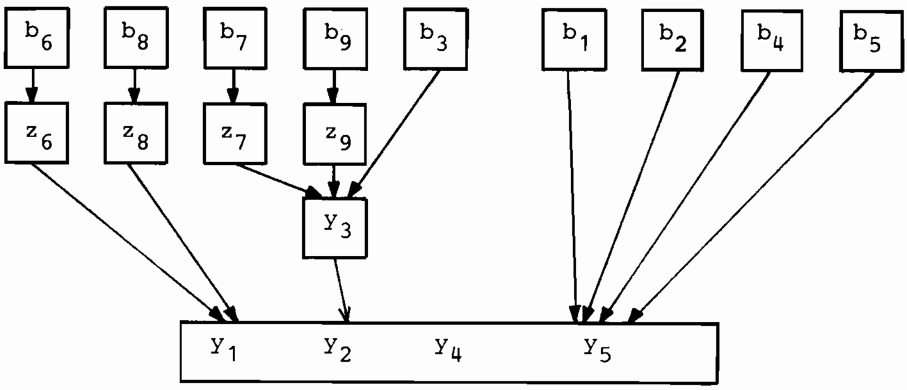


Figure 3.

Figures 2 and 3. An agricultural model, after Girshick and Haavelmo.

jointly determined by all variables that precede in the ordering. The example shows that the most general representation of the causal ordering is by an oriented graph that is, in some sense, monotonic. It is based on a study by Girshick and Haavelmo.

My second topic is the identifiability of parameters. This problem has popped up in many fields. In many circumstances it has traits similar to those of the problem of defining and tracing causal chains. Simon combines the two problems in the title and in the content of his article. I am inclined to think that the identifiability problem logically stands by itself and arises also in other forms. I do not want to take too much time for it in this discussion because I want to get on to some of the other topics listed in Figure 1. Let me just briefly mention where the identifiability problem has arisen independently in many fields, mostly in social science fields in the early stages, but later also in other fields. So-called *multiple factor analysis* in psychology by Thurstone, at the time Professor of Psychology at the University of Chicago, is one case in point. The psychologist has performance scores on a number of test questions and wants to draw inferences from these many variables about a smaller number of variables that he interprets as distinctive faculties of the mind of the respondent. This is a problem where you postulate a certain mathematical structure that connects unobserved and observed variables by relations involving some parameters. The problem of identifiability is to determine those parameters of that structure whose values would in fact be implied if you fully knew the probability distributions of the observed variables.

In public opinion research, Lazarsfeld of Columbia University has developed the quite similar methods of *latent structure analysis*. Here the responses are "yes" or "no" to a number of survey questions. Latent structure analysis is designed to use these responses to a large number of questions in order to trace and establish a much smaller number of predispositions in the mind of the respondent: his basic opinions.

The third field, with which I personally have been more concerned and involved, is that of *econometrics*. The first paper known to me that stated the identifiability problem in this field was never published. It was written by Ragnar Frisch for a conference in connection with the work that Jan Tinbergen did on business cycles for the League of Nations. This work was taken up further by Trygve Haavelmo and by a group of econometricians in the Cowles Commission at the University of Chicago, by another Norwegian, Olav Reiersöl, and by many others. The basic problem there is that in the description of the business cycle one uses many equations that often involve some of the same variables occurring in two or more different equations. Does the fact that these variables are interrelated in so many different ways get in the way of the problem of estimating any one of them? The aim of that work is to develop criteria for determining whether a certain equation is not identifiable, that is, cannot be reconstructed even from the whole probability distribution of the variables; or, in a less conclusive way, whether it is identifiable supposing you already knew the coefficients in the other equations.

Largely after the work on identifiability problems described above had found its form, a substantial new development arose out of the field of systems engineering, under the name *systems theory*. What I know of this work I have learned at IIASA from conversations with John Casti and with Vladimir Strejc of Czechoslovakia. A fundamental book is that by Rudolf Kalman and coauthors. The analogies and differences between that work and the above studies reflect the problems of the fields of origin and application in an instructive manner.

I go now to my next topic, the <u>resilience</u> of a system. I will not need to say much to introduce the concept. It has already been explained by Häfele,* Holling,* Grümm,** and others. What is involved is that you have a system with a number of variables that is defined in terms of a set of differential equations. Each one of these equations defines or determines the time derivative of any one of these variables in terms of the contemporaneous values of all the variables. And, as the previous speakers have indicated, in general these equations are nonlinear. In particular one will have in the state space (the space of these variables) trajectories that may or will converge to certain attractor sets. These may be single points, or limit cycles, or other more complicated sets. Which one of these competing attractors attracts a certain path depends on the initial position in the state space from which the path originates. The state space is therefore partitioned into basins that feed into the respective attractors. Now, from an ecological or societal point of view different attractors have different valuations attached to them--some desirable, some perhaps catastrophic. The notion of resilience applies to the effect, on the system, of shocks or interruptions that are not themselves part of the model, but are rather some outside disturbances. One of the measures of resilience would be a measure associated with the momentary state of the system. For instance, it has been proposed to use as such a measure the distance of the momentary state to the boundary of the basin that you want to stay in. The implicit assumption is that the larger that distance, the smaller the chance that a jolt or disturbance could flip the system out of that basin into another less desirable one.

The distance concept is here used as one of several alternative measures of what you might call safety from expulsion. This may well serve as a good first approximation. However, I

---

*This volume.

**Volume 2.

feel that the notion or the description of the possible disturbances is not explicitly present in that definition. Also, the definition of distance is subject to the choice of units of measurement of the variables. As Grümm has explained, you can use that choice, maybe, to apportion the units in accordance with the size of shocks that you expect might operate in each dimension. That already goes in the direction I regard as desirable and natural in the definition of the resilience concept. If one wants to quantify a concern with the possibilities for remaining in the preferred basin, then there is a probability concept in the background. I would therefore expect that the explicit use of probabilistic models, in the form of stochastic differential equations, would be the next step in obtaining greater precision in expressing the problem under discussion. A lecture given by Yu. Rozanov of IIASA* last summer indicated to me in an expository way the nature of the change in the models that comes about by that further refinement.

That is all I have to say specifically on the subject of resilience. However, my remarks were also intended as a take-off point for the next topic, judgmental probability, on which I want to dwell somewhat longer. That is the topic of probability concepts that differ from the classical one, the classical frequency definition, that has held sway in the physical sciences for several centuries. If I speak of the probability of a disturbance or a jolt of a kind that has not previously occurred, what do I mean by the term probability? The concept needed here is in the same area of thought as Häfele's observation with regard to "hypotheticality"** as an unavoidable aspect of any exploration of the future. Choices with regard to resources, energy technology, more generally the future face of the economy and of society, are made without much or any experience of some of the alternatives one by necessity chooses among. Therefore, as Häfele has described very eloquently, there is an aspect of hypotheticality in the forward-looking deliberations in systems analysis. I want to make a few remarks not particularly on that idea by itself, but on its implications for the probability concept that, in a sense, goes with it. As an example, good decisions on research, development, and demonstration of new energy technologies require the pooling of judgments of those who, in a relative sense, know best what the possibilities of such future technologies are most likely to be. From contacts with work of this kind in the United States, I find that the practical man tends to resist requests for estimating the means or the variances of certain future variables that are associated with the

---

*See H.R. Grümm, ed., in the list of references (Measures of Resilience).

**This volume.

outcome, say, of R&D projects. But the decisions have to be made. Not making a decision is itself a decision. So the decisions have the character of a wager, of what you might call a forced bet or a forced gamble.

Suppose you are forced to state odds on a future uncertain event, against an opponent who can then choose which side of the wager he will take against you. The odds you will end up choosing then reflect your judgmental probability, revealed under the stress of necessity. Since as I said I am concerned with the concepts, not with the technicalities, I want here to summarize the main content of a theory mentioned by Ralph Keeney,* a theory that formalizes the idea of consistency in decisions under uncertainty as a basis for defining such probabilities. I am speaking here of the concept that has been successively named "subjective probability", "personal probability", "judgmental probability", and that was developed successively by Frank Ramsey in England, Bruno de Finetti in Italy, and my late Yale colleague Leonard J. Savage in the United States. I also want to mention a beautiful exposition in a paperback volume by Howard Raiffa that reviews this whole development and adds to it.

As far as the terminology is concerned I find "subjective probability" not very suitable. "Subjective" is often regarded as not a good thing; "objective" is good. Well, the concept in question is something in between subjective and objective. Certainly, subjective emotions or feelings are not to come into it. I find "personal" better in the sense that it describes an inference from one person's evaluations. But I find "judgmental" still better, because it is not necessarily the case that decisions reflect just one person's opinion. It may be the pooled opinions of a committee, of a group of people who for purposes of taking the action have pooled their evaluations. The term judgmental also covers that case.

I also see an analogy with something that is often done in numerical computation. If you have certain data that you know only up to a certain number of decimal places, but you expect to use these numbers again and again in a long chain of computations, then you deliberately add a number of spurious zero decimals, so that, if you consult that same number many times over, your rounding errors don't produce inconsistency in your use. Now, I think you can look at a judgmental probability as similar in purpose. If you design a sequence of decisions you want successive decisions to use the same probability for any given outcome, and not go from one numerical value of some such probability to another, as you go from one component of a complex decision to another.

---

*See Volume 2.

In Figures 4, 5, and 6 I offer a tabular paraphrasing of the postulates, introduced by Savage to formulate the concept of judgmental probability. All postulates involve the interplay of two entities, *states of nature* (labeled by Arabic numerals) and *acts* (or *choices*, labeled by Roman numerals). The acts could correspond to decisions to engage (or not engage) in one or more alternative R&D projects. The states of nature would then represent mutually exclusive hypotheses about the as yet unrevealed secrets of nature, each of which would imply definite *consequences* (or *outcomes*) for each of the acts. In the figures these consequences are denoted by letters a,b,....

The first postulate says that the decision maker has a definite preference ordering of all the available acts. The next three postulates express properties of this ordering that impose various considerations of consistency on it. The second postulate is illustrated by Figure 4. It says that, if for certain states of nature--in this case the ones labeled 1 and 2--the consequences do not depend on the act chosen, then the ordering of the acts does not depend on what these act-independent consequences are. So, in Figure 4, the choice is independent of a and b, but may well depend on any or all of c, d, e, f.

The third postulate connects choices within two pairs of acts whose consequences under five alternative states of nature line up as shown by Figure 5. One can interpret it by saying that preference of act III over act IV translates as a preference of consequence c over d, which in the light of the previous postulate translates as preference for act I over II.

The fourth postulate, illustrated by Figure 6, moves in the direction of assessing the probabilities. Again, acts III and IV are uniform in their consequences. Acts I and II now also have one or the other of these consequences, but which it is in each case is now aligned differently with the states of nature; the first act has consequence a in states 1 and 2, and the second has that same consequence a in states 2, 3, and 4. And now the statement is a little more complicated. It says that the ordering of acts I and II depends only on the following data: the ordering of III and IV, which in a sense determines whether a is better than b (or b better than a); but also on the set of states of nature--the pair (1,2) in this case--where a occurs in act I, and on the set of states of nature--the triple (3,4,5) in this case--where a occurs under act II. It depends just on that and nothing else. The postulate does not say *how* the preference between acts I and II depends on that between III and IV. But what you see coming is that if preference for III over IV is combined with that for I over II, then the decision maker thereby reveals that he deems the pair (2,3) of states of nature taken jointly more probable than the triple (3,4,5).

		STATES OF NATURE				
		1	2	3	4	....
ACTS	I	a	b	c	d	....
	II	a	b	e	f	....

The ordering of acts I and II does not depend on consequences a and b.

Figure 4.

		STATES OF NATURE				
		1	2	3	4	5
ACTS	I	a	b	c	c	c
	II	a	b	d	d	d
	III	c	c	c	c	c
	IV	d	d	d	d	d

I is preferred to II whenever III is preferred to IV.

Figure 5.

		STATES OF NATURE				
		1	2	3	4	5
ACTS	I	a	a	b	b	b
	II	b	a	a	a	b
	III	a	a	a	a	a
	IV	b	b	b	b	b

Figure 6.

Figures 4, 5, and 6. Savage's postulates 2-4.

The fifth postulate goes still further in this direction by asserting, roughly speaking, that you can subdivide the set of states of nature as finely as you need to. This postulate then allows you, via a limiting process, to construct the judgmental probability for each pertinent state of nature. To make sure that this will work, one more postulate, the sixth and last one, excludes the case where all the acts are rated the same, so that there is indifference between any two acts. Taking those six postulates together, the notion of judgmental probability is now fully defined and has its own axiomatic foundation. This foundation is different from that of Kolmogorov's axioms of probability, inspired by the frequency notion in repeated trials, that underlie much of the thinking about probability in relation to the physical sciences. The present ideas have their own independent standing and relevance for the types of decision-related uncertainties that we are now discussing. In fact, the reasoning not only produces the existence of a numerical judgmental probability for each state of nature. It also associates a numerical utility with each consequence, in the sense that a most preferred act under the postulates is also one that maximizes the expected value of the utility of the consequences of that act, calculated by using as weights the judgmental probabilities of the states of nature that call forth these consequences.

That concludes this particular "module", and I will now go on to my last topic, that of allocation of resources. Figure 7 shows the form of the so-called linear model of technology. In a sense this is the simplest representation of production possibilities in a production system that allows one to discuss the allocation-of-resources problem in terms of specific production processes. I do not say that this is the most realistic model. But it does have a rather wide range of pertinence. In particular, the work on linear programming, mathematical programming, and process analysis is based in large on this model. The model has a long history in economic thought, but our present understanding was greatly helped by contributions from mathematicians, who are quite prominent in the list of its authors. In temporal order, I believe, I mention Léon Walras, John von Neumann, Wassily Leontiev (in the thirties), L.V. Kantorovich, George Dantzig--both of whom we are fortunate to have with us here--myself, and an increasingly widening number of other people. The basic notions are two. Along the top I list *processes*. Any one process is represented by a column of technologically given coefficients and, as a decision variable x_i recorded at the top of the column, the level at which the process is operated. Along the side I have *goods*, classified as outputs and as inputs, with minus signs for all the inputs and plus signs for the outputs. In general, one would also have intermediate commodities; iron ore would be transformed into pig iron, which then would be transformed into steel, which in turn would be transformed into useful

	PROCESSES AT LEVELS					
	x_1		x_i		x_m	
OUTPUTS						
y_1	a_{11}	$\cdots$		$\cdots$	a_{1m}	
$\vdots$	$\vdots$		$\vdots$		$\vdots$	
y_j = heat		$\cdots$	a_{ji}	$\cdots$		
$\vdots$	$\vdots$		$\vdots$		$\vdots$	
y_n	a_{n1}	$\cdots$		$\cdots$	a_{nm}	
INPUTS						AVAILABLE
$-z_1$	$-b_{11}$	$\cdots$		$\cdots$	$-b_{1m}$	$-b_1$
$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$
$-z_g$ = coal		$\cdots$	$-b_{gi}$	$\cdots$		$\vdots$
$\vdots$			$\vdots$			$\vdots$
$-z_h$ = labor		$\cdots$	$-b_{hi}$	$\cdots$		$\vdots$
			$\vdots$			$\vdots$
$-z_k$ = grate		$\cdots$	-1	$\cdots$		$\vdots$
$\vdots$	$\vdots$				$\vdots$	$\vdots$
$-z_p$	$-b_{p1}$	$\cdots$		$\cdots$	$-b_{pm}$	$-b_p$

Figure 7. Input/output table for the linear model of technology.

$$\hat{U} \equiv \text{Max } U\,(y_1,\ldots,y_j,\ldots,y_n)$$

subject to $x_i \geq 0$, $(i = 1,\ldots,m)$,

$$\ldots\ldots\ldots\ldots\ldots\ldots$$

$$z_g = b_{g1}x_1 + \ldots + b_{gm}x_m \leq b_g$$

$$\ldots\ldots\ldots\ldots\ldots\ldots$$

"Shadow price" p_g of input g is $p_g \equiv \dfrac{\partial\hat{U}}{\partial b_g}$.

Figure 8. Maximization of the utility function, and shadow prices.

things. I have left out the intermediate commodities. Just to indicate one possible use of this model, I will go to Figure 8 that defines an optimization in these terms: we maximize a utility function in terms of the final outputs subject to constraints. The first constraint requires the process levels to be non-negative (in accord with their natural definition). The second constraint says that, for all g, the total of the g-th input good required by the different processes, that is the linear expression

$$b_{g1}x_1 + \dots + b_{gi}x_i + \dots + b_{gm}x_m \quad ,$$

does not exceed the amount b_g of that primary input that is available. The maximization would be a particular application of the linear model. but not the only one.

There are different possible definitions of the objective function, and Kantorovich has given one of these. He takes as given the ratios in which the final outputs are to be produced and then maximizes the output of any one of these, the others to be proportional. That is a very interesting and precise definition. Another definition, which has been used more in connection with the market economies, is a utility function that increases continuously with each of its variables and is concave (or preferably strictly concave), which alleviates mathematical difficulties and is not too far out, I think, as an assumption.

Coming back now to the matter of communication problems among the professions, I want to use this model to make a few remarks on <u>energy analysis</u>. This is the name for a method of defining and estimating the energy content of different goods in the economy, which has been applied a good deal recently. The list of references includes a special issue of the journal *Energy Policy* that is devoted entirely to this line of work.

I would like to speculate a little about motivation and sources of inspiration for this work. The first law of thermodynamics, the conservation of energy, is the great intellectual experience of all physical scientists, and indeed of the citizen educated in science. It took centuries to be formulated, and when it was there it was a marvelous piece of insight into nature. This history has, I think, contributed to the formulation and motivation of "energy analysis". I would like to say that the primitive concepts of economics are different ones. They are as important in economics as energy and matter, electromagnetic equations, and so on are in physics. On the primitive concepts of economics one may differ, but I would list them as: 1) needs, desires, and preferences of consumers; 2) human labor, as a contribution to the production process; 3) primary resources, which may be exhaustible or renewable; and 4) technology. If I were required to give a list of four, this would be it. Energy as such is not one of those, but primary fuels occur under number 3, primary resources.

Now I would like you to join me in a thought experiment for which we go back to Figure 7. Suppose you have that kind of information, a big model, entirely on tapes. One tape contains the coefficients b_g and b_{gi}. Each coefficient b_{gi} is identified by the number i that labels the process and the number g of the good. Each availability b_g is labeled by g only. Then there is another tape that contains a printout of the labels and technological names of the processes, and a third tape that contains a printout of the labels and names of the goods. Due to somebody's carelessness, the last two tapes are lost in transportation. You still have the first tape, so you can print out, with the numerical labels of the processes and of the goods, a full table of coefficients in any form or sequence you want to. The question I ask--no, the statement I make--is that this printout contains all the analytical information about how the production economy can be made to do various things, except that the "things" are defined in terms of these labels and not in terms of explicit names of processes and goods. Still, the analytical apparatus has been preserved. The question I now put to you is: would you be able to recognize the energy commodities from a printout of that tape? I think you just might, because of the following characteristics of energy: a great deal of convertibility of one form of energy into another; also, a great deal of substitutability of one form of energy for another in various uses. So, if after the loss of two tapes you still have this information, you might from your general knowledge of technology be able to trace various forms of energy again, but you would have some difficulties. Labor would be a similar category. Many kinds of labor skills are convertible by retraining and substitutable by arranging the jobs differently. So energy is not unique in that sense. In fact, payments to labor make up a much greater share of the national income than do payments for primary energy.

Assume now that the missing tapes have been found. Then energy analysis takes the table and deletes all the primary input rows that are not energy in one form or another. Then, on the basis of the remaining information, the energy analyst traces the energy content of the various goods. I think the result is interesting and valuable. But there is a risk in doing that and no more, in the sense that one is thus led to think of energy as if it were the one and only scarce primary commodity. Economists have been reproaching energy analysts with creating what might be called an energy theory of value. Energy analysts have not accepted that reproach. They have said, no, we are just making a calculation in terms of energy alone. But since energy is not the one absolute scarce commodity to the exclusion of all others, wouldn't we therefore also want to take into account other primary factors?

The column in the center of Figure 7 represents a very simple energy process: heating your living room. By putting coal on the grate you produce heat, you use up coal, you apply your labor by carrying the coal up from the basement, and you also make use of the grate on which the coal is burned. You have two important non-energy inputs there: labor, and the use of a capital good. The point I want to emphasize is that for good allocation of resources one has to take account of all the important inputs to all the important processes. An example is the various alternative processes for producing or converting energy, which themselves have also been a focus of concentration for energy analysis--that special part of it has been called "net energy analysis". In that area there is also the practice of defining the "energy content" of electric energy in terms of the primary inputs of coal or water power or oil that has been used in producing that electric energy. This is appropriate, but one would also want the capital cost to be entered in there.*

How does one take these other inputs into account in a calculation that refers to some distant future for which there are as yet no market prices? Or even if the calculation refers to the present, but the prices either are administrative prices or, if they are market prices, are distorted by the exercise of market power (or, in an extreme case, monopoly)? Here I come back to optimization as either a description of the goal of good planning, or a description of the work of a really competitive market. Implicit in the idea of maximization is the notion of a shadow price. I want to define that concept, since you will have heard the term a good deal and perhaps wondered what it really is. I will not speak of duality theory involving quantities and prices represented in two different spaces. I will just give a definition which, barring particular mathematical accidents, is equivalent to the definition of the shadow price in terms of duality theory. Suppose I have successfully maximized the utility function of the outputs under the constraints determined by the availabilities $b_1,\ldots,b_p$. Then I write $\hat{U}$ for the maximum value of $U(y_1,\ldots,y_j,\ldots,y_n)$ attainable under the constraints. I then differentiate that maximum with respect to one of the availabilities. That derivative I define as the shadow price of that particular input. So now my recommendation with respect to the calculation of energy versus other inputs, in the absence of meaningful market prices, is to weight each of these inputs by its shadow price, and in that way get a notion of the relative importance of energy versus other inputs.

---

*Note added after the Conference: for a proposal to this effect see the paper by R. Turvey and A.R. Nobay, cited in the list of references (Energy Analysis).

Even if primary energy prices, market or shadow, were still to double or triple, I would think that other inputs taken together would quantitatively still be of substantially greater importance.

REFERENCES

1. CAUSAL ORDERING OF VARIABLES

Simon, Herbert A., Causal Ordering and Identifiability, Ch. 3 of Hood and Koopmans, eds., *Studies in Econometric Method*, Yale University Press, New Haven, Conn., 1970; reprinted in Simon, *Models of Man*, Wiley, New York, 1957.

Koopmans, Tjalling C., and Augustus F. Bausch, Selected Topics in Economics Involving Mathematical Reasoning, *SIAM Review*, 1 (1959), 79-148, Topic 11.1.

Girshick, M.A., and Trygve Haavelmo, Statistical Analysis of the Demand for Food: Examples of Simultaneous Estimation of Structural Equations, *Econometrica*, 15 (1947), 79-110; reprinted in Hood, William C., and Tjalling C. Koopmans, eds., *Studies in Econometric Method*, Yale University Press, New Haven, Conn., 1970.

2. IDENTIFIABILITY OF PARAMETERS

Thurstone, L.L., *The Vectors of Mind*, 1935, and *Multiple-Factor Analysis*, 1947, both University of Chicago Press, Chicago, Ill.

Frisch, Ragnar, Statistical versus Theoretical Relations in Economic Macrodynamics, mimeographed, 1938, prepared for a conference of the League of Nations held in Cambridge, England, to discuss the work of J. Tinbergen on business cycles in the USA.

Koopmans, Tjalling C., Identification Problems in Economic Model Construction, *Econometrica*, 17 (1949), 125-144, reprinted in Hood, William C., and Tjalling C. Koopmans, eds., *Studies in Econometric Method*, Yale University Press, New Haven, Conn., 1970.

Koopmans, Tjalling C., and O. Reiersöl, The Identification of Structural Characteristics, *Annals of Mathematical Statistics*, 21 (1950), 165-181.

Reiersöl, O., On the Identifiability of Parameters in Thurstone's Multiple Factor Analysis, *Psychometrica*, 15 (1950).

Lazarsfeld, Paul F., The Logical and Mathematical Foundation of Latent Structure Analysis, in S.A. Stouffer et al., *Measurement and Prediction*, Princeton University Press, Princeton, N.J., 1950, pp. 362-412.

Kalman, R.E., P.L. Falb, and M.A. Arbib, *Topics in Mathematical System Theory*, McGraw Hill, New York, 1969.

Casti, J., *Illusion or Reality?: The Mathematics of Attainable Goals and Irreducible Uncertainties*, internal paper, IIASA, 1976.

3. MEASURES OF RESILIENCE

Grümm, H.R., ed., *Analysis and Computation of Equilibria and Regions of Stability*, CP-75-8, IIASA, 1975; especially the presentations by P. Walter (pp. 47-65), H.R. Grümm (pp. 83-87), D.D. Jones (pp. 123-136), Yu. Rozanov (pp. 179-196), A.D. Bazykin (pp. 197-201), A. Molchanov (pp. 219-225).

4. JUDGMENTAL PROBABILITIES

Ramsey, Frank P., Truth and Probability (1926), in *The Foundations of Mathematics and Other Logical Essays*, Kegan Paul, London, and Harcourt Brace, New York, 1931.

de Finetti, Bruno, *Theory of Probability*, Wiley, New York, 1974 (translated from the Italian edition of 1970, drawing on previous work beginning in the thirties).

Savage, Leonard J., *The Foundations of Statistics*, Wiley, New York, 1954.

Raiffa, Howard, *Decision Analysis (Introductory Lectures on Choices under Uncertainty)*, Addison-Wesley, Reading, Mass., 1968.

5. ALLOCATION OF RESOURCES

Kantorovich, L.V., *The Best Use of Economic Resources*, Harvard University Press, Cambridge, Mass. (translated from Russian edition, 1959), 1965.

Dantzig, G.B., *Linear Programming and Extensions*, Princeton University Press, Princeton, N.J., 1963.

Koopmans, T.C., Concepts of Optimality and Their Uses, to appear in *Les Prix Nobel en 1975*, Stockholm, Sweden, 1976; to be reprinted in *Science* and the *American Economic Review*, 1976.

5A. ENERGY ANALYSIS

IFIAS Report on a Workshop on Energy Analysis and Economics, International Federation of Institutes for Advanced Study, Stockholm, Sweden, 1975.

Energy Policy, 3, 4 (1975), Special Issue on "Energy Analysis".

Turvey, Ralph, and A.R. Nobay, On Measuring Energy Consumption, *Economic Journal*, 75 (1965), 787-793.

Theoretical Aspects of Policy Studies

L. Kantorovich

The activities of this unique Institution have long attracted my attention. I believe that the uniting function of the Institute is its most important one. On the one hand, by considering various areas of application of systems analysis, the Institute unites within the framework of its projects scientists and practitioners of different fields; on the other hand, and no less important, it unites scientists and experts of different countries and even of different social systems, and so contributes to the synthesis of various scientific schools and diverse practical experience. One can only wish IIASA every success in its promising activities.

Elaboration of the general aspects of the development problem in systems analysis is topical and interesting. While systems theory itself is still in its beginnings, systems analysis cannot be done using purely theoretical concepts. To make it realistic, more meaningful, and applicable, it should be based on the generalized experience of specific and advanced fields of knowledge and activity. Therefore, investigating economic systems, apart from the knowledge we gain about the systems themselves, enhances our knowledge of the methods of systems analysis in general.

Economic systems are distinguished by their extreme complexity and diversity. For example, while a mechanical system has, as a rule, a definite dimension (the number of degrees of freedom), the dimension of an economic system is in general indefinite: it depends on the form of aggregation. The variables can be continuous or discrete: the economic system is simultaneously controllable and autonomous, and is inertial; the processes may be deterministic or stochastic.

These factors created great difficulties in system description, modeling, and research, but they generated extremely diverse approaches to analysis. The economic problem can serve as a touchstone for new systems methods and concepts.

An important stage in analyzing a complex system is the model description. An adequate model can provide substantial means of discovering system peculiarities, predicting reactions, and constructing an effective controlling mechanism. At the same time, the inevitable inadequacies of the model as a description of the real system always leave room for criticism and an a priori doubt about the conclusions of the analysis. That is why some verification criteria are necessary. An effective means for obtaining these is to construct a series of more precise models incorporating a greater number of factors or using different modeling principles. Even the simplest models can lead to valuable conclusions; and though the resultant quantitative characteristics may greatly differ from the real ones, they can express correct relations, adequately reflect the character of dependence, and the like. This is confirmed by modeling experience in physics and engineering sciences.

An illustration is the development and application of the static and dynamic optimal economic models. The linear discrete dynamic economic model is based on the assumption that the economy consists of elementary production processes (or activities after Koopmans). In such a process, at any given period of time some ingredients (products, resources) are consumed in pre-set amounts, and others are produced. Assuming that the economy is linear, its development is characterized by the intensity of activities. These activities are subjected to constraints which, together with the optimality criterion, determine the system's outcome. These models proved to be, to a large extent, a universal and efficient means of describing the functioning and development of economic systems related to various branches and different levels of an economy.

Besides the general system of an economy, we may also mention, for example, dynamic models related to the following problems:

- Planning of development and allocation of an industrial sector;
- Optimal fuel/energy balance;
- Development of an ameliorated agriculture system;
- Rational use of equipment, and structure of amortization payment.

Analysis of these models by mathematical programming and other techniques has given effective means for planning and has led to important conclusions of a qualitative nature. These conclusions concern the meaningful characteristics of a system as well as its relations to its subsystems and to outside systems. For the socialist economy, this analysis led to insights into the price system and resource evaluation. These characteristics also relate to the possibility of hierarchial organization of the management of a complex economic system. Thus the analysis deals with the dynamics of evaluations, and its use in the estimation of investment effectiveness. Moreover, such an analysis also provides valuable means for decision-making in the process of design, for economic comparison of alternatives, and for the assessment of prospective impacts.

Special emphasis should be placed on the importance and urgency of these problems in the context of a socialist economy, especially of our country. In Western countries economic criteria and economic practice were formed over centuries. By contrast, the problem of scientific centralized management of the economy, when the means of production were concentrated and socialized, emerged abruptly. Planning was done not as a supporting regulatory tool but as a most essential component of economic activities.

Hence, scientific analysis of economic indicators based on optimization principles was of great significance; it refined and improved the concepts and methods of calculating these indicators and made it possible to make a number of important practical decisions in the USSR and other socialist countries.

Along with the model described, other meaningful models of economic dynamics are used. The first is the classical von Neumann model of a developing economy. It was on the basis of this model that the first conclusions on the efficiency rate of investments were made. Subsequent asymptotic analysis of dynamic systems confirmed these conclusions and allowed their extension to more realistic models.

Asymptotic analysis resulted in some interesting conclusions, such as the existence of an objectively determined growth rate, turnpike theorems (stating that optimal transition from one state to another over a long period takes place mainly along or near turnpikes). One can expect that they may prove to be applicable to the development of more general systems as well.

In order to make the description of an economic system more realistic, modeling must be enriched with new techniques. The linear static and dynamic models of an economy and the linear programming approach are complemented by advanced techniques of convex, nonlinear, integer, and stochastic programming. I should like to mention the interesting studies showing that most conclusions about valuations in linear, deterministic systems hold for stochastic systems as well. A significant contribution was made to the analysis of stochastic systems and the methodology of stochastic programming.

Comparison of alternatives and options in the linear model on the basis of evaluation assumes that possible deviations in ingredients are relatively small. In analyzing greater interferences in the system and incorporating large-scale objectives, specific methods have to be elaborated. In some cases these are methods of discrete analysis. Pattern-type modeling serves the same purpose. This program method does not oppose general linear methods such as the Leontiev model and other complete models; it is complementary rather than being a substitute.

New problems--for example, ecological ones--stem from the scientific and technological revolution. These are most difficult as a rule, since they are characterized by complex interconnections and demand new information that is often lacking.

The most urgent issue requiring new methods of analysis and attracting great attention by researchers is the analysis of scientific and technological progress. This analysis includes both the investigation of general progress and the assessment of particular innovations, taking account of feasibility and spread rates, as the basis for decision making.

With dynamic evaluation systems the effects of implementing various innovations can be determined. However, the necessity for forecasting the relevant data makes these models hard to apply. Perhaps more productive is the approach based on aggregated information and statistical characteristics revealing the dynamics of costs and the effect of introducing and spreading innovations. More account should be taken of the contribution of each particular innovation to overall technological progress. Without this, it is impossible to find the best solution to the problem of evaluating and introducing innovations, and determining optimal principles of financing and price policy.

Continuous development models that are described by differential and functional equations are used for analyzing the same problem. Also interesting is the attempt to include technological progress endogenously, and to use the technique of optimal management control.

One of the means of considerably improving evaluation of the impact of technological progress is the adjustment of models to account for the structure of funds, and the change in its spectrum through development of the system.

The variety and complexity of problems related to the further elaboration of the theory of economic system development, and the growing requirements for analysis, present us with the task of further refining models of developing economic systems and techniques of investigation.

The Systems Approach to Solving National Economic Problems

H. Koziolek

INTRODUCTION

In this presentation I will discuss only a few selected aspects of the systems approach applied to the national economy of the GDR. I shall concentrate on how that approach works or is going to work in our economy, using a few current examples such as housing. But first I should like to say a few words about the substance of the systems approach as we conceive it, and the conclusions that can be drawn at present, from the point of view of one who works on the border between economic science and practice.

In dealing with economic problems at the national level, we are confronted with complex social systems that are of a higher order than technical or natural systems. They comprise characteristics of technical systems (feedback mechanisms, hierarchic structure, self-organization) as well as other characteristics. The systems approach here is something of an abstraction, because the economic problems to be solved are inseparably linked with the continued development of socialist economic integration, the international division of labor, and world trade in general. To us the systems approach means planning the development targets of our socio-economic system by bringing them into accord with the most efficient use of the limited resources available. The decisive instrument of the systems approach is thus planning and its evolution. It includes the use of mathematical methods of systems analysis, although these are not the only means of improving politically determined decision and planning processes. Input/output analysis, linear programming, and the like thus serve as a basis. We are trying to extend mathematical modeling to ever larger areas; in this connection, I have been much impressed with the close relationship between mathematical modeling and planning in the Bratsk-Ilimsk case studies.* Where this is not yet possible, we are using other methods for taking significant factors and relations into account in decision-making. The systems approach means methodological diversity rather than one-sidedness. This is also a condition for assuring the necessary complexity in real-life decision processes.

---

*See H. Knop, this volume.

A major concern of systems analysis is to take adequate account of objective societal relations, the selection of goals, and the choice of appropriate means for attaining those goals. In our socio-economic system the central decision is the choice of a strategic orientation for the development of the whole system; this applies to the main goals as well as to the means of changing the system. That orientation is "...the further increase in the material and cultural standard of living, in the creation of conditions conducive to the all-round development of the personality on the basis of rapid development of socialist production, in increased effectivity, in scientific and technical progress, and in the growth of productivity" [1, p. 139]. With this decision on the principal task for the further development of socialist society, in coordination with other socialist countries, the main premise is given for the systems approach over a long-term period. Its realization requires the setting of priorities and preferred objectives within the framework of the political organization of socialism.

Decisions on the development of all subsystems are coordinated so that balanced development is ensured. The decision process is very complicated, because a large number of interrelated decisions must be made; different time horizons must be considered; many interests, indexes, and decision criteria must be balanced against one another; and the uncertainty of information must be taken into account.

The planning and decision process is an iterative one. This is illustrated by the planning system of the GDR (Figure 1), which has the following main components.

- *Forecasts* of social processes, particularly socio-economic and socio-political one, of scientific-technical problems (to reveal new possibilities in natural science and technology), and of social and economic processes, such as development of individual elements of the socialist way of life, demographic problems, price and market studies. These long-term studies are closely associated with analytical work.

- *Long-term planning*, which acts as strategic instrument of the State for national social development. Work here is concentrated on the basic design of the elements of the socialist way of life, on priorities in science and technology, on the development of the skills and qualifications of workers, on securing the energy and raw-material basis of the economy, and on changing the long-term economic structure so as to increase its effectiveness significantly.

- *Five-year planning* as the main instrument for the continuous balancing of the branches of the national economy as well as for that of the regions. All the principal processes of societal activity are stimulated by the five-year plan.

- *Annual planning*, which defines the five-year plan in accordance with the results of the past period and on the basis of new findings, and which serves as the direct means of realizing the objectives.

- *Selection of possible solutions* based on forecasts, which is the cardinal problem of planning. The findings from forecasts must be transformed into statements that can be quantified subject to national economic standards and restrictions. Programs relating to the national economy have proved their worth as methodological planning instruments in the GDR. They are drawn up for those targets that have a high degree of economic interdependence and are of strategic importance for developing the working and living conditions of the people (such as housing, and assuring adequate energy fuels and raw materials).

The quality of the target decisions depends largely on careful investigation of the overall social system and its subsystems. This implies scientific analysis of the present and anticipated needs of the people; of the national economic structure, socialist economic integration, and international cooperation; of the technical, technological and natural resources of countries; and of population development (the societal work potential and its qualification structure, the development of the sciences into a direct productive force, the political aspects of international relations, and the like).

The purpose of this approach is to ensure a demand-structured growth of the national income. This is a decisive criterion of economic growth and the condition for developing a socialist way of life.

This paper focuses on the scientific determination of targets, demands, and resources--the most important decision problems of economic and social policy.

SOCIETAL PREMISES FOR STRATEGIC GOAL DETERMINATION

A cardinal task of the systems approach to solving economic questions is the adequate consideration of the dialectic relations between aim and means. For the socialist society, "the economy is the means to an end, a means for the ever greater satisfaction of the growing material and cultural demands of the working people" [2, p.39]. A complex decision orientation for both the dynamics of the economy and the structural balancing of the different spheres of the socio-economic system is thus established (Figure 2). In practice, this means treating economic and social policy as one entity and taking (societal and individual) demands as the starting point for economic planning.

The reality of the social targets depends primarily on the material production capability. The socialist economy is always

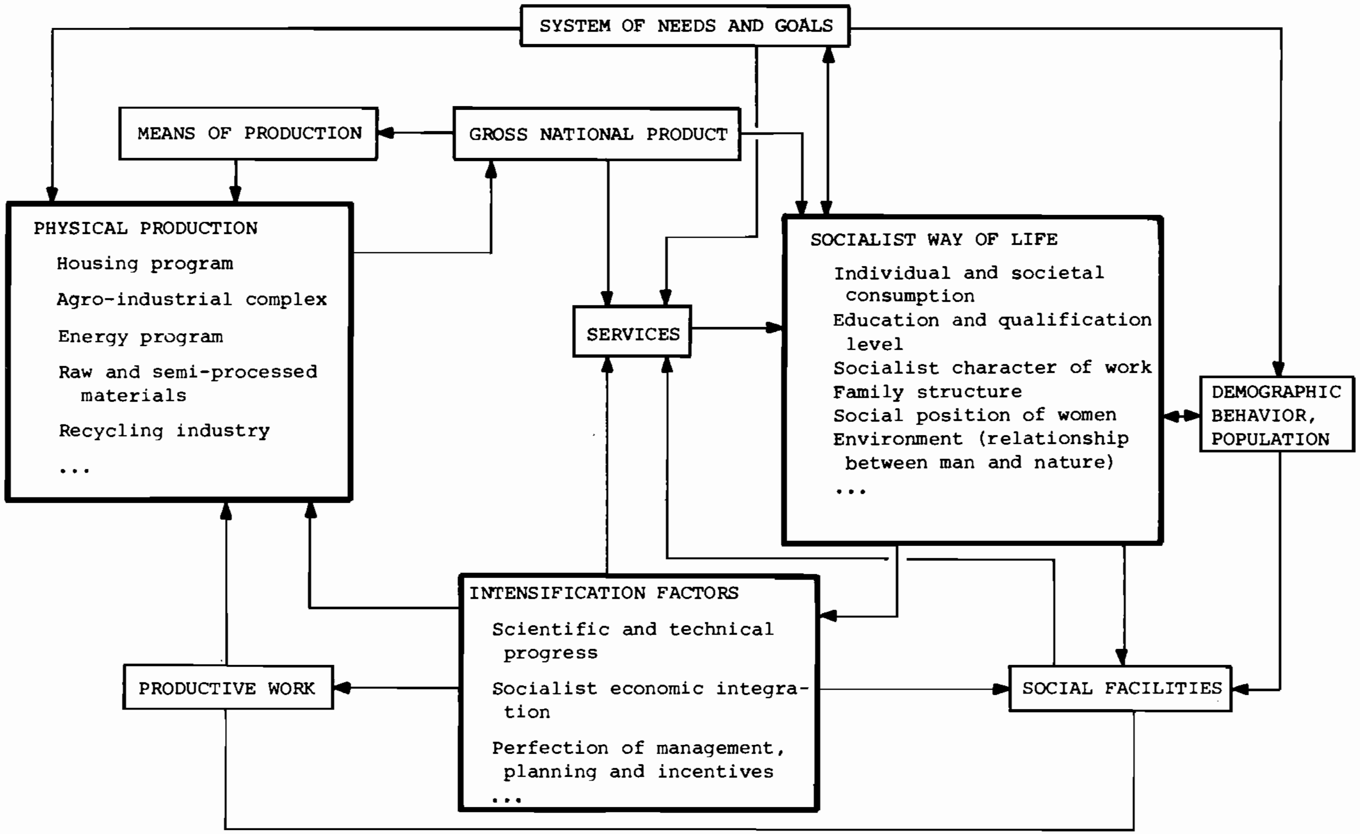


Figure 1. Reproduction system of socialist society.

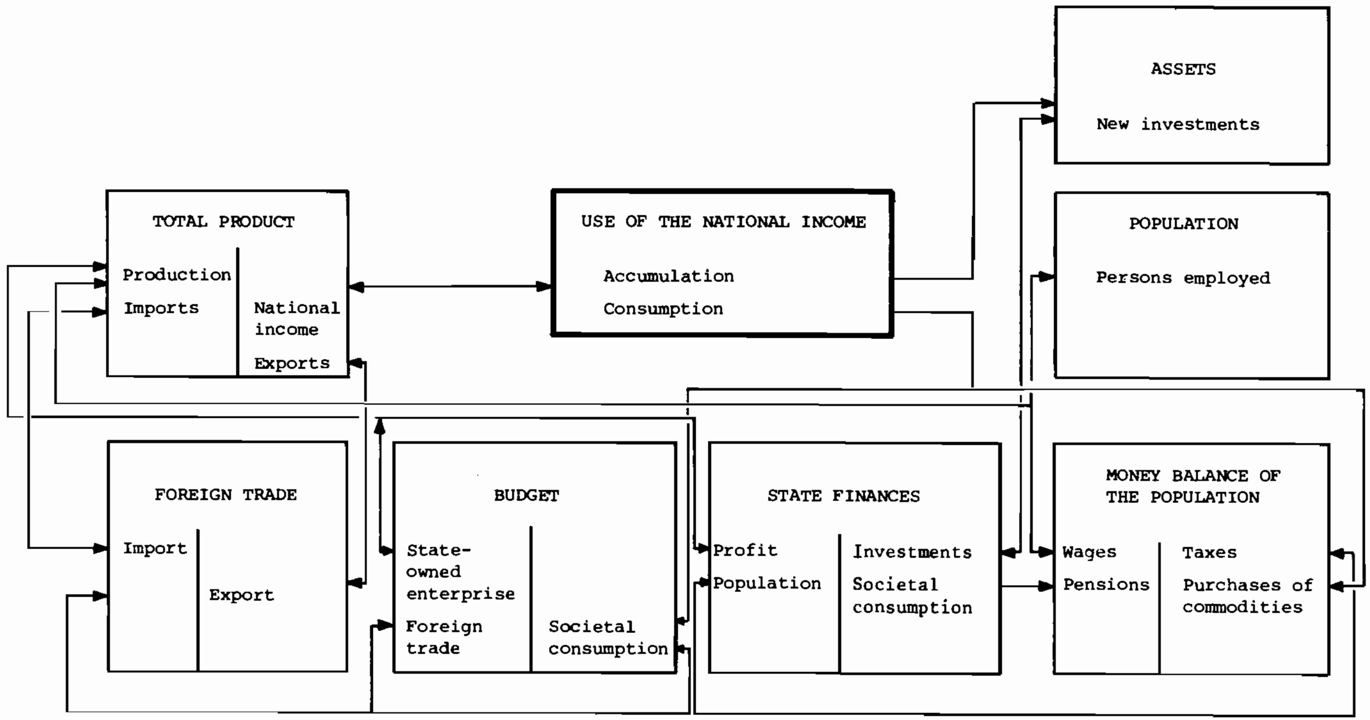


Figure 2. Relationships between the economic balances (selected items).

performance- and growth-oriented, independently of current economic trends; growth is essential for increased prosperity and standard of living. A long-term, stable increase in national income is decisive for assuring and further developing the achieved standard of demand satisfaction, expanding the non-productive spheres, and extending the necessary investments in the productive spheres.

Well-known causes--price development on the world market, raw materials, energy, and the environment--have changed the conditions for growth. The result, also for national economic systems, is that still higher demands are made of the productivity and effectiveness of labor. The main issue here is the linking, in conformity with the system, of scientific and technical achievements with the consciously determined, balanced development of all subsystems. In the GDR this process is indivisible from intensified utilization of the qualitiative factors of economic growth, that is, intensification of production. It requires decisions to generate the national economic end-product and the national income to meet demand with the lowest possible effort. At the same time, intensification must take place such that greater efficiency of labor and greater job satisfaction form an integrated whole. This is a decisive measure for uniting rationality and humanity in social activity that corresponds to the design of the socialist nature of work.

These relationships underline the fact that effectiveness calculations cannot proceed from a single element of the production process; rather, the basis must be the overall system embracing the production, distribution, and consumption cycle. Specification of the objective function of economic planning --including substantiation of priorities and preferences--is of great importance here. Neither abnormally low consumption nor a consumption cult is an aspiration of socialist society. Instead, the aim is to develop and satisfy the demands corresponding to the all-round harmonious development of the personality. The laws governing the development and satisfaction of demands is therefore of fundamental importance for solving national economic problems. This applies to decisions on:

- The relationship between the manufacture of capital and consumer goods,
- Investments in relation to consumption,
- The relationship between production of material goods and the services industry,
- The relationship of societal and individual consumption funds,
- The relationship of monetary and commodity funds.

We regard the elaboration of targets and tasks for the demand spheres of individual and societal consumption and productive consumption as a significant way of achieving greater comprehensiveness in planning (Figure 3). This includes working conditions, nutrition, housing, clothing, culture, health, communications, recreation, and sports, all important basic necessities of the people. The demands of productive consumption include raw and semi-processed materials, fuels, energy, mechanical engineering, preservation of the environment, and water economy. These demand areas are interdependent. It is the task of systems analysis to examine all the demands and prepare the necessary decisions. Various methods are used, including qualitative structuring of the dependency of demands on other factors; functional analysis of the relationships between demand areas; mathematical-statistical methods--extrapolation, multiple regression, elasticity functions, factor analysis--to quantify demands and their interdependencies; demand research, interview and evaluation, forecasting, and so forth.

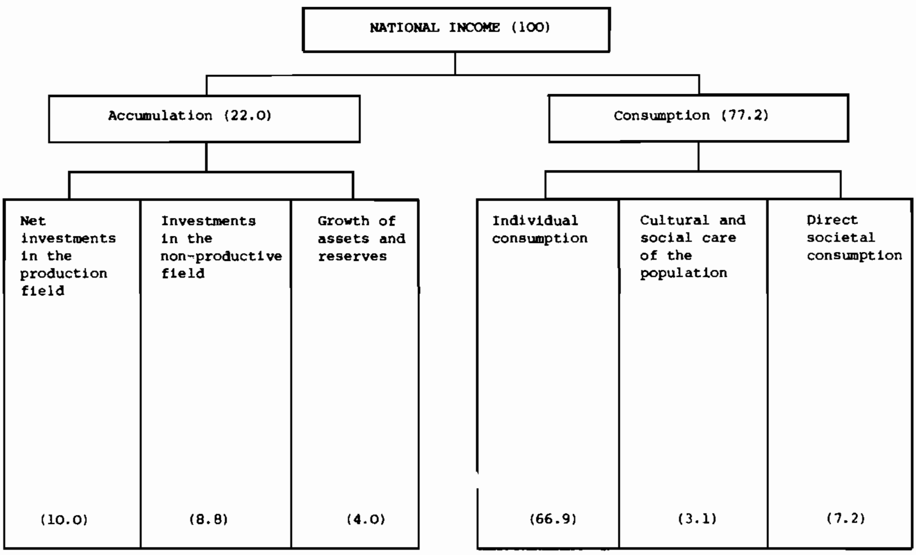


Figure 3. Distribution of national income of the GDR in 1974.

One decision problem consists in identifying the most effective use of available means and resources for attaining the socio-political aims. The priority and sequence of demand satisfaction must be established and the necessary expenditure proportion considered, including determination of rational forms of satisfying demand. Such an approach corresponds to the criterion of socialist society that provides for the planned creation of a uniform social organism--the harmonious development of all spheres of the social system. Goal preferences worked out for the GDR envisage, for example, priority for meeting the demands of the working class, full employment, solution of the housing problem at stable low rents, improvement of working conditions, an increase in the material and cultural standard of living, and maintenance of stable prices and tariffs.

These aims can be achieved only by a growth-oriented economy. Here, the part of the overall system that most decisively influences effectiveness and offers the best possibility satisfaction of demand had to be identified: solution of the housing problem.

THE HOUSING PROGRAM

The housing program is of central importance in the social development of the GDR up to 1990. As a result, the premises and subsequent decisions are set in social dimensions (see Figure 4). Based on forecasts and analysis, the objective of the program has been formulated as follows: "...satisfaction of housing demand by building and reconstruction of dwellings in the context of the urban infrastructure, by social and community facilities, and by satisfaction of the demand for consumer goods to furnish the dwellings...". The aim is that every household have its own accommodation by 1980 and receive accommodation conforming to its social requirements by 1990-2000. This objective, considered here as an example for other targets in demand-oriented national economic programs, illustrates the main aspects of the way in which these are elaborated.

The central position of the housing program results chiefly from the complex character of demands in this sphere. Such important social needs as recreation, education, information, interpersonal communication and individuality, and the efficient organization of housework converge here. The substance--socially effective and economically tangible forms of demand satisfaction--promotes the well-being of people in society. Thus, the solution of the housing problem has a feedback effect--on increasing work productivity and motivation, reduced manpower fluctuation, population growth, and the like--which influences the system as a whole as well as all its parts. The housing sphere also determines future social structure, the content and way of life of future generations. Sociological consequences result also from the ratio of newly built housing to modernized old houses. Simple extrapolation of current demand has proved to be inadequate for solving these problems. Future requirements can be met only by considering the current economic potential and the real resources of society. Implementation of the GDR housing program so far has shown that effectiveness can be significantly increased if the systems approach is applied. Soviet experiences in program planning have been valuable in this connection. For example, it was necessary to calculate carefully within which period the housing problem could be solved with existing resources, and to what extent and what standard of quality the appropriate steps

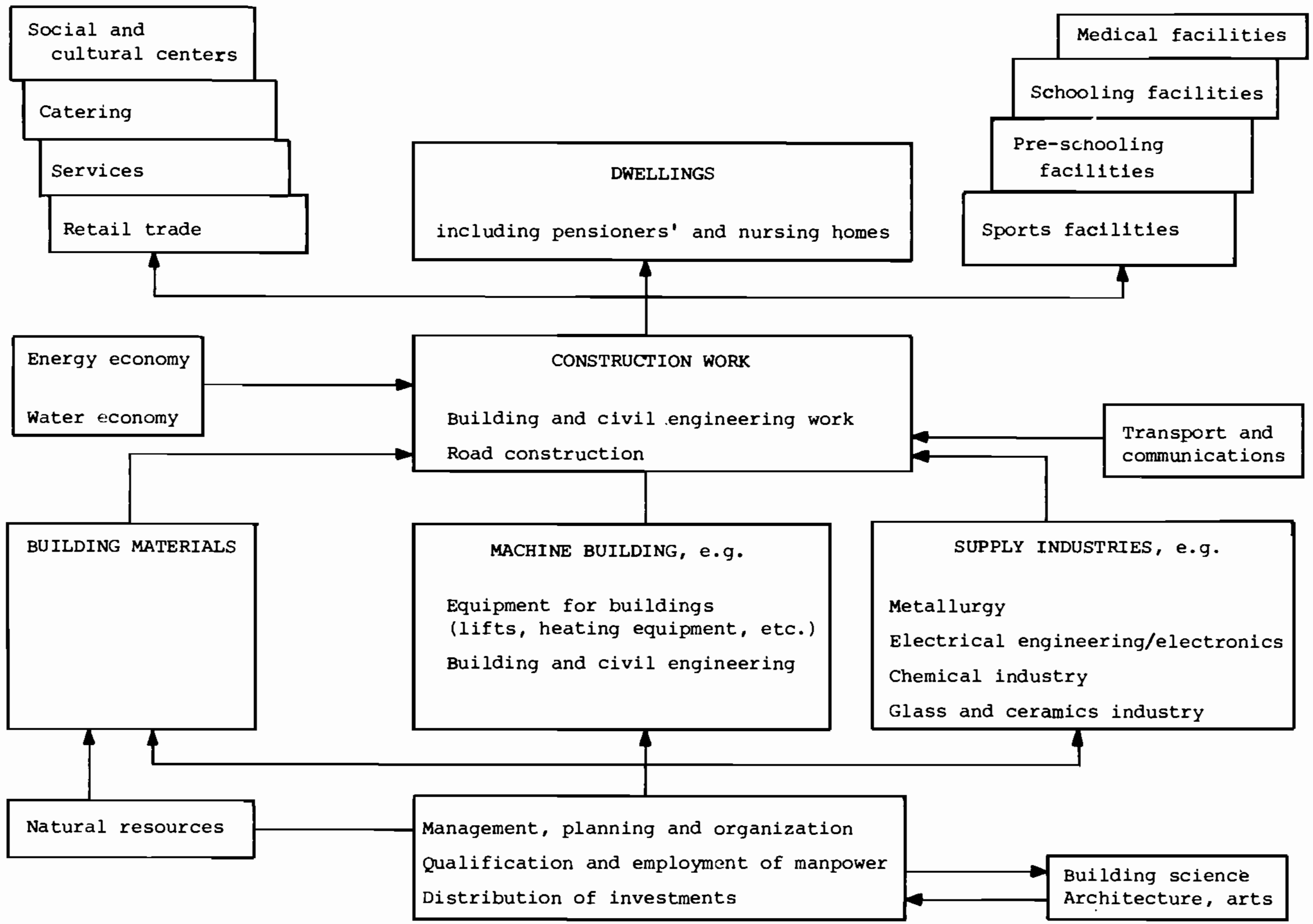


Figure 4. The comprehensive housing program.

can be taken in each five-year planning period. This also involves systems analysis of subsequent decisions for other fields and branches. Input-output analysis was used to calculate the variants.

Upon commitment of extensive material and financial resources for housing depend the following scientific, technical, and economic decisions:

- The planned supply of manpower, particularly through vocational guidance, increased training capacity, and balanced regional mobility of skilled labor;
- Assuring the necessary scientific lead time for introducing modern technologies;
- Extension of capacity of the building materials industry;
- Balanced development of infrastructure, services, and social facilities;
- Fulfillment by the furniture, electrical-appliance, and textile industries, and other branches, of the requirements resulting from mass demand for modern furnishings.

RAISING THE MATERIAL AND CULTURAL STANDARD OF LIVING

In general, it is important to substantiate a decision on the distribution of consumption funds--that is, increasing incomes when prices are stable or when they are changing. It is obvious that, depending on the decision, different social groups will be affected, the satisfaction of different demands stimulated, and the development of productivity promoted to different degrees. With increased performance, the means that influence the standard of living of the population via societal funds also expand (Figure 5). About one third of the real income of wage and salary earners comes from this source. A significant advantage of societal consumption funds lies in the fact that they are largely employed in a demand-related manner--for instance, to maintain stable consumer prices, low rents, and low tariffs for services and transport, and to satisfy housing demand and cultural, intellectual, and health requirements. At the same time, social differences among population groups are diminished by the societal consumption funds, and certain forms of satisfying demand are promoted.

Of special importance are the long-term decisions that must be made concerning the material premises for satisfying the growing demand and their dynamics. The economic and social aims and effects, and the necessary premises, are illustrated using the area of nutrition (Figure 6).

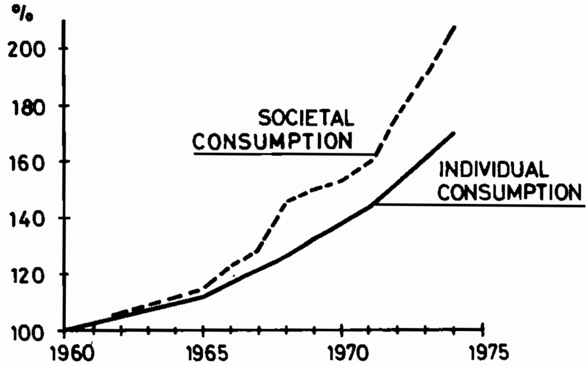


Figure 5. Development of societal versus individual consumption funds.

ECONOMIC GROWTH, SOCIAL REVOLUTION, AND POPULATION DEVELOPMENT

A decisive factor in designing a social systems is the standard of education and qualification of the labor force. That level reflects the fact that the education problem cannot be considered only from the standpoint of current economic needs, but comprises questions of the way of life, professional training, and cultural education. This progressive trend is underlined by a comparison of age groups (see Figure 7). Only 44.5% of those between 55 and 60 are skilled workers (have completed vocational training), while the figure for those between 25 and 30 is 79.9%.

A historical disproportion in qualifications between the sexes (see figure) is also being adjusted. This development illustrates the further enhancement of the social position of the woman, whose contribution has become an inseparable part of economic and social life in the GDR. (Nearly half of all persons employed in the GDR are women. This equals an employment rate of over 84% of all women.) It is for this reason that the greater reconcilability of the occupational and social activities of women with their tasks as mothers and within the family is of direct economic and socio-political importance. Decisions in the household sector are closely linked with the growth and structure of the gross national product and the distribution of the national income, and undoubtedly influence also demographic behavior. Without going into the socio-economic determinacy of the population law in detail, in the experience of the GDR, its connection with economic and social policy is indisputable. Attention is being given to further stimulation of the birth

Requirements	NUTRITION		
Means to satisfy the requirements	Consumer goods	Individually paid	Stocks of commodities of retail trade
		From social funds	Food subsidies
	Services	Individually paid	Restaurants, canteens, school meals
		From social funds	Subsidies from State and enterprises
Requirements for capacities and investments	Consumer goods industry		Frozen foods, prepared foods
	Services industries		Restaurants, school canteens
Changes in use of available time	Working time		
	Time for domestic duties		Less time for preparing meals
	Free time		Two hours more free time per week
Effect on standard of living			Health Sickness level Catering for school children

Figure 6. Effects of decisions in the nutrition sphere.

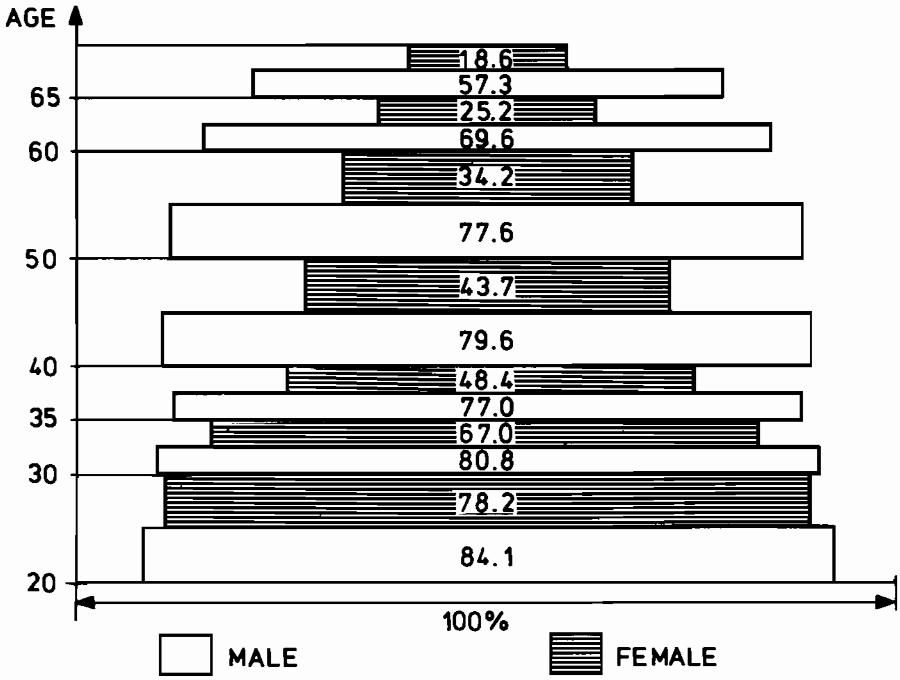


Figure 7. Professionally trained manpower in the GDR, 1971.

rate. The achievement of a normal population distribution is not only a condition for future economic growth; research into the dynamics and statics of population structure is important for establishing demand tendencies and for forecasting and planning of the labor potential with its qualitative, quantitative, and regional interdependencies.

The health of the population is a sensitive barometer of the standard of living. The maintenance and improvement of health is not only a personal desire of the citizen but also part of societal wealth. It corresponds to the basic humanitarian principle of socialist society that the State assumes the responsibility and cost for health protection. This is shown by the growing satisfaction of specific demands in all stages of life from birth to old age, and by social and medical care tailored to different population groups. Along with continued improvement in medical care and medical equipment, social medicine is gaining in importance: interdisciplinary research into the complex interactions between scientific and technical progress, standard of living, and health. Decisions in this sphere presuppose a systems approach that takes material resources and health education into account.

INTENSIFICATION AS THE PRINCIPAL MEANS OF ECONOMIC GROWTH

The decision for intensification is primarily one for driving ahead scientific and technical progress and for consistent rationalization and reconstruction of existing enterprises. This includes the creation of new production capacity in conformity with the need for a balanced development. Under socialist conditions we attach importance to perfecting management, planning, and incentives so as to provide favorable conditions for the creativity of producers, for the more effective organization of production, and for utilization of the advantages of the international division of labor.

A major condition for economic growth lies in the ability to supply the national economy with raw and semi-processed materials to meet growing demand. In the GDR we see the solution in creating favorable relations between the possible increase in raw-material supply and the improvement of the material economy. Science and industry must make a significant contribution here. With the help of input-output analysis, we have investigated how expenditures are currently distributed and where the focal points are for increased effectiveness. Using the systems approach, we are examining in detail the sequence of production processes, from raw materials to end products (consumer goods and capital equipment). To make full use of a resource-conserving approach, an entire system of measures is necessary, including a stable high quality of products and their parameters, particularly performance specifications and an improved performance/weight ratio. Optimization techniques are used for decisions on the use of materials and for optimal product design. Also involved are basic decisions on changes in the economy directed toward the use and centralized manufacture of semifinished products and components of plastic or other substitution materials and toward the increased use of secondary raw materials and industrial wastes. The task of establishing a recycling industry must be solved by interlinked measures in the fields of research, technology, collection, and storage.

It is known that the development of the energy economy plays an outstanding role in intensive economic growth. In the socialist economy implementation of a long-range program to assure a balance between energy production and growing demand presupposes numerous national and international decisions. This decision area includes such basic problems as optimal utilization of domestic energy resources and selection of optimal technologies in terms of consumption, investments, and running costs. A system of mathematical models (Figure 8) is used for systems analysis of the energy economy and for substantiation of decisions. The system already presented at IIASA* demonstrates the practical relevance of the ideas of Kantorovich, Koopmans, and others.

---

*See W. Häfele, this volume.

An important and complex sphere of social development in the GDR is the planned formation of a socialist agro-industrial complex (Figure 9). With industrialized methods of production and

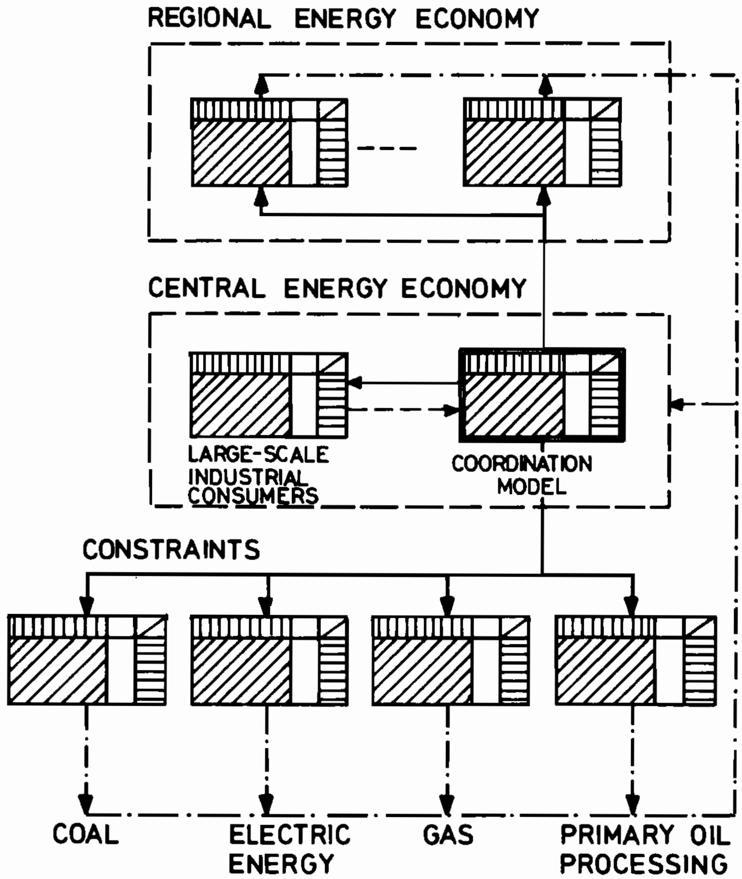


Figure 8. Model system of energy economy.

processing of agricultural products, we are trying to improve still further the supply of food for the population, and raw materials for industry, from our own agriculture. This is a fundamental alternative to an imported supply and the associated development of an export potential. Various methods of systems analysis--for instance mathematical-statistical methods, input-output analysis, linear programming--are used for substantiation of decisions relating to the agro-industrial complex. Detailed input-output balances for animal and plant production exist in the GDR. All these methods are aids in working out measures that are economically balanced for all the interlinked branches of the economy involved through the means of production, direct production of agricultural raw materials and products, and marketing. Creating the material basis for the agro-industrial complex on the national scale requires the planned interconnection of such branches as farm machinery construction, the chemical industry, the building industry, water management, energy supply, and transport. Along with the larger dimensions and new organization of labor, the character, substance, and conditions of work also change, and living conditions are transformed so that they gradually approach those in the urban areas.

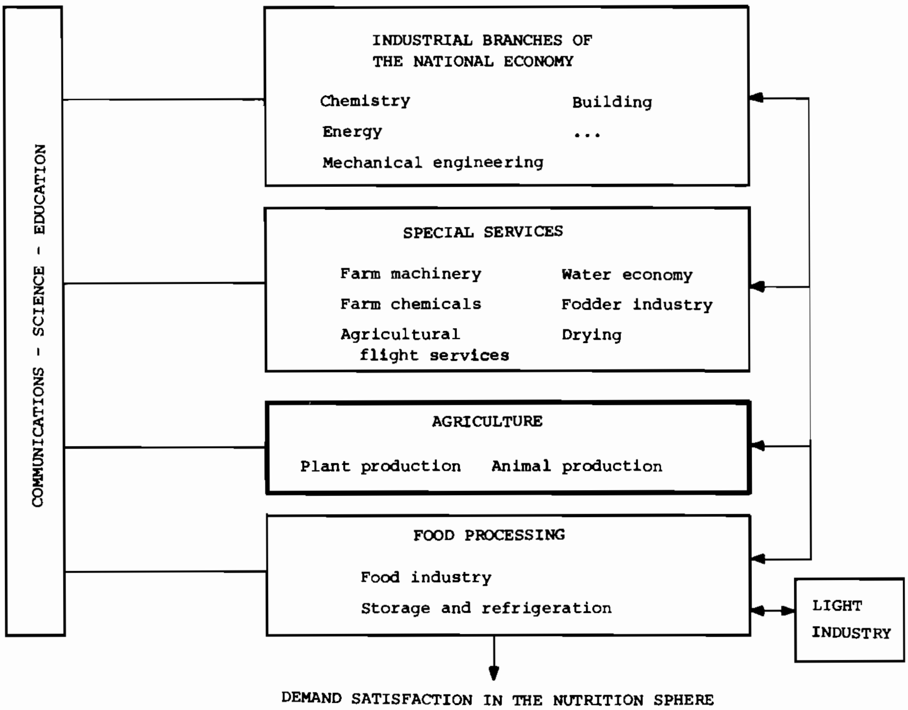


Figure 9. Agro-industrial complex requirements.

An important problem in industry and other spheres is the protection of the natural environment. The reduction and elimination of natural environmental damage is expensive, but is nevertheless a primary motive and aim of production in our country. Our decision alternative lies in using R&D and investments in such a way that qualitatively new technologies are applied on an intensified scale, ensuring economic utilization of pollutant-free raw materials in order to restore natural conditions. In certain fields it is possible to use materials with virtually no waste by applying closed material cycles; but this presupposes an interaction at the enterprise and branch levels beyond the barriers of spheres of competence, even beyond the borders of countries.

We hope to gain further scientific input for practical decision-making from the cooperation within IIASA in this and other fields.

References

[1] *Programm der Sozialistischen Einheitspartei Deutschlands* (draft), Dietz Verlag, Berlin, 1976.

[2] E. Honecker, *Bericht des Zentralkomitees an der VIII. Parteitag der Sozialistichen Einheitspartei Deutschlands*, Dietz Verlag, Berlin, 1971.

Systems Analysis and International Organizations

J. Lesourne

INTRODUCTION

If we consider applied systems analysis as operations research fecundated by general systems theory--obviously an oversimplified definition--we must recognize that its origin brings us back to World War II and the immediate post-war period, and that, for a long time, it was almost exclusively at the service of national decision makers: ministers, top civil servants, military chiefs, corporation executives, heads of regional or local communities, and the like. But in recent years, a significant change has taken place. Applied systems analysis (ASA) has begun to be a very important subject of international cooperation. IIASA is the most conspicuous example of this trend, but it is only the brightest star of a galaxy. The Club of Rome reports were already international in character; the United Nations Organization and its various agencies have laid more and more emphasis on systems analysis; the Commission of the European Community has launched a systems study on "Europe plus Thirty"; the Organisation for Economic Cooperation and Development has just initiated a project on "the future development of advanced industrial societies in harmony with that of the developing countries"; and a much longer list could be quoted.

Recognition of this exploding phenomenon immediately raises certain questions that are of general interest, but that may also prove essential in connection with IIASA. They are the following:

- Why is systems analysis developing so fast at the international level?

- How should the relations between national policy makers and international teams in applied systems analysis be conceived?

- What does this imply for the management of big international projects?

- How is the evolution of systems analysis to be mastered at the international level?

In considering these questions, we must keep in mind that many systems analysts, despite what they say, are not really interested in a dialogue with policy makers. They are in fact interested in knowledge, in how a system works; and they are interested in playing at the game of policy-making. Thus in practice they probably underestimate the basic problems of policy-making.

Throughout the discussion, the useful dichotomy introduced at IIASA between global issues and universal issues will be maintained.

INTERNATIONAL DEVELOPMENT OF ASA

The development of ASA at the international level implied a positive decision--or, at least, an absence of veto--by many national decision makers. So it is important to understand what their reasons may have been.

Of course, sometimes these reasons may have been, so to speak, *technical*, corresponding to the hope of acquiring at low cost knowledge that others have developed at a higher level. In this case, universal issues are potentially as interesting as global issues. But I believe that this managerial attitude is far less widespread than the recognition of a *political* need for international cooperation in ASA. The depth of this recognition of course depends on a real understanding of the nature of systems analysis.

For some, who do not really know what systems analysis is, what is essential is to promote international cooperation so as to decrease possible tension between countries; and after all, systems analysis is as good for that as any other field. For others, a clear consciousness of the global issues facing the world is a daily fact. Problems related to population, energy, food and agriculture, location of industrial activities, have to be studied; and since they are global, it is obviously necessary to complement national efforts at the international level.

I would credit with more profound insight the policy makers who have perceived that these global issues have to be studied in different places--within United Nations agencies, at IIASA, at OECD, within the European Community, and so on--because the way in which these issues can be studied depends on the similarities in or differences between the national societies financing the research. Hence, to each international organization correspond specific biases and taboos. For instance, the great interest--but sometimes also the limitation--of IIASA is that it is common to advanced societies of both East and West.

Finally, there is a small set of policy makers who have a clear picture of what ASA is. They realize that the elaboration in common of studies aiming at better decision processes is an effective way of improving the identification of conflicts and tensions within the world; and that, with the production in common of basic information on the global issues involved, it is a way of progressively changing national attitudes toward the solutions of these issues. This attitude transfers to the systems teams in international organizations a huge responsibility to maintain interest in and understanding of their work, and underlines the importance of the relations between international ASA and policy makers.

INTERNATIONAL ASA AND POLICY MAKERS

At the dawn of applied systems analysis, relations between the research team and the policy makers were conceived in a simple and rather naive way. One day, a policy maker must take a decision (unique or repetitive). He tells the research team what the problem is and formulates his objectives. The research team enumerates the constraints, defines the feasible solutions, describes the consequences, evaluates them with respect to the objectives--all this with the help of a suitable model of reality. During this process, the policy maker waits politely for the solution, and finally makes up his mind after having received the report of the research team.

For international ASA, the facts are pretty far removed from this fairy tale:

- For important issues, decisions are taken constantly all over the world by decision makers who act independently, or almost independently, one from another.

  General de Gaulle said that you do not solve big problems; you learn to live with them and to influence their nature progressively. Is this not obvious for big global issues such as energy or food and agriculture?

- For every major decision, there is not really one, but many decision makers or groups of decision makers, so that it is possible to assert, with equal truth, either that the decision is taken several times, or that it is never formally taken and only becomes less and less improbable.

- The time that is generally available to study and make the decision depends on local power-game conditions, and is considerably shorter than the time necessary for adequate systems analysis.

- The problem is not truly defined, since the policy makers are to a large extent unaware--even qualitatively--of the parts of the world system that may be influenced by a certain type of decision. Conversely, they cannot associate with a subsystem relevant decisions for its control.

- Finally, the objectives are not given. For many reasons: the objectives of different governments may be conflicting; within one country, various groups may attach different weight to possible objectives; essentially, goals are built and adapted progressively as a consequence of political processes, and it is frequently more important to establish procedures that will generate adequate goals than to define the goals themselves.

These facts have a major impact on the relations between international ASA and policy makers. More precisely, they induce *six consequences*.

1. Between the final policy makers (for instance, ministers) and the international research teams, a whole *series of intermediaries* is necessary--from the top civil servants able to write within two days a two-page note on a key issue, to the study teams of administrative bodies and the national research institutes in ASA or related basic scientific disciplines. Some of these intermediaries may be dead ends, since they may have, at the national level, no real relation with policy makers.

2. But this direct line of communication is not the only one that counts. Of interest also are the *relations with all the groups*--which obviously differ from one country to another--*that have an impact on the attitudes of policy makers* and play a part in the articulation and aggregation of political issues: scientific or industrial communities, opinion leaders, mass media, public opinion. For instance, the impact of the Club of Rome reports on political decision makers was through books and press articles.

3. Special attention must be devoted to the *relations with the decision makers engaged in the financing process*. Good research, good communication with national scientists, good relations with national policy makers in the field studied are not enough to ensure that the people who have the difficult task of allocating scarce public funds will be aware of the effectiveness of ASA.

4. An essential part of the work of an international team in ASA is to *identify essential issues and define the corresponding problems*, their main features, and their limits. Somebody has said, with some justice, that the Meadows team should have begun to work after the writing of its report, since the only use of the report was to make clearer what the terms of reference of research in this might be. Häfele is quite right in underlining in his report that it took his team two years to master the importance of concepts such as resources, constraints, demands, objectives, and strategies in the field of energy.

5. Since it is not tied to a particular decision maker, an international research project must be *multi-purpose* and *multi-goal*. It must provide a basic understanding of how a universal or global subsystem works. It must enumerate the various kinds of policies involved and establish the relations between the policies and the organizational processes. It is on this body of knowledge that national teams will build the models emphasizing the problems interesting one country, or will complete in a few weeks or months the special studies asked for by their national policy makers. The necessity of exploring a whole range of goals results directly from the variety of final users. Rather than one model, a battery of models making it possible to explore different aspects of a highly complex reality is the nucleus around which the acquired knowledge may be organized.

6. The very nature of the relations between international ASA and national policy makers decreases its comparative advantage over national ASA when the systems studied are not of any great size and do not generate a regular flow of issues for a long period: the establishment of adequate relations would be too long and too costly.

This analysis, if it captures the essence of reality, leads to certain propositions as far as the management of big international projects is concerned. It may explain why IIASA has had to choose certain strategies, and it may suggest a few directions for improvement.

MANAGEMENT OF INTERNATIONAL ASA

A short-term objective of international ASA is probably to contribute to greater consistency between the objectives of national policy makers and the decisions they take. Results in this direction seem necessary to initiate the long subsequent process of altering the goals of decision makers of different nations so as to make them more convergent. Hence, the construction of appropriate communications with these persons must be one of the dominant policies of the management of international ASA.

This has certain consequences. First, projects have to last several years--five years rather than three--not only because of the inevitable *complexity* of the subsystems chosen, but also to have *time* to establish the communications network. Projects that are too small are not worth the relation costs they generate. Their message is partly wasted along uselessly noisy channels. 1976 will see the publication of the work of Holling's team on the budworm, but the team was disbanded two years ago, and part of the scientific exchange to which its work might have given birth will be lost. Thus, the structure of IIASA has to be permanent enough to permit the progressive organization around it of a satisfactory international information system. Some of the NMOs had just succeeded in adapting themselves to IIASA's structure when this structure had to be changed--for very good reasons, I must admit. The stability of the big projects need not prevent emphasis being put successively on different aspects of reality.

Second, a project must be big, because the cost of communication is not proportional to scale: for bigger projects the part of the budget that must be spent on communications is smaller.

Third, for each of its projects, an international ASA team, in close cooperation with its Council or Board, should really study the national structure of research and policy-making in this field. Explicit recognition of the need for such an assessment would considerably accelerate the construction of the requisite information network. A typology of intermediate communication centers could be devised, with a proper definition of the kind of messages in which they are interested and the sort of language in which these would be received. An understanding of the key policy issues that the control of the subsystem implies for the different countries would also be of the utmost interest.

I consider that these aspects must be regarded as an intrinsic part of any big system study. As a fourth consequence, therefore, a communications policy should be explicitly defined for each project. It would describe the information targets, along with the frequency, length, and levels of the messages or the exchange of information. We already know some of these targets:

- In very special cases, final policy makers;
- The top civil servants who are their permanent advisers;
- Research teams close to these civil servants and engaged in short-term applied research;
- Civil servants allocating funds;
- Research centers interested in basic or longer-term research;
- The scientific community as a whole;
- Mass media and opinion leaders;
- Public opinion.

The diversity of these targets implies a similar diversity in media: short policy papers, technical reports, scientific papers, conferences, seminars, personal contacts, books. In spite of the tremendous effort made by IIASA, I am convinced that the matter has not yet been really explored and considered as a systems analysis exercise. Of course, such a policy is necessarily costly, but we must accept it, since it is a condition of the overall efficiency of international ASA. Moreover, the longer and the bigger a project, the less relatively costly it becomes. In defining the size of the resources devoted to a project, an explicit and important share should be reserved for communications, and a specific program approved. It should be recognized that this program is not secondary to scientific work, but is equally important.

These communications necessities lead to a fifth consequence. IIASA must be especially careful on two fronts: with scientists and with practitioners. Scientists will not forgive IIASA any theoretical or mathematical deficiencies, and will judge it not on the realism of its studies but on the purely formal level of the abstract developments; and practitioners will not forgive errors of magnitude in figures, over-simplification in the description of reality, or eccentricity in the policies proposed.

All the "grandeur et servitude" of the profession of international systems analyst lie in this double-front situation.

We begin to realize that ASA is conditioned as much by the links with policy makers as by the nature of the systems themselves. These links impose on an institute such as IIASA very stringent conditions:

- A few big permanent projects, since no one project could be of enough interest to all the NMOs;

- A matrix structure to prevent each project team from living in isolation;

- A very large part of the budget spent on communications;

- A project size that consequently cannot, without serious drawbacks, decrease compared with the present one;

- A prudent policy on new membership, since each new NMO generates heavy communications costs.

As an international organization, IIASA has then a lot to learn about information problems, and it has to apply its own techniques to this question; but it may reasonably ask for indulgence from the national policy makers. To establish adequate communications between systems analysts and modern governments is, even at the national level, one of the most formidable tasks of our society: what the policy makers know, the systems analysts generally ignore; and what the systems analysts know, the policy makers have just a small amount of time to learn. These barriers are higher still at the international level. To recognize this difficulty is a condition of success. It should also help to decrease the risk of future dissatisfactions and improve control of the future evolution of relations between international ASA and policy makers.

CONTROL OF RELATIONS IN INTERNATIONAL ASA

Our relations with policy makers depend also on our relations with public opinion, scientific research, and various branches of technology. When some of these interactions are not properly controlled, certain pathological features appear that pose a threat to the efficiency of ASA. So I would like to consider these four aspects briefly.

Public Opinion

If we look at the last quarter of a century, we realize that there is a kind of cycle in the relations between ASA on the one hand and mass media, public opinion, and policy makers on the other. The phenomenon is easy to describe. New techniques develop. One group of policy makers asks for an applied systems study using these techniques, with interesting results. The Press hears of this and makes an event of it, grossly overestimating its meaning. This is the start of a wave of fashion with its cumulative amplifying characteristics. But the Press is not concerned with regular flows of information; it works on exceptions. For public opinion, memory of the techniques begins to wane at the very time when limitations, known from the start by specialists, are realized. This is the period of recession, with its reaction of contempt. Aggressive attitudes toward science, deeply rooted in human hearts, bloom and flourish. But soon technical progress, real or superficial, will launch the whole process over again.

For public opinion in the West, OR died ten years ago, like forecasting in the last 30 months. Prospective studies are probably just at the beginning of their decline. Systems analysis (under this name) and global modeling are still in the expansion phase. But, if we are not careful, not for long.

Already, all over the world, press papers on IIASA or other international projects explain that the scientists are going to save the world, that they are going to tell governments how to manage the universe and which decisions to take. Such an overestimate of the modest, serious scientific endeavor of international ASA is full of danger. It neglects the essential political and social factors that command the future of the world and will certainly generate disillusion in public opinion.

Scientific Research

But in addition to public opinion, a second stratum must be kept in mind for proper control of the evolution of ASA: the scientific community, and especially that part of it engaged in pure research in economic and human sciences. We must not forget that our capacity to represent complex systems adequately depends largely on the progress of the pure sciences. Of course, ASA has to postulate relations in a concrete situation, even when pure sciences give no clue. ASA mixes "hard" and "soft" science to achieve its practical purposes; but it must not cultivate the dangerous art of embedding in complex computations a shallow and unscientific understanding of the surrounding world. Hence, ASA has to think how it can draw nourishment from the development of pure science. For the moment, this problem is nonexistent at IIASA because it is a very young institute, but it may come in time.

Branches of Technology

Having to reformulate its relations with science on the one hand, ASA has, at the same time, to accept intimate coexistence with the various technologies on the other hand, and to transform itself into a family of specialized arts in the various applied fields. This, after all, is the common fate of any expanding discipline.

Policy Makers

I think that the relations with public opinion, with pure science, and with the technologies are very important for the stability of our future relations with policy makers. What we must do, by a profound study of our communications with policy makers, is to present as honest an image of international ASA as possible, so that they do not pass from overappraisal to unjustified contempt. In other words, in our efforts in the direction of policy makers we should:

- Avoid overselling, but maintain a constant flow of information;

- Never consider relations with policy makers as established once and for all;

- Adapt the topics selected to changes in political needs;

- Nevertheless, maintain these topics for long enough to produce results in terms of policies.

CONCLUSION

All of us who believe that international ASA can make a real contribution to solving the difficult problems of the world must at the same time be aware of the vital role of relations between international ASA teams and the national societies that sponsor the research. Progress along these lines will be long and uneven. Phases of despair will alternate with phases of hope, and success is not assured. But who would reduce his efforts if even a small part of the future of the world is at stake?

CLOSING SESSION

Invited Comments of the National Member Organizations

For the Polish Academy of Sciences

(Professor J. Kaczmarek)

I have the honor and the pleasure to lead the delegation of the Polish Academy of Sciences to the first Conference of IIASA.

Our Academy, as one of the founding members, sets great store by the activities of this Institute, which was called into being because of the vital need to solve complex problems facing the world today. These problems should be treated in such a way as to foster and promote human development on the basis of generally recognized principles of humanism--in our understanding and conviction, socialist humanism. Research activities concerning contemporary economic and technical development are among the essential tasks of the Institute. Solving these problems, of great importance to the entire globe as well as to individual countries, transcends the capacities of any one country. The only means of dealing with them quickly and efficiently is by well-organized international cooperation.

The climate of détente and cooperation among countries of different social and political systems, the auspicious changes redounding from the resolutions of the Conference for Security and Cooperation in Europe, the consultations and contacts at the top level--all this creates better conditions for scientific cooperation. We could and should make full use of them. Efforts in that direction are supported by the scientific and creative media in Poland, as in all socialist countries and, as I believe, in all the progressive world.

The initiative taken by the Soviet Union and the United States to establish IIASA as a center of creative cooperation of scientists from countries of different political, social, and economic systems has proved sound, especially now in the favorable political climate generated by the Helsinki Conference. Hence we wish to express our thanks and pay tribute to the main initiators of this idea, J. Gvishiani and M. Bundy.

In the last three years IIASA has tried to create teams of specialists and to establish research programs. It has also obtained certain results. If these were measured by the criteria applied to the activities of a stabilized scientific institute, they would be recognized as relatively meager. But the years 1973-1975 were the period in which all the Institute's activities were initiated, and its results must be seen in that perspective.

The characteristic mark of IIASA's activities so far is that the Institute has to a high degree a universal character, fully open and almost equally available to countries with National Member Organizations (NMOs) and to all other countries. Its early research work tended to develop science, enlarge learning, and evolve methodology rather than to provide solutions to problems.

Work that can be of value for the development of our country was started. I have in mind the cooperation for optimizing the configuration of the new region of exploitation of big coal deposits near Lublin. In the opinion of the Polish Academy of Sciences, the Institute could become a leading international scientific center, qualified to solve problems of up-to-date management and of steering complicated economic, technological, and social processes. It is therefore necessary to conclude as quickly as possible the stage of determining IIASA's structure and program, and to increase its effectiveness with respect both to the long-term needs of the supporting countries and to topical problems of regional, national, and global scale.

While endorsing the reasons for creating the Institute, I wish to submit, in the name of the Polish Academy of Sciences, some comments intended to define IIASA's tasks more precisely. It seems that the main endeavor of the Institute should be to elaborate those methods and undertake those activities promising quick results that will serve the interest of the NMOs. The research personnel should consist of distinguished specialists from NMO countries, in accordance with the research potential of each country and especially its resources of trained staff. Sharing their learning, their abilities, and their creative talents by working in teams, these scientists could contribute significantly to the solution of urgent issues in the scientific, technical, economic, and social development of their countries.

Civilization needs two important components: energy, and raw materials and their processing. The first is reflected in the IIASA program on global energy systems; but research on the second is lacking. In this connection, I believe that it would be useful to consider another global program, dealing with selected material resources and their processing and including the question of integrated industrial automation.

National institutions with a high scientific potential and level of research are engaged in work on the same problems IIASA is dealing with. It therefore seems essential that the Institute use not only its own resources, but also, and sometimes mainly, the achievements of the entire world of science. One might claim that IIASA's main task should consist in correctly selecting the problems of interest to the countries supporting it, elaborating coordinated programs for them, inviting the help of national institutions in particular tasks, and making a synthesis of their research. This creative scientific role of IIASA and its function as a coordinator should be the feature that distinguishes it from national research institutions.

The usefulness of the research topics selected will depend on the degree to which they are of interest to the countries represented in IIASA's membership. We believe that the topics selected so far are of importance to our country, and I think to all the participating countries. The question is thus one of developing a style of work that permits the elaboration of a methodology for solving problems common to many nations, and to approach them through well-chosen case studies. Examples of this approach can already be seen in the work of IIASA and should become the rule.

We believe that the Institute, as an international center of systems analysis, should perform advisory functions for national bodies. These would consist in elaborating recommendations, and in visits by IIASA experts in order to consult national teams participating in Institute programs or doing their own research in systems analysis. We intend to approach IIASA with such proposals in the near future.

Many countries would also find it useful if IIASA supplied them with up-to-date scientific information. IIASA could perform and distribute analyses, opinions, forecasts, and similar materials on selected problems, based on an organized worldwide inflow to the Institute of unpublished papers and on contacts with prominent research centers and scholars. In short, the Institute should become an information bank in systems analysis.

The number of scientific personnel in systems analysis in our country, and I believe in other countries, is not yet sufficient. A useful activity of IIASA would be to school young scientists, and to prepare materials and assistance for their schooling on a national basis. Conceiving and carrying out such a program should have a place in the Institute's work.

We are convinced that realization of these proposals should add substantially to IIASA's scientific standing; and the advantages and benefits to the NMOs and their countries would certainly be great.

Finally, I should like to bring up the problem of the Institute's finances. We appreciate that the build-up phase involved considerable expense not related to the research activity. But that period should now be considered as finished; the main financial means should be applied to the research program, keeping organization and administration expenses to a minimum. We also believe that a discussion in the near future, on a differentiation of membership contributions according to the possibilities and economic potential of each country, is necessary. The Polish Academy of Sciences is not empowered by our authorities to further increase its membership contribution.

In concluding, may I express our satisfaction that the program presented by the Director of the Institute comprises elements that meet our desires. We give our full support to the program and the style of work proposed by Dr. Levien.

We assure you that the Polish Academy of Sciences will do its best to support IIASA's development, to foster mutual cooperation in the best interest of the supporting countries, my own included, and to contribute substantially to research in the field of systems analysis.

For the Max Planck Society for the Advancement of Sciences, Federal Republic of Germany

(*Professor K. Gottstein*)

As the available time is rather limited, let me just concentrate on two points.

First, this Conference has again confirmed that IIASA, in a surprisingly short period of time, has reached a high standard in the quality of its work. How has this become possible? I think there is one main reason: the first Director of IIASA, Howard Raiffa, succeeded in enlisting, right from the beginning, the cooperation of really first-class scientists such as Koopmans, Dantzig, Häfele, and others. It is very important to make certain that this situation does not change in the future, that National Member Organizations do not become complacent in their support for IIASA. The quality reached should not be taken for granted. On the contrary, every effort should be made to maintain, and if possible increase, the attractiveness of IIASA to excellent scientists. Of course, there must also be a good number of young scientists at the beginning of their careers, but medium-quality people should be avoided as far as possible.

Second, Dr. Levien has explained that there are projects which start "from the top", that is from general considerations, and then work their way down toward the details of given facts. Other projects start from this "bottom" and work their way up toward the top. Dr. Levien also stressed IIASA's intention to come into closer contact with policy-making. I think this means that the "bottom-up" approach will need increasing support. After all, the real problems of politics are rather down-to-earth, or, in this terminology, down-to-bottom. This is probably also in line with what Professor Raiffa had in mind when he expressed his hope that IIASA will wet its toes with increasingly difficult problems--difficult in the sense of controversial. The real world is full of controversial problems, and IIASA was created to deal with them. This does not necessarily mean solving them. Mr. Lesourne has quoted the opinion of the late General de Gaulle that politics is not a matter of solving problems, but of living with them and replacing them by more manageable ones. I think that IIASA can indeed help in this process, and that this Conference has been a good start. In fact, a look at the list of participants shows that IIASA is already attracting increasing attention from policy makers. My suggestion would be that IIASA concentrate more and more on problems that are of significance in this sense. The questions arising out of the necessary cooperation between industrialized and developing countries were frequently mentioned during the coffee breaks at this Conference as potential objects for future IIASA work. Of course, given limited resources the beginning of new projects might necessitate the closing down of others that have reached conclusion.

In the Federal Republic of Germany we are thinking about ways and means to improve the benefits that international policy makers could derive from the work of IIASA. Most important here will be the improvement of personal contacts with IIASA.

Finally, it is my pleasure to thank the Director and staff of IIASA for the excellent arrangements made for this Conference.

For the Hungarian Committee for Applied Systems Analysis

(*Dr. S. Ganczer*)

I would like to make use of this opportunity to assure you that we consider IIASA a very important international institute from both the scientific and the political point of view.

In our opinion, the activity of IIASA so far has justified its creation and the hopes of those who initiated its establishment. We are convinced that the research plan that was presented at this Conference provides a suitable framework for the coming years, that it allows IIASA to carry out studies in accordance with the goals it was created for.

We regard the matrix organization of the research work a very useful means for concentrating the Institute's activities on a few really crucial global and universal issues.

The success of the future research at IIASA depends on several factors, and many of them have already been mentioned. I would like to stress here the need for a tight coordination and cooperation with other international and national institutes. This would enlarge the research potentials of IIASA, and would help to avoid duplication in research. As for the limited resources of IIASA, I think more consideration could be given to the possibility of increasing the share of work done outside, at institutes of the National Member Organization countries, since some of the research tasks seem not to need residence at IIASA.

We have found this Conference very useful. It has provided a good opportunity for both evaluating past activity and assessing the future research plan. We thank the director, Dr. Levien, and his staff for the excellent and careful organization of the Conference. May I note, however, that earlier distribution of the conference papers could in my opinion have resulted in more lively and more effective discussion.

Finally I would like to assure the leadership of IIASA that the Hungarian Committee for Applied Systems Analysis--within its limited possibilities--will do its best to help the Institute in realizing its plans.

For the National Academy of Sciences, United States of America

(*Professor G. Hammond*)

It is my pleasure and honor to speak for our National Academy of Sciences. The Conference has highlighted things we know but often forget. We know of the ultimate interdependence of the Earth and the living beings that inhabit it. Everything we do to each other or to the Earth affects in at least some small way all the other parts of the system. Similarly the natural physical changes that occur around the Earth affect us. We want to understand the nature and dynamics of these interconnections, the ways in which we affect each other and our one world. We want to know, so that we can try to make those interventions mentioned by Handler that "make a difference". This is the essence of systems analysis.

IIASA represents a noble attempt by people from many countries to join together in trying to understand the connections in our world, expressed in terms of both global and regional problems. The dual intention to develop analytical methods and to provide models in specific problem areas is sound. The methodology must grow if systems analysis is to develop- and IIASA should be a part of that forward thrust, if only to assure rapid infusion of the best new methods into the applications, the most important part of IIASA's activity. We hope that scenarios developed in the analysis of current problems will be of a quality suitable for use by decision makers, and that these will hear of and use the results.

I also hope that the IIASA analysts will not become so fatally preoccupied with the important applied problems of today and tomorrow that they forget the long, long future that will be the present for our descendants. Just as we are all interdependent in our time, we are also connected to the future. What we do now will inevitably affect the world in which people will live in the future.

At this Conference, IIASA's staff have shared their work with us, both the efforts that are flourishing and those that are not. There is no shame in the fact that some programs have gone slowly; the Institute would not be worth while if it engaged only in activities so limited in scope or so easily understood that rapid progress is certain. We have seen evidence of high morale and esprit de corps in the Institute staff. I also note with approval that there is constructive self-criticism, a function crucial to an activity such as IIASA.

Let me speak briefly of the responsibilities of the Institute's supporters. These include not only the Council and their constituent member organizations but also all those who have attended this Conference. I feel that, for better or worse, each of you has assumed some responsibilities toward the Institute. This does not imply approval of all the Institute's programs; but if there are those who disapprove of all our programs, I think they must tell us how and why.

Some of the work of the Institute can be done by each of us when we return home. The importance of getting very good people to come to IIASA cannot be overemphasized. We can help the Director in his recruiting mission by telling people of the Institute, its work and its goals; we can persuade institutions in our home countries to enable some of their best talent to spend some time at IIASA.

The people who have attended this Conference also have a role to play in relating effectively the acute financial conditions of the Institute. The effects of general inflation and devaluation of the dollar are a matter of simple arithmetic, and none of you can have failed to note the high cost of living and doing business in Vienna. The Council and Director have reduced their goals for growth below the original targets, to a level the Council considers the minimum size for viability. I hope that you will attest to the fact that the statement of need is real.

We all bear a responsibility in explaining to others the essence of systems analysis itself. It is a new and developing field, widely misunderstood and the subject of enormous skepticism. Some of that is surely justified; but we can at least give the critics substantial information, so that their criticism can be directed toward specific, rather than diffuse, targets. Those of us who see promise in this infant but growing field can explain what we see as its promise.

While we applaud the work of the Director and his staff, we must also remind them that a halting response to their pleas for more support is not just a callous and petty reaction. When Member Organizations ask their governments for increased support of IIASA, they are asking the sacrifice of something else--probably some other scientific enterprises in our various countries. I believe that the IIASA program is strong enough to warrant such a sacrifice, but it behooves us to feel and express empathy for the decision makers who can give us more only by taking it away from other scientific endeavors. As someone else said earlier in the Conference, there is no free lunch.

Finally I wish to add a personal note. During the short time that I have been a member of this Council, it has been a pleasure and a source of great satisfaction to work with its Chairman. Dr. Gvishiani has been kind, helpful, and inspiring to me as I have taken on duties for which I did not feel well prepared. His sprit has contributed an invaluable part of the leadership that created and maintained IIASA.

For the Academy of Sciences of the Union of Soviet Socialist Republics

(*Academician Yu. A. Ovchinnikov*)

Allow me, on behalf of the Presidium of the USSR Academy of Sciences and the Soviet delegation, to greet you--the participants of the first Conference of the International Institute for Applied Systems Analysis.

The USSR Academy of Sciences is the National Member Organization from our country. It has broad international ties with scientific organizations of more than 90 countries. Mutual exchange of scientists, advanced studies, lectures, participation in joint research on a bilateral and multilateral basis--all these are traditional, and very broad, forms in our scientific relations with other countries. Our participation in IIASA is a new, specific form of international relations. We can say that, for the first time in the two and a half centuries of its history, the Academy of Sciences of the USSR is taking part in the activities of an organization such as IIASA. This is a symbolic manifestation of the level of development attained by humanity and of the scale of problems facing scientists of all nations.

The scientific and technological revolution opened up new opportunities to mankind. However, we are now confronted with problems that either never arose in former days, or that, if they did arise, were never of such urgency and scale. The very fact that the problems came up--problems of space exploration, exploitation of the world's ocean resources, rational utilization of natural resources, environment protection on a global scale--gives one an idea of the growing complexity and dimensions of the tasks people are faced with. And at the same time, there have been great increases in the cost of solutions to the problems and their implementation.

The multi-faceted and multidisciplinary nature of these problems call for integration and coordination of the activities of scientists and specialists in various fields. Their global importance and the limited resources available for their solution neccessitate the cooperation of a great number of nations. This is why it is ridiculous to hear that the international division of labor is beneficial for one group of countries and non-beneficial for others. Those who make that statement are either incompetent or, to put it mildly, not sincere. It has always been the case that one country leads in some field of knowledge; this is only natural. We need not stress this point; our task is to identify the ways and means of making the best use of the scientific achievements and resources of individual countries for the welfare of all mankind.

In the Soviet Union, for example, great progress has been made in the theory and practical application of centralized planning and management methods on the regional and sectoral levels and for the country as a whole. At a recent IIASA conference, our foreign colleagues had an opportunity to get acquainted with our experience in developing the Bratsk-Ilimsk Territorial Production Complex.

The achievements of our country in providing towns with energy from a centralized supply are well known; this direction, which is only at the initial stage of development in the West, has lately acquired great importance. Power blocks of one million kW capacity have been installed at atomic power stations. They are among the most powerful reactors in the world. Blocks of 12-15 million kW capacity are planned for development in the new five-year period. Progress is also being made in thermonuclear power engineering. The thermonuclear reaction has been developed in laboratory conditions with Tokamak-10--one of the world's largest fusion reactors. Soviet scientists and engineers are proud of their achievements in nuclear physics, a field in which the cooperation of scientists from different countries has already yielded fruitful results. We are happy to have contributed to it. Indeed, the achievements and ideas shared by our scientists with their counterparts elsewhere have considerably influenced world progress in this sector.

An important event took place recently in the Soviet Union: the XXVth Congress of the Communist Party (CPSU). The Congress summarized the achievements during the period after the previous Party Congress. Special emphasis was laid on the development of science. The Party Congress called on Soviet scientists to concentrate their attention on urgent problems of scientific, technological, and social progress, and stressed the necessity to use the increased opportunities in the USSR for further comprehensive development of economic, scientific, and technological links with other countries. The Congress attached great importance to the development of world cooperation on such global problems as energy, environmental protection and development, and elimination of the most dangerous and widespread diseases. These problems are known to be in the focus of IIASA's attention.

Speaking of the activity of IIASA, one cannot but note that the Institute is developing at a favorable time, in the atmosphere of détente. Moreover, its activity makes a contribution to détente, showing the possibilities brought about by international cooperation. In fact, IIASA is one of the examples of materializing détente.

There are grounds for believing that IIASA can be considered not only as a promising scientific institution, but also as a prototype of international organizations of the future. And perhaps we are witnesses of a historic event--the first Conference of the first international institute with a broad profile.

Summing up the results of the initial period of the Institute's existence, we can evaluate its activity favorably. It took the Institute a very short time to be set up, to begin its work, and to obtain the first results. IIASA has been recognized as one of the leading centers of international cooperation in science. It is important to note that a really creative and friendly atmosphere reigns at the Institute. Scientists from many countries feel at home there. Credit for that should be given to the founders of the Institute, the members of its Council, and of course its first Director, Professor Raiffa. Together they have created a good basis to be built on by their successors. We can see that with goodwill, scientists of West and East, regardless of the differences in their ideologies, can successfully cooperate in solving common problems.

The first period of the Institute's life has come to an end. A detailed analysis of its work should be given. It is clear today that to a great extent, the strength of the Institute depends on a proper balance of fundamental and applied research; it is also clear that the Institute should have the support of scientific institutions in the participating countries. In the future, IIASA's scientific potential will directly depend upon the level of participation of these institutes in IIASA's research. IIASA is called upon to unite the efforts, not only or even primarily of individual scientists from various countries, but of scientific teams in member countries. Scientists working at IIASA should be supported by their national institutions, and should draw on their experience. In this connection, it is feasible to strengthen the role of IIASA as a coordinator of systems research in the supporting countries.

No doubt there are great potential reserves for strengthening and developing IIASA. We should like to express our wish that the Director, Dr. Levien, and the management of IIASA will make better use of the existing potentials in organizing and planning the work of the Institute. On our part, we will try to increase the support and participation of the institutes of the Academy of Sciences of the USSR and other scientific institutions of the Soviet Union. Not long ago a decision was adopted to establish an institute for systems analysis in our country. We hope that this institute will work in close contact with IIASA.

On the whole, we highly appreciate the Institute's work from the time of its creation to the present day. The Soviet scientific institutions will continue to participate actively in the Institute's program and do their best to promote its development. We wish the Institute further success in the treatment of global and large-scale problems, as well as those of a more applied character that have direct influence on scientific and technological progress.

For the Austrian Academy of Sciences

(Professor O. Preining)

Our era is characterized by rapid change, and hence by the importance of prediction techniques to permit feedback in time. Furthermore, there exists the need for planning for longer and longer periods. National plans in fields such as energy or food resources, however, do not and cannot reasonably cover time periods longer than 10 to 15 years.

Here, IIASA fills the gap with its unique task of analyzing possible futures through long-term forecasts and scenarios giving the needed background for national planning, and resulting in the--hopefully--optimal management of the process of change in technical and social structures. This basic direction of IIASA's policy, and its role as a link between countries of different social and economic order, are beyond doubt of great significance. There are however, several aspects that in our opinion need some critical consideration.

The most important point probably is the following. In dealing with universal and global problems, the individual must not be forgotten. The effects of changes on the large scale must at the same time be studied on the small scale. The effect on the life and life style of all people is, in our opinion, an essential parameter in the evaluation of planning options. There certainly are many factors that cannot easily be described quantitatively, but nevertheless it would not be wise to leave them out on that account. The tool, the mathematical model, must not become the master, commanding how a problem should be solved. In close connection with this, we strongly favor a wider distribution and popularization of the information gained. Not only should other research institutions and decision makers be informed, but--as Lesourne pointed out in his brilliant presentation*--we must communicate the results of our work to the general public in a way they will understand.

It is our opinion that in the future managers and decision makers in East and West, and in North and South, will need the consent and support of the people, who must understand the problem in order to accept solutions. Proper "risk assessment" and the definition of "acceptable risks" can be achieved under only those conditions. Benefit-risk evaluations will determine crucial decisions and therefore can never be left to technocrats, scientists, and managers alone.

In our view, IIASA should step in here by studying how the broad public can be effectively informed; how we can interest the people in making the effort of informing themselves on the vital

---

*J. Lesourne, this volume.

issues of our societies; and how the information should be handled, prepared, and distributed. Case and model studies in this area would be of great importance.

In regard to the global problems, we would like to stress the following point. The basic concern of a scientist should be to get a view that is neither pessimistic nor optimistic, but realistic. There are real problems and tensions among different countries. One problem that we want to see without illusions, and that is, at least for Austria, very important, is how to find the best policy for a small State in a world dominated by big powers. The voice of the small often has little weight, as we experienced recently on a small issue--the date of this Conference. Small countries are not too pleased with certain aspects arising from highly aggregated world models that assume an equilibrium of interests. A small number of large energy parks, for instance, would in the present situation entail the complete dependence of the many small countries on the few big powers.

Now, we should like to comment in more detail on IIASA's projects. In the Energy project, more than marginal emphasis should be placed on the study of possible and feasible conservation measures. The possibilities of energy savings without reduction of the quality of life should be examined more closely, as should the question of luxury consumption and growing motorization. The production of short-lived goods instead of technologically and economically feasible long-lived ones is another "hot issue" that IIASA should not fear to take up. These kinds of problems could, if left alone, one day get out of control. Furthermore, IIASA could, by its potential, assume a key role in the assessment of energy resources on an international, a global scale. International cooperation on this issue has already started, but in our opinion needs more momentum. This is another concrete idea we wish to contribute--to intensify the efforts that have already been started in a promising way within the Energy project.

When dealing with energy options such as nuclear, solar, coal, etc., all implementation steps must receive equal attention. The technological assessment, the estimation of the technical and economic feasibility of an option, are certainly not minor questions. We think that the IIASA Energy project has to some extent neglected these aspects. This is the more regrettable as these questions belong to the already "classical" part of systems analysis (to mention only the work of Stodola, *The Prospects of the Heat Engine*, which appeared about half a century ago).

A short remark on the topic of food and agriculture: without doubt a lot of valuable work has been done in this field; however, one hot political issue was most elegantly avoided in the Conference. This is the ambiguous character of the relations between rich and poor countries, the question of aid versus exploitation by big powers and of the growing worldwide influence of multinational companies. These issues, vital for all mankind, have to be seen in perspective, in the inseparable unity they form, if efforts to achieve basic changes for the better are not to be doomed from the very beginning. The reasons for such an approach are not merely altruistic: we all live on the same planet and form one system; and underdeveloped nations--a very important subsystem--need not always cooperate. Possessing valuable raw materials, it is quite easy for them to form effective lobbies whenever they feel forced to do so in the interest of their development.

One more remark concerning regional programs. There is more to be considered than energy and environment. In our opinion, the effects on small social groups and even on individuals should be taken into account, for instance by including social indicators as essential parameters in all model studies, as I have already mentioned. Human reactions must be included in the models. Behavioristic considerations and feedback loops should be used to an extent considerably greater than practised so far in the otherwise deterministic models.

Finally, we want to state that IIASA is very young and has done remarkably well. To materialize something everyone thought highly desirable but almost impossible; to get a joint East-West non-governmental interdisciplinary institute going, to overcome all prejudice, language barriers, barriers from dialects, sociolects, and all other -lects arising from ideology and/or science --all this is practically a miracle.

We Austrians are glad that it happened, and proud that it happened here near Vienna. This justifies a hope we all have: that after all, mankind as a whole faces the same problems, and therefore people can understand each other and can cooperate to solve them.

For the Academy of Sciences of the German Democratic Republic

(*Academician W. Kalweit*)

Permit me, on behalf of the delegation of the German Democratic Republic and on my own behalf, to express my sincere thanks to Dr. Gvishiani, the Chairman of the Council; to Dr. Levien, Director of IIASA; and to all those who have contributed to this first IIASA Conference. We feel that your efforts in holding this Conference were attended by great success. Today, at its conclusion, we can say that the first Conference of IIASA was in full accordance with the provisions of its Charter. As you know, the Academy of Sciences of the German Democratic Republic is one of the founding members of IIASA, and so it gives us great pleasure that the Institute has lived up to our expectations.

One of the major aspects of IIASA is that it is an international institution, where scientists from socialist and nonsocialist countries work together in solving research problems.

In this way it contributes substantially to implementing the policy of international détente in the spirit of the Final Act of the Helsinki Conference.

The work accomplished by IIASA is of outstanding scientific relevance. Our responsibility for the future of mankind demands of us that we investigate global and universal problems. IIASA, as a forum of interdisciplinary research, offers unique possibilities for research into complex questions, for example of natural resources, energy, health, and environment. The work carried out within the frame of the Large Organizations project is a case in point. In particular, the results of the conferences on the experience gained with the Tennessee Valley Authority and in construction of Bratsk-Ilimsk show that international scientific cooperation can be both interesting and useful.

The GDR has actively participated in the work of the Institute since its foundation. Scientists from the GDR have held long-term research and administrative posts as well as short-term assignments, and have contributed to the successful performance of IIASA's tasks. I may assure you that the GDR will support the Institute also in the future.

Our appreciation of the positive aspects of IIASA's activities does not mean that we see no room for improvement. Of course, after three years of existence one cannot expect all problems to have been solved. I believe that a state in the Institute's development has now been reached that makes it possible to think about some of these problems; and that measures should be taken to ensure its increased effectiveness.

We think it appropriate to strive for long-term planning of research tasks, a clearer formulation of subjects, and in particular a more exact description of the results. It is especially important to select research topics of practical benefit to supporting countries. We are convinced that you will agree that this last aspect could vitally influence the posture adopted by the participating countries in terms of their support to IIASA.

At an Institute that is bound by its name to concern itself with an applied systems approach, great emphasis should attach to cooperation among projects and integration of tasks.

Finally, it appears desirable to involve national organizations of the participating countries more closely in the work of IIASA.

These brief comments are intended to enhance the activities of the Institute. In this spirit, I wish IIASA much success in its future work to the benefit of the participating countries, science and international understanding.

For the Japan Committee for the International Institute for Applied Systems Analysis

(*Professor K. Miyasawa*)

First of all, I would like to congratulate the Director and staff of the Institute on the progress of the IIASA Conference, and to express my sincere gratitude to the Austrian people for their warm hospitality. Our Institute can be proud of the high quality of its achievements in such a short period.

I hope that, through this Conference, the important role of IIASA in resolving the difficulties mankind faces will be recognized, not only by a small group of scientists, but by a wide range of people from many countries. Such an understanding by the public will provide the basis for insuring the Institute against financial difficulties and will be the driving force to its further advancement. I hope and I believe that the Conference was successful in arousing public interest.

Let me briefly express my feeling about the Institute's research activity. Unlike other organizations, IIASA has the privilege of making comparative case studies of human behavior in the socialist and non-socialist countries as expressed in the production of goods, resource allocation, regional development, and so forth. We should avail ourselves of this opportunity; but at the same time I think that we must not take unfair advantage of it.

Our case studies will certainly reveal many interesting differences, and similarities, in the organization of economic systems and the activities of governments from country to country. But our research should not remain at the level of fact finding. Through such comparative studies, IIASA is expected and intended to create new concepts and theories that will contribute to the promotion of the welfare of all humanity. I hope our Institute will continue its search for a theory, or perhaps a kind of metatheory, that will help to resolve conflicts among nations and to guide human beings all over the world to a better life.

For the National Centre for Cybernetics and Computer Techniques, People's Republic of Bulgaria

(*Dr. L. Glushkov*)

On behalf of the Bulgarian scientists and experts attending this Conference, I would like to give you our impression of IIASA.

Frankly, we are surprised that IIASA has become a mature organization producing valuable results in less than four years. We must commend the efforts of Dr. Gvishiani and the IIASA staff in bringing the Institute to this level. This is a valuable achievement; and, speaking as a representative of a founding member of IIASA, I think it is also the achievement of all the

National Member Organizations and their countries. The reports presented here, and the plan proposed for future research, allow us to conclude that the experimental period has ended and a new stage is beginning--one directed toward more and more valuable results.

Our country gives continuing attention to all the problems IIASA has faced since its inception. This is evidenced by the presence of highly qualified Bulgarian scientists at IIASA, and by the creation of effective links between IIASA and national research organizations.

The best symptom of maturity is concentration. We are happy to see IIASA focusing on four areas--areas big enough to need concentration and complex enough to need international collaboration.

As far as specific problems are concerned, we will give increasing interest to the social aspects of applied systems analysis, and to their impact on decision-making and on the decision makers and policy makers themselves. We believe that this is becoming a central problem in our age of discontinuity; that is why we are going to participate more actively in this area of IIASA's efforts.

Another topic of interest to us is the Water Resources project, which has proved its effectiveness. A general agreement between IIASA and the Bulgarian Water Authority was signed in January 1976. We have established a very fruitful collaboration between IIASA and the national Research Centre on Water Resources in Bulgaria: a joint workshop was organized, and international collaboration in solving specific national problems has proved to be an excellent way to achieve useful results.

International cooperation in health care has also been shown to be valuable. We support this item of IIASA's research plan, and we hope to contribute to national and regional health care modeling.

Energy problems--especially those of new technologies and the effective use of energy resources--are of interest to us. So too are IIASA's food and agriculture studies. We hope that IIASA can, within a short period, define its objectives in this field and produce results of value to all of us.

In our view, it is desirable that the Institute continue its efforts in the area of integrated industrial systems in order to summarize and distribute experience in building modern industrial complexes.

Our specialists intend to participate more actively in IIASA's activities in computer networking.

In summary, we share the opinion that IIASA is concentrating on problems of common interest, focusing its limited resources for greater achievement and for more valuable results. We will be happy to see IIASA become preeminent in applied systems analysis research.

For the Royal Society, United Kingdom

(Mr. P.C. Roberts)

We have one general comment on the work of IIASA, and this relates to the word "applied" in "applied systems analysis". The concern of the British National Committee is in the emphasis on applications. We are fully aware of the importance of advances in methodology but are unequivocal in our conviction that the work in methodology should grow out of the needs that emerge in application studies. At one extreme there could be theoreticians devising structures of great intellectual elegance, and at the other extreme a mere assembling, cataloguing and describing of data. While it is not suggested that IIASA should be identified with either of these extremes, we believe that the balance has been weighted unduly towards the ivory tower of the academic. Quite apart from the intrinsic merit of making a successful marriage between methodology and application, the esteem in which IIASA is held and the support that it needs from the member countries is dependent on the degree to which this union is achieved. Our views on the specific projects and programs stem from these considerations.

The matrix structure, introduced this year, has good support from our Committee. It promotes the interchange of information, the cross-linkings being imperative in this interdisciplinary work; and we hope it will bring the theoreticians into immediate contact with the practitioners. The rationalization of the original 11 research areas into four, with two cross-cutting themes, is sensible, giving coverage to all major subjects yet being consistent with the limited resources available to the Director. Of these research areas, most are developing a coherent strategy for future research, rather than the somewhat dissociated tasks of previous years.

I will not take time here to go through all the research topics, with which we are basically very pleased; our finer comments have been passed to the Director. I will mention first the Industrial project--part of the Management and Technology area. As a separate project in previous years, a case study of integrated control in the steel industry was carried out. A lot of effort went into this, and a very good state-of-the-art monograph is being produced. We would have expected to see continuing activity, reapplying methodology in this important industry. The proposed work on computerized management information systems, whilst worth while in itself, leaves this other work rather in the air. Secondly, I would comment on the System and Decision Sciences area. This is stated to be a service to all the other projects, but our Committee feels that this role must be recognized more in the work it does. I will reiterate the point previously made--that methodology should be done because it is required in the solution of an ongoing project, not for its own sake. Similarly the Computer Science project should make available services that projects have indicated they will need. IIASA cannot expect to achieve results in fundamental computer research, when one looks at the number of commercial firms attempting the same work with far greater funds.

It is a general point, accepted by most projects, that IIASA must aim for attainable goals. Tasks uncompleted, or badly completed, are not good for the Institute's reputation, and deprive other projects of those funds.

As a last comment, let me say a little about the two major themes. The global concept is an obvious interconnecting strategy, and the allocation of energy research as the first global investigation is sensible. Professor Häfele's plans are, as usual, well thought out, and the work will undoubtedly be well done. Again we have presented some minor points and biases on this topic to the Director. The idea of extending the work to food and agriculture, water, population, etc., is good.

Our Committee agrees that the philosophy behind the Integrated Regional Development program is sound, but it is too new and ill-defined to warrant any real criticism as yet. However, I wonder whether here the vastness of the task and the worldwide variations in techniques make this a larger task than at first envisaged. It is too soon to judge, and we look forward to seeing these plans develop.

In this, necessarily short, summary of my Committee's views, I have unfortunately glossed over the agreement on the good areas of the research plan, and the congratulations for work well done. Our Committee does not overlook these: on the contrary, we believe the Institute is achieving most important results, and we do our best to show this to governmental, academic, and industrial sectors of the UK. But we consider that one of the National Committee's roles is to advise the Director, and this we will continue to do, liked or not, heeded or not, whenever we see room, in our opinion, for improvement.

Closing Remarks

J. Gvishiani

The first IIASA Conference is over. The Council's general impressions of the Conference are reflected in a special resolution we have adopted, but it is perhaps premature to make any serious judgment of all that has been said at the Conference.

As the Charter of the Institute stipulates, the Conference is the major forum for review of the Institute's work and plans, for linking its programs with other national and international research efforts, and for fostering understanding of its work by scientific and decision-making communities and by the general public.

Given these objectives, which are obviously very important in determining the future of IIASA, it is of course impossible to draw any definite conclusions now. As the Director has said, this will require time for analysis by the Institute's staff. At the next meeting of the Council, we intend to discuss the implications of the Conference on the Institute's research program. Before that, in mid-September 1976, we will have an Executive and Finance Committee meeting. We intend to examine all aspects of the Conference thoroughly in order to generalize this first experience for the future. The Institute would welcome any additional remarks you may have after returning home.

Meanwhile, I would like to convey to you some of my impressions, which are shared by the Council and, I am sure, by most of you. The Conference is a success. It is a success because it was able to attract such a distinguished audience from more than 20 nations and from many international organizations, representing the scientific community, government circles, industry, public sectors, and public media. It is a success because for three and a half days this audience has been involved in the work of the Conference, thus providing a response to the Institute's activities that is vitally needed.

Many of you gave a high valuation of the first results of the Institute's work and made constructive propositions for extending and improving our research efforts. Some of you have been critical, and we wholeheartedly welcome the constructive criticism. I may add that we are usually much more critical at our Council and Executive Committee meetings, for if the Institute is dealing with modern methodology based on principles of scientific management, one of these principles is that managers should never be satisfied with performance. They must always look for something new, and this sense of innovation will always remain in an institute like ours. Nevertheless, it is important to have a balanced review that cannot be given by the Council and the Director. We need an independent assessment, and I am sure that all of you are independent in your criticism, in your evaluation. This is particularly important for the Institute because it needs encouragement in the areas we are and will be dealing with. So we hope that this criticism implies your active participation in the future work of IIASA, in order to correct what might appear to be wrong in our approach. After all, the Institute is still in its infancy, and by any standards, national or international, all of us can be proud of what has been achieved in only three years of its existence.

I am particularly grateful to the speakers transmitting the views of our National Member Organizations. They are truly encouraging, and we hope that the support of the National Member Organizations will be strengthened, as this is a decisive factor for the activities of the Institute.

A number of new research topics or subtopics were suggested, and I share the view of the Director that to the extent possible they will be reflected in our program. But there remains the problem of how to be selective, how to concentrate our efforts when the interest and magnitude of each topic are so great that it is difficult to do serious research with only our in-house resources. The role of IIASA in developing contacts among our National Member Organizations, among those international institutions that might participate in these studies, is immensely important. We now have a nucleus that is strong. In the next stage of the Institute's development, we must enlarge our activities, bringing together scientists from all parts of the world and sharing the results of our work with them. We must also think of ways in which we can intervene in the process of stimulating concern among scientists facing the important problems we have heard so much about at this Conference. We must think about the United Nations conferences dealing with such problems, and the role the Institute might play in these events. I might mention here that, as our publications and reports show, the Institute's staff and the scientists cooperating with IIASA are participating in practically all important scientific events today.

A lot of work is still ahead of us. We are not sure that our role is clearly defined. A number of questions remain open, and we need to find answers. But it is reassuring--and I think the Conference has demonstrated this--that we have skillful management at the Institute, we have a number of prominent scientists working with us, and we are confident that this number will increase.

I would like to use this occasion to say a few words about how pleasant it is to work in the Council and the Executive and Finance Committees, and with the recently created Membership Committee. Since the founding of the Institute, the Council and the Director have worked hand in hand. We sometimes have scientific discussions at the meetings of the Council; we occasionally disagree on certain matters in which individual scientists or Council members have their own views; but we have never had any conflicts, and I am happy to say that we have never literally voted. We vote only where voting is required by the Charter; we have made all of decisions unanimously.

This background permits us to set some targets and objectives that will be of great value for the development of the Institute; and we will seriously consider any suggestions that you might make.

I want to inform you that today the Council adopted with great pleasure a resolution admitting the Swedish Committee for IIASA as a member of the Institute. We now have 15 members of IIASA. I would like to add that the Finnish delegation participating in the Conference has asked us to announce that a Finnish national organization will apply to become a member of the Institute; we will vote on this membership at our next Council meeting. As the Director has told you, there are a number of other candidates; I have mentioned only those whose intention to join IIASA is very clear.

In a day or two most of you will return home. We hope that all of you will share for a long time to come what we call the "spirit of IIASA"--the spirit that has undoubtedly been one of the main factors contributing to the success of this unique scientific institute. This spirit has to be further nurtured, developed, and I would say disseminated if we want the world to live in peace and security. We need you to broaden our efforts, to make them as international as possible; this is the only possible way of dealing with the problems besetting mankind.

Let me thank you for coming here, and for your active and constructive involvement in the work of the Conference. On this occasion I would also like to thank the Republic of Austria for its help in realizing the concept of IIASA. In this connection, the Council has today adopted the following special resolution:

> On the occasion of the first IIASA Conference, May 10-13, 1976, the Council wishes to express its deep gratitude for the important contribution of the Austrian Government to the establishment and development of the Institute. The Council is grateful for the assistance of the Austrian authorities in the creation of a favorable environment for the research work, in particular for provision of Schloss Laxenburg as a magnificent home for the Institute. The Council appreciates the continuing attention and support the Austrian authorities have given to the Institute's welfare, to its activities, and to its position in the international scientific community.
>
> The Council is very honored that His Excellency President Kirchschläger graciously extended his patronage to the Conference and is very appreciative of the personal interest that he has shown in the Institute.

The Council is very honored that His Excellency Chancellor Kreisky agreed to open the Conference, and appreciates his warm remarks about the Institute and the concern for IIASA's welfare that they manifest.

The Council is grateful for:

- The participation of Frau Minister Firnberg and her active support and guidance, and that of the Ministry of Science and Research, during the Institute's establishment in Austria;

- The ready assistance of the Ministry of Foreign Affairs, Minister Bielka and Secretary-General Haymerle;

- The hospitality of the City of Vienna and Mayor Gratz for giving continuous support in providing and keeping up the Institute's facilities in Laxenburg as well as for entertaining the Conference;

- The hospitality of the Companies of the State-owned Austrian Industry as provided by General Director Geist.

The contribution of Austria, in particular the Federal Government, the Province of Lower Austria, and the City of Vienna, has been an essential factor in the Institute's development, and the Council believes it to be an important contribution to international cooperation in science.

Finally, on behalf of the Council, may I convey our appreciation and sincere thanks to the Director, the Secretariat, and the staff members of IIASA who contributed to the success of the Conference by making our work run so smoothly and our stay in beautiful Vienna so pleasant. I hope to see you all at the next IIASA Conference. Thank you for your attention; I now officially close the first IIASA Conference.

APPENDIXES

Appendix 1: About the Authors

Academician Abel Aganbegyan, Soviet Union, is a member of the USSR Academy of Sciences, Director of the Institute of Economics and Industrial Engineering of the Academy's Siberian Branch, and a Professor of Mangement Sciences at the Novosibirsk University. He is a visiting scientist at IIASA, working with the Large Organizations group.

Professor Gerhart Bruckmann, Austria, is a Professor of Statistics at the University of Vienna, and Director of the Institute for Socio-Economic Research of the Austrian Academy of Sciences. He has been a consultant to IIASA in the area of global modeling since November 1972.

Dr. McGeorge Bundy, United States, former special advisor to US Presidents Kennedy and Johnson, is President of the Ford Foundation. In 1967, Dr. Bundy, together with Professor Gvishiani, launched the discussions which led to the establishment of IIASA.

Mr. William C. Clark, Canada, a research scholar from 1973 to 1975 in the area of ecological systems, is currently with the Institute of Resource Ecology, University of British Columbia.

Professor George B. Dantzig, United States, of Stanford University, is a former leader of the IIASA Methodology group, and a current member of its Advisory Committee. Professor Dantzig has received the 1976 President's Medal for Science, and is a member of the US National Academy of Sciences.

Professor Wesley Foell, United States, is on leave from the Institute for Environmental Studies, University of Wisconsin-Madison. He has been a IIASA scholar since early 1975, and is currently leader of its research work in ecology and the environment.

Professor Jermen Gvishiani, Soviet Union, has been Chairman of the IIASA Council since its inception in 1972, and played a leading role in the foundation of IIASA. He is Deputy Chairman of the State Committee of the USSR Council of Ministers for Science and Technology.

Professor Wolf Häfele, Federal Republic of Germany, formerly of the Nuclear Research Center, Karlsruhe, came to IIASA in 1973 as leader of the Institute's research energy systems. He was appointed Deputy Director of IIASA in November 1974.

Professor Philip Handler, United States, is the President of the US National Academy of Sciences. Professor Handler is a biochemist, educator, administrator, and co-author of the book "Principles of Biochemistry".

Professor C.S. Holling, Canada, joined IIASA in 1973 as the first leader of the Ecology project, which included the study of biological resources and environmental systems. He is currently with the Institute of Resource Ecology, University of British Columbia.

Dr. Dixon D. Jones, Canada, joined IIASA in 1973 to work with the Ecology project. He is currently with the Institute of Resource Ecology, University of British Columbia.

Professor Zdzislaw Kaczmarek, Poland, joined IIASA in 1974 as leader of its water resources activities. Before coming to the Institute, Professor Kaczmarek was Deputy Minister of Sciences, Higher Education and Technology in the Government of Poland, and head of the Environmental Engineering Department of the Technical University, Warsaw.

Academician Leonid V. Kantorovich, Soviet Union, is a mathematician and Deputy Director of the Laboratory for the Use of Statistical and Mathematical Methods in Economics, Siberian Department, of the USSR Academy of Sciences. Academician Kantorovich was awarded the State Prize in 1949; he is the recipient of the Lenin Prize; and together with Tjalling Koopmans, United States, was awarded the 1975 Nobel Prize in Economic Sciences.

Professor Hans Knop, German Democratic Republic, came to IIASA in 1974 to lead its research in the design and management of large organizations. He is from the University of Economic Sciences, Berlin.

Professor Tjalling Koopmans, United States, of Yale University, spent one year as leader of the IIASA Methodology group. Together with Academician Kantorovich, Soviet Union, he is the recipient of the 1975 Nobel Prize in Economic Sciences.

Academician Helmut Koziolek, German Democratic Republic, is a IIASA honorary scholar, and a former GDR representative to the IIASA Council, of which he was Vice-Chairman. He is a member of the Academy of Sciences and Chairman of the Economic Research Council of the German Democratic Republic.

Dr. Bruno Kreisky is the Federal Chancellor of the Republic of Austria. Dr. Kreisky has received the Gold Grand Cross of Honor, and more than twenty foreign honorary awards.

Mr. Jacques Lesourne, France, is the French representative to the IIASA Council, of which he is Vice-Chairman. He is currently head of an OECD study on the future development of advanced industrial societies in harmony with that of developing countries.

Dr. Roger Levien, United States, formerly of the Rand Corporation, Washington, D.C., came to IIASA as a research scholar and leader of the Survey project in 1974. He succeeded Howard Raiffa as Director of the Institute in November 1975.

Professor Hans Mottek, German Democratic Republic, is an environmentalist and Professor of History of Industrialization. Professor Mottek is a member of the Academy of Sciences of the German Democratic Republic.

Professor Eduard Pestel, Federal Republic of Germany, is a Professor at the Technical University of Hannover, and co-author with Mihailo Mesarovic of the study "Mankind at the Turning Point".

Professor Ferenc Rabar, Hungary, from the INFELOR Systems Engineering Institute, Budapest, has been affiliated with IIASA since 1973, and is leader of its research in food and agriculture.

Professor Howard Raiffa, United States, was the first Director of IIASA (1972-1975), and has been associated with the Institute since its earliest stages, serving from 1968-1972 as a science advisor in the negotiations which led to the founding of IIASA. He is currently Professor of Managerial Economics at Harvard University.

Academician Michail Styrikovich, Soviet Union, is head of the Department of Energetics of the USSR Academy of Sciences, and is a member of the IIASA Advisory Committee for the Energy Systems group.

Appendix 2: Conference Participants

REPRESENTATIVES OF NATIONAL MEMBER ORGANIZATIONS AND INVITEES FROM NMO COUNTRIES

The Academy of Sciences, Union of Soviet Socialist Republics

The Austrian Academy of Sciences

The Austrian Diplomatic Corps

The Committee for the International Institute for Applied Systems Analysis, Canada

The Committee for the International Institute for Applied Systems Analysis of the Czechoslovak Socialist Republic

The French Association for the Development of Systems Analysis

The Academy of Sciences of the German Democratic Republic

The Japan Committee for the International Institute for Applied Systems Analysis

The Max Planck Society for the Advancement of Sciences, Federal Republic of Germany

The Natioanl Centre for Cybernetics and Computer Techniques, People's Republic of Bulgaria

The National Academy of Sciences, United States of America

The National Research Council, Italy

The Polish Academy of Sciences

The Royal Society, United Kingdom

The Hungarian Committee for Applied Systems Analysis

INVITEES FROM NON-NMO COUNTRIES

REPRESENTATIVES OF INTERNATIONAL ORGANIZATIONS

IIASA PARTICIPANTS

Council Members

Scientific Staff

The Academy of Sciences, Union of Soviet Socialist Republics

Academician Yu.A. OVCHINNIKOV
Head of Delegation
Vice President
Academy of Sciences of the USSR
Leninsky Prosp., 14
Moscow, V-17

Academician Abel G. AGANBEGYAN
Institute of Economics and
Industrial Engineering
Siberian Branch of the
Academy of Sciences of the USSR
Novosibirsk, 90

Professor O.I. AVEN
Institute of Control Sciences
Profsojuznaya, 81
Moscow, V-279

Professor V.B. BELOUSOV
c/o State Committee for the USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow, K-9

Dr. A.P. DRUCHIN
c/o State Committee for the USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow, K-9

Professor S.V. EMELYANOV
Corresponding Member of
the Academy of Sciences of the USSR
Deputy Director
Institute of Control Sciences
Profsojuznaya, 81
Moscow, V-279

Academician V.M. GLUSHKOV
Director
Institute of Cybernetics
Ukrainian Academy of Sciences
Kiev

Academician L.V. KANTOROVICH
Mathematics Division
Academy of Sciences of the USSR
Leninsky Prosp., 14
Moscow, V-17

Professor G.I. KAVALEROV
Deputy Minister
Ministry of Instrumentation
and Automation
Ogareva 5
Moscow, K-9

Professor B.S. KHOREV
Center for Population Studies
Moscow State University
Leninskye Gory
Moscow

Professor Boris Z. MILNER
Institute of US and Canada Studies
Academy of Sciences of the USSR
2/3 Khlebny per.
Moscow, G-69

Professor A.A. POKROVSKY
Director
Institute of Nutrition
Moscow

Professor S.S. SHATALIN
Corresponding Member of
the Academy of Sciences of the USSR
Deputy Director
Central Economical Mathematical
Institute
Leninsky Prosp., 1
Moscow, V-17

Professor E.S. SHERSHNEV
Deputy Director
Institute of US and Canada Studies
Academy of Sciences of the USSR
2/3 Khlebny per.
Moscow, G-69

Academician Michail STYRIKOVICH
c/o State Committee for the USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow, K-9

Professor L.N. SUMAROKOV
c/o State Committee for the USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow, K-9

Professor Dimitri I. VALENTEI
Center for Population Studies
Faculty of Economics
Moscow State University
Leninskye Gory
Moscow

The Austrian Academy of Sciences

Dipl.Ing.Dr. Leopold BAUER
Institute of Energy
Technical University
Wiedner Hauptstrasse 7/4
1040 Vienna

Dr. Erich BIELKA
Bundesminister für Auswärtige
Angelegenheiten
Ballhausplatz 2
1010 Vienna

Professor Paul BLAU
Institut für Gesellschaftspolitik
der Kammer für Arbeiter und
Angestellte Wien
Prinz Eugen Strasse 20
1040 Vienna

Min.Rat Dr. BOLHAR-NORDENKAMPF
Bundesministerium für Handel,
Gewerbe und Industrie
Schwarzenbergplatz 1
1051 Vienna

Dr. James BOTKIN
Academic Director
The Salzburg Seminar
Schloss Leopoldskron
Salzburg

Dr. Rudolf BURGER
Bundesministerium für
Wissenschaft und Forschung
Sektion Forschung
Währingerstrasse 28
1090 Vienna

Dr. Hertha FIRNBERG
Bundesminister für Wissenschaft
und Forschung
Minoritenplatz 5
1010 Vienna

Dr. Peter FLEISSNER
Senior Scientist
Institute for Socio-Economic
Development
Fleischmarkt 20/3
1010 Vienna

Dr. Wilhelm FRANK
Sektionschef
Bundesministerium für Handel,
Gewerbe und Industrie
Sektion IV (Energie)
Schwarzenbergplatz 1
1010 Vienna

o.Prof.Dipl.Ing.Dr. Paul GILLI
Institut für Dampfkesselbau,
Reaktortechnik und Wärmewirtschaft
der Technischen Universität Graz
Kopernikusgasse 24
8010 Graz

Mr. Leopold GRATZ
Bürgermeister von Wien
Neues Rathaus
1082 Vienna

Prof.Dr. Hans GRÜMM
Scientific Technical Director
Österreichische Studien-
gesellschaft m.b.H.
Lenaugasse 10
1082 Vienna

Dr. Hans HÜBNER
Industrial Management and
Innovation Research
University of Innsbruck
Innrain 52
6020 Innsbruck

Dkfm.Dr. Heinz KIENZL
Generaldirektor
Österreichische Nationalbank
Otto Wagner-Platz 3
1090 Vienna

Bundeskanzler Dr. Bruno KREISKY
Ballhausplatz 1
1014 Vienna

Dr. Herbert MARGARETHA
Consultant
Bossigasse 2/a
1130 Vienna

Ing. Fred MARGULIES
Secretary
Gewerkschaft der Privatangestellten
Deutschmeisterplatz 2
1010 Vienna

Dr. Peter MIELING
General Manager
Shell Austria AG
Rennweg 12
1030 Vienna

Professor Dr. Othmar PREINING
Universität Wien
1. Physikalisches Institut
Strudelhofgasse 4
1090 Vienna

Dr. H. RAUCH
Mayor of Laxenburg
Schlossplatz 7-8
2361 Laxenburg

Dr. Norbert ROZSENICH
Abteilungsleiter
Bundesministerium für Wissenschaft
und Forschung
Währingerstrasse 28
1090 Vienna

Professor Dr. Franz SEITELBERGER
Rektor der Universität Wien
Dr. Karl-Lueger Ring 1
1010 Vienna

Dr. Ferdinand STEINHAUSER
Universitätsprofessor und Direktor
Zentralanstalt für Meteorologie
und Geodynamik
1190 Vienna

Professor Walter STÖHR
Interdisciplinary Institute for
Urban and Regional Studies
University of Economics
Hasenauerstrasse 42/8
1190 Vienna

Frau Dr. Erna WODAK
President of the
Austrian Friends of IIASA
Rennweg 6a
1030 Vienna

Hofrat DDr. Elmar WALTER
Bundesministerium für Wissenschaft
und Forschung
Sektion Forschung
Währingerstrasse 28
1090 Vienna

The Austrian Diplomatic Corps

Mr. L. AVRAMOV
Counsellor
Bulgarian Embassy
Schwindgasse 8
1040 Vienna

His Excellency T.H. BOT
Ambassador of the Netherlands to Austria
Untere-Donaustrasse 13-15/8
1020 Vienna

His Excellency Wiley T. BUCHANAN
Ambassador of the United States to Austria
Boltzmanngasse 16
1090 Vienna

His Excellency A. CAGIATI
Ambassador Of Italy to Austria
Rennweg 27
1030 Vienna

His Excellency M.T. EFREMOV
Ambassador of the Union of Soviet Socialist Republics to Austria
Reisnerstrasse 45-47
1030 Vienna

His Excellency Horst GRABERT
Ambassador of the Federal Republic of Germany to Austria
Metternichgasse 3
1030 Vienna

Dr. C. Julius HOFFMANN
Permanent Representative of the Federal Republic of Germany to the International Organizations in Vienna
Metternichgasse 3
1030 Vienna

Mr. J. HUMANN
First Secretary
French Embassy
Technikerstrasse 2
1040 Vienna

His Excellency Jussi MÄKINEN
Ambassador of Finland to Austria
Untere Donaustrasse 13-15
1020 Vienna

Mr. Konstantin MALINOWSKY
Counsellor
Embassy of the Union of Soviet Socialist Republics
Reisnerstrasse 45-47
1030 Vienna

His Excellency Hugh MORGAN
Ambassador of Great Britain to Austria
Reisnerstrasse 40
1030 Vienna

His Excellency Mostafa NAMDAR
Ambassador of Iran to Austria
Schwarzenbergplatz 2
1010 Vienna

His Excellency Lennart PETRI
Ambassador of Sweden to Austria
Obere Donau-Strasse 49-51
1020 Vienna

Dr. PRYSTROM
First Secretary
Polish Embassy
Hietzinger Hauptstrasse 42c
1130 Vienna

Dr. R. RAHMAN
Counsellor
Pakistan Embassy
Gloriettegasse 22
1130 Vienna

Mr. Ernst ROTH
Permanent Representation of the Federal Republic of Germany to the International Organizations in Vienna
Metternichgasse 3
1030 Vienna

His Excellency G. SCHRAMM
Ambassador of the German Democratic Republic to Austria
Frimbergergasse 6-8
1130 Vienna

Dr. Gerhard THOMAS
Counsellor
Permanent Mission of the German Democratic Republic to the International Organizations in Vienna
Bauernmarkt 6/5/12
1010 Vienna

The Committee for the International Institute for Applied Systems Analysis, Canada

Mr. E. ARMSTRONG
Assistant Deputy Minister
Department of the Environment
Government of Canada
Ottawa, Ontario K1A OH3

Dr. A.R. DOBELL
Deputy Secretary
Planning Branch
Treasury Board Secretariat
160 Elgin Street
Ottawa, Ontario MRN 575

Professor Michael FLORIAN
Director
Transportation Research Center
P.O. Box 6128
Montreal 101, Quebec

Dr. P. GENDRON
President
Pulp and Paper Research Institute of Canada
570 St. John's Boulevard
Pointe Claire, Quebec

Mr. Fred W. GORBET
Senior Policy Adviser
Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario

Mr. J. GRATWICK
Vice-President, Research and Development
Canadian National Railways
P.O. Box 8100
Montreal, Quebec H3C 3N4

Professor C.S. HOLLING
Institute of Resource Ecology
University of British Columbia
Vancouver, British Columbia

Dr. M.J.L. KIRBY
Assistant Principal Secretary to the Prime Minister of Canada
Room 207, East Block,
Parliament Buildings
Ottawa, Ontario K1A OA2

Dr. George LINDSEY
Chief, Operational Research and Analysis Establishment
Ottawa, Ontario K1A OK2

Professor John H. MILSUM
Director, Divison of Health Systems
University of British Columbia
4th Floor, I.R.C. Building
Vancouver, British Columbia

Dr. Harry SWAIN
Policy Analyst
Treasury Board Secretariat
Government of Canada
1804-5770 Spring Garden Road
Halifax, Nova Scotia

<u>The Committee for the International Institute for Applied Systems Analysis of the Czechoslovak Socialist Republic</u>

Mr. F. CIFERSKY
Head, Department of Automated
Management Systems
Federal Ministry of Technology
and Investments
Slezska 9
12029 Prague 2

Dr. Lubomir PETRAS
Director, Department for Mine
Construction
Ostrawa

Mr. J. VRBSKY
Senior Specialist
Federal Ministry of Technology
and Investments
Slezska 9
12029 Prague 2

Mr. J. ZALUD
Head, Department of Scientific
and Technological Forecasts
Federal Ministry of Technology
and Investments
Slezska 9
12029 Prague 2

The French Association for the Development of Systems Analysis

Mr. Maurice COMTET
Chef du Service Evaluation
Prospective - DRST
Société ELF-AQUITAINE
7, rue Nélaton
Paris

Mr. Pierre CREYSSEL
Directeur Administratif et Financier
Centre National de la Recherche
Scientifique et Technique (CNRS)
15, quai Anatole
75700 Paris

Professor R. GIBRAT
Conseiller scientifique
A.F.D.A.S.
101, avenue de Villiers
75017 Paris

Mr. Robert JANIN
Chef Adjoint du Service de la
Production Thermique
Electricité de France
3, rue de Messine
75008 Paris

Professor Germain KREWERAS
University of Paris
Bureau Universitaire de Recherche
Operationnelle
40, rue Lacépède
75005 Paris

Mr. Paul MENTRE
Délégué Général à lEnergie
35, rue St. Dominique
75700 Paris

Professor Bertrand MUNIER
Professor of Economics
Faculté des Sciences de Luminy
70, route Léon Lachamp
13009 Marseille

Mrs. Claire de NARBONNE
Secretaire General de A.F.D.A.S.
35, rue St. Dominique
75700 Paris

Mr. NIVELET
Institut de Recherche
d'Informatique et d'Automatique
78150 Rocquencourt

Mr. PELEGRIN
Directeur de l'Ecole Nationale
Supérieure de l'Aéronautique
et de l'Espace
31055 Toulouse - l'Espinet

Miss PRAT
CNES
129, rue de l'Université
75700 Paris

Mr. Bernard WALLISER
Chargé de Mission
Direction de la Prévision
Ministère des Finances
9, rue Croix-des-Petit-Champs
75001 Paris

Mrs. VERGUESE
Scientific Journalist
"Le Monde"
Paris

The Academy of Sciences of the German Democratic Republic

Academician W. KALWEIT
Head of Delegation
Vice-President of the
Academy of Sciences of the
German Democratic Republic
Otto-Nuschkestrasse 22/23
108 Berlin

Dr. FISCHER
Department Head
Ministry of Science
and Technology
Berlin

Dr. KHAN
Director of Institute
of Energetics
Torgauerstrasse 114
7024 Leipzig

Professor Helmut KOZIOLEK
Academy of Sciences of the
German Democratic Republic
Otto-Nuschkestrasse 22/23
108 Berlin

Professor Dr. Hans MOTTEK
Academy of Sciences of the
German Democratic Republic
Otto-Nuschkestrasse 22/23
108 Berlin

Professor Dr. Horst STROBEL
Hochschule für Verkehrswesen
"Friedrich Liszt"
Friedrich-Liszt-Platz 1
Dresden

Mr. W. VOIGT
Academy of Sciences of the
German Democratic Republic
Otto-Nuschkestrasse 22/23
108 Berlin

The Japan Committee for the International Institute for Applied Systems Analysis

Professor Kazuhiko ATSUMI
Director
Institute of Medical Electronics
Faculty of Medicine
University of Tokyo
7-3-1, Hongo, Bunkyo-ku
Tokyo

Mr. Hirotaka EGASHIRA
Assistant Manager
Sumitomo Metal Industries Ltd.
Düsseldorf Office
Königsallee 48
4000 Düsseldorf
Federal Republic of Germany

Mr. K. FUJIMOTO
Head, Jetro-Japan Trade Center
Auerspergstrasse 6
1010 Vienna
Austria

Mr. Norishige HASEGAWA
President
Sumitomo Chemical Co., Ltd.
15 5-chome, Kitahama, Higashi-ku
Osaka

Professor Tadeo MIYAKAWA
Professor of Management Science
Department of Business
Administration
Hitotsubashi University
2-1 Naka, Kunitachi
Tokyo

Mr. Atsuyuki SUZUKI
Research Associate
Department of Nuclear Engineering
Faculty of Engineering
University of Tokyo
7-3-1, Hongo, Bunkyo-ku
Tokyo

Mr. Tetsutaro SUZUKI
Vice-President
National Institute for Research
Advancement (NIRA)
1-1 Nishi-Shinjuku 2-chome
Mitsui Bldg. 37th Floor
Shinjuku-ku
Tokyo

Mr. Toru UDO
The Japan Committee for IIASA
P.O. Box 104, W.T.C.
Tokyo 105

Mr. M. UEMATSU
Secretary
Japan Committee for IIASA
P.O. Box 104, W.T.C.
Tokyo 105

Mr. Teruo USHIJIMA
Associate Professor
University of Electro-Communications
Tokyo
c/o Université de Paris VI
Chambre 2074
Résidence Universitaire
Bures-Nord, Bat. 233
91440 Bures sur Yvette, France

Mr. Masa-aki YOKOTSUKA
Secretary
Sumitomo Chemical Co., Ltd.
Düsseldorf Office
Georg Glock Strasse 14
4000 Düsseldorf 30
Federal Republic of Germany

The Max Planck Society for the Advancement of Sciences,
Federal Republic of Germany

Dr. Rudolf AVENHAUS
Gesellschaft für Kernforschung
Karlsruhe
Weberstrasse 5
7500 Karlsruhe

Professor Dr. Karl Heinz BECKURTS
Director
Kernforschungsanlage Jülich
Victor Gollanczstrasse 2
517 Jülich

Dr. Klaus BLECH
Ministerialdirector
Leiter des Planungsstabes
des Auswärtigen Amtes
Adenauer Allee 99-103
5300 Bonn

Professor Klaus GOTTSTEIN
Max Planck Institut
Starnberg
Riemerschmidstrasse 7
813 Starnberg

Dr. Rolf GREMMELMAIER
Director
Siemens AG, Research Laboratories
Guenther-Scharowsky-Strasse 2
8520 Erlangen

Dr. Rudolf HARDE
Vorsitzender des Vorstands
Gesellschaft für Kernforschung mbH
Weberstrasse 5
7500 Karlsruhe

Dr. Peter JANSEN
Institut für Angewandte System-
technik und Reaktorforschung
Kernforschungszentrum Karlsruhe
P.O. Box 3640
7500 Karlsruhe

Professor Hermann L. JORDAN
Vorsitzender des Vorstands
Deutsche Forschungs-
und Versuchsanstalt für Luft-
und Raumfahrt e.V.
Linder Höhe, Postfach 90 60 58
5000 Cologne 90

Dr. Rudolf KERSCHER
Deputy Secretary General
Stiftung Volkswagenwerk
Kastanienallee 5
Hannover

Professor Dr. Gert von KORTZFLEISCH
University of Mannheim
Schlossuniversität
68 Mannheim

Professor Dr. Eduard PESTEL
Vizepräsident der Deutschen
Forschungsgemeinschaft
Kennedyalle 40
5300 Bonn
Bad Godesberg

Dr. Hermann SCHMITZ-WENZEL
Ministerialrat im Bundeskanzleramt
Adenauer Allee 139-141
5300 Bonn

Dr. SCHRÖTER
Bundesministerium für Forschung
und Technologie
Referat 213
Postfach 12 03 70
5300 Bonn 12

Mr. Wolfgang ZUCKSCHWERDT
Bundesministerium für Forschung
und Technologie
Stresemannstrasse 2
5300 Bonn

The National Centre for Cybernetics and Computer Techniques, People's Republic of Bulgaria

Mr. Dimitr BAEV
Scientific Secretary
Central Research Institute for Automation
J. Vishovgradsky 46
Sofia

Director Emil BOJANOV
Central Research Institute for Automation
J. Vishovgradsky 46
Sofia

Mr. Angel CENOV
Deputy-Director
Institute of Social Hygiene and Organization of Public Health
D. Nesterov 15
Sofia

Mr. Lubomir GLUSHKOV
Head of Department
Institute for Social Management
Pionersky put 21
Sofia

Mr. Mincho HADJIISKI
Associate Professor
Board on New Energy Sources
Council of Ministers
Square Slaveikov 4a
Sofia

Mr. Lazar LAZAROV
Specialist
Committee for Science, Technical Progress, and Higher Education
Gr. Ignatiev 15
Sofia

Mr. A. LUKANOV
First Deputy Minister for Foreign Trade
Sofia

Mr. Boris MIHAILOV
Associate Professor
Senior Counsellor
Council for Social Development
2, Dondukov Boulevard
Sofia

Professor N. NAPLATANOV
Director
Institute of Engineering Cybernetics
Bulgarian Academy of Sciences
Sofia

Mr. Nocho PAPASOV
Minister for Science and Technology
Sofia

Professor Eng. Trayko PETKOV
Deputy Minister
Ministry of Information, Post, and Telecommunications
2, Volov Street
Sofia

Mr. Boris PURVULOV
Associate Professor
Vice President
Council for Social Development
2, Dondukov Boulevard
Sofia

Mr. Ivan STOIKOV
Specialist
Committee for Science, Technical Progress, and Higher Education
Gr. Ignatiev 15
Sofia

The National Academy of Sciences, United States of America

Dr. Gerald O. BARNEY
National Program Coordinator
Rockefeller Brothers Fund
30 Rockefeller Plaza
New York, New York 10020

Dr. McGeorge BUNDY
President
The Ford Foundation
320 East 43rd Street
New York, New York 10017

Mr. Warren M. CANNON
Director
McKinsey and Company, Inc.
245 Park Avenue 18th Floor
New York, New York 10017

Professor George B. DANTZIG
Stanford University
Operations Research Center
Stanford, California 94305

Professor Henry DAVID
Professor of Public Affairs
University of Texas at Austin
Lyndon B. Johnson School of
Public Affairs
Austin, Texas 78712

Professor W.R. DILL
Dean of the Faculty of
Business Administration
New York University
100 Trinity Place
New York, New York 10006

Dr. N. HACKERMAN
Chairman
National Science Board
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Dr. Philip HANDLER
President
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418

Dr. Charles J. HITCH
President
Resources for the Future
1755 Massachusetts Avenue, N.W.
Washington, D.C. 20036

Dr. J.D. HOLMFELD
Science Policy Consultant
Committee on Science and Technology
United States House of Representatives
Rayburn House, Office Building 2319
Washington, D.C. 20515

Professor Tjalling C. KOOPMANS
Department of Economics
Yale University
Cowles Foundation
P.O. Box 2125, Yale Station
New Haven, Connecticut 06520

Professor Irving LEFKOWITZ
Systems Engineering Department
Case Western Reserve University
University Circle
Cleveland, Ohio 44106

Dr. Roger W.A. LEGASSIE
Assistant Administrator for
Planning and Analysis
United States Energy Research
and Development Administration
Washington, D.C. 20545

Dr. Daniel P. LOUCKS
Associate Professor
Department of Environmental
Engineering
Cornell University
Ithaca, New York 14853

Dr. Thomas F. MALONE
Director
Holcomb Research Institute
Butler University
Indianapolis, Indiana 46208

Mr. Harvey McMAINS
Vice President and Executive
Director
National Bureau of Economic
Research
261 Madison Avenue
New York, New York 10016

Mr. Augustus NASMITH, Jr.
Assistant
National Academy of Sciences
Office of the Foreign Secretary
2101 Constitution Avenue
Washington, D.C. 20418

Dr. Carol NEWTON
Health Sciences Computing Facility
School of Medicine
University of California
Los Angeles, California 90024

Dr. C.D. PERKINS
President
National Academy of Engineering
2101 Constitution Avenue
Washington, D.C. 20418

Professor Howard RAIFFA
Littauer Center
J.F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

Mr. Robert D. SCHMIDT
Executive Vice-President
Control Data Corporation
8100 34th Avenue
South Minneapolis, Minnesota 55420

Mr. L. Donald SHIELDS
Member of the National Science
Board
President of the California
State University at Fullerton
Fullerton, California 92634

Mr. Paul SITTON
Special Assistant to Dr. Handler
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Mr. John STREMLAU
Assistant Director
Conflict in International
Relations Program
The Rockefeller Foundation
1133 Avenue of the Americas
New York, New York 10036

Professor H. WAGNER
School of Organization and
Management
56 Hillhouse Avenue
New Haven, Connecticut 06520

Dr. Alvin M. WEINBERG
Director
Institute for Energy Analysis
Oak Ridge Associated Universities
P.O. Box 117
Oak Ridge, Tennessee 37830

Dr. Beatrice E. WILLARD
Executive Office of the President's
Council on Environmental Quality
722 Jackson Place, N.W.
Washington, D.C. 20006

<u>The National Research Council, Italy</u>

Professor Augusto CLERICI
Facolta di Architettura
Politecnico di Torino
Via Mattioci 39
Turin

Mr. Umberto MONTALENTI
Director of Promotion and Planning
Fiat S.p.A. - Centro Ricerche
Strada Torino 50
Orbassano (Turin)

Professor Antonio RUBERTI
Dean
School of Engineering
University of Rome
Via Eudossiana 18
Rome

Professor Gabriele SCIMEMI
University of Rome
Via Taramelli 5
Rome

Mr. Mario SILVESTRI
Chairman of the Technology Committee
Consiglio Nazionale delle Ricerche
(CNR)
Via Amedeo d'Aosta, 9
Milan

The Polish Academy of Sciences

Professor Jan KACZMAREK
Head of Delegation
Scientific Secretary of the
Polish Academy of Sciences
Warsaw

Mr. K. BANY
Office of International Relations
of the Polish Academy of Sciences
Warsaw

Professor Ryszard DOMANSKI
Rector
Akademia Ekonomiczna
Marchlewskiego 146
Poznan

Professor W. FINDEISEN
Institute of Automatic Control
Technical University of Warsaw
Nowowiejska 15/19
Warsaw

Professor K. PORWIT
Director
Planning Institute of the State
Planning Commission
Warsaw

Professor SIKORSKI
Committee for Informatics
Polish Academy of Sciences
Warsaw

Professor A. STRASZAK
Director
Institute for Organization,
Management and Control Science
KRN 55
Warsaw

The Royal Society, United Kingdom

Dr. Martin BEALE
Director
Scientific Control Systems Ltd.
Brick Close, Kiln Farm
Milton Keynes, Buckinghamshire

Mr. James D. CAMERON
Editor
John Wiley & Sons, Ltd.
Baffins Lane
Chichester, Sussex PO19 1UD

Professor W. HRYNISZAK
Chairman of the Advisory Board
The Energy Centre
University of Newcastle-Upon-Tyne
37, Jesmond Road
Newcastle-Upon-Tyne

Dr. Ronald W.J. KEAY
Deputy Executive Secretary
The Royal Society
6 Carlton House Terrace,
London SW1Y 5AG

Sir Maurice KENDALL
Project Director
World Fertility Survey
International Statistical Institute
35-37 Grosvenor Gardens
London SW1 WOBS

Mr. A.G. McDONALD
Chief Scientific Officer
Department of Health and Social Security
151 Great Titchfield Street
London W1P 8AD

Professor C.G. PARKS
Shrivenham College
Swindon, Wiltshire

Mr. Peter ROBERTS
Department of the Environment
Marsham Street
London SW1P 3EB

Professor H.H. ROSENBROCK
F.R.S.
Manor Lodge
Mill Lane
Cheadle, Cheshire

Mr. Rolfe C. TOMLINSON
Managing Director
Operational Research Executive
National Coal Board
Coal House, Lyon Road
Harrow, Middlesex HA1 2EX

The Hungarian Committee for Applied Systems Analysis

Dr. I. DANCS
Secretary
Hungarian Committee for Applied
Systems Analysis
Orszagos Tervhivatal Elnoekhelyettes
V. Arany Janos u. 6-8
1370 Budapest

Dr. Laszlo DÁVID
Head
Water Resources Development Section
Hungarian National Water Authority
Fö Str. 48-50
1011 Budapest

Dr. Sandor DOLESCHALL
Director, Executive Manager
Central Research Institute for
Physics
Konkoly Thege ut 29-33
1121 Budapest

Dr. Jozsef HATVANY
Division Head
Computer and Automation Institute
Hungarian Academy of Sciences
Kende-U 13-17
1502 Budapest

Dr. KOVACS
Computer and Automation Institute
Hungarian Academy of Sciences
Kende-U 13-17
1502 Budapest

Dr. Kalman KULCSAR
Professor and Director
Institute of Sociology
Hungarian Academy of Sciences
Uri u. 49
1014 Budapest

Dr. L. LACKO
Deputy Head of Department
Hungarian Committee for Applied
Systems Analysis
Orszagos Tervhivatal Elnoekhelyettes
V. Arany Janos u. 6-8
1370 Budapest

Dr. Geza NYIRY
Deputy Director
Research Institute for Applied
Computer Sciences
Csalogany 30-32
Budapest

Professor B. SZOKEFALVI-NAGY
Bolyai Institute
Aradi Vertanuk Tere
6720 SZEGED

Dr. E. ZALAI
Hungarian Committee for Applied
Systems Analysis
Orszagos Tervhivatal Elnoekhelyettes
V. Arany Janos u. 6-8
1370 Budapest

Invitees from Non-NMO Countries

Mr. Göran FICK
Executive Secretary
Science Policy and Research
Management
Royal Swedish Academy of Engineering
Sciences (IVA)
P.O. Box 5073
102 42 Stockholm, Sweden

Mr. Georges A. GRIN
Coordinator and Science Advisor
Council of the Federal Institutes
of Technology
10, Place de la Gare
1003 Lausanne, Switzerland

Dr. Elisabeth HELANDER
The Academy of Finland
Lauttasaarentie 1
00200 Helsinki 20, Finland

Professor Dr. J.M.L. JANSSEN
Technische Hogeschool Twente
Postbus 217
Enschede, The Netherlands

Mr. Markku LINNA
Head of Bureau
Ministry of Education
Rauhankatu 4
00170 Helsinki 17, Finland

Mr. L.J. MOSTERTMAN
Director
International Courses of
Hydraulics and Sanitary Engineering
Onde Delft 95,
Delft, The Netherlands

Professor Dr. Gerhart W. RATHENAU
Member of the Scientific Council
for Government Policy
Professor of the University of
Amsterdam
Hoge Duinlaan 24
Aalst-Waalre, The Netherlands

Professor Pekka SALMINEN
Technical Research Center of Finland
Electrical Engineering Laboratory
02150 Espoo 50, Finland

Professor Jean SIOTIS
Graduate Institute of International
Studies
Deputy Director, Centre de
Recherches sur les Institutions
Internationales
11A av. de la Paix
1211 Geneva 20, Switzerland

Dipl.Eng. Veronika SUNI
Secretary General
Ministry for Foreign Affairs and
Technological Cooperation between
Finland and the USSR
Pohjoisranta 4
00170 Helsinki 17, Finland

Professor Dr. Pieter de Wolff
University of Amsterdam
Jodenbreestraat 23
Amsterdam, The Netherlands

Representatives of International Organizations

United Nations Environment Programme (UNEP)
P.O. Box 30552
Nairobi, Kenya

Dr. S.A. EVTEEV
Director of Policy Planning Office

United Nations Centre for Regional Development
Marunouchi 2-4-7
Naka-ku
Nagayo 460, Japan

Mr. Fu-chen LO
Chief, Comparative Studies

United Nations Industrial Development Organization (UNIDO)
P.O. Box 707
1010 Vienna, Austria

Mr. L. BABIC
Chief, Industrial Planning Section

Dr. Young Rin CHO
Global and Conceptual Studies Section
International Centre for Industrial Studies

Mr. F. Le GUAY
Office of the Executive Director

World Health Organization (WHO)
Avenue Appia
1211 Geneva 27, Switzerland

Dr. Norman T. BAILEY
Health Statistical Methodology

Food and Agriculture Organization of the United Nations (FAO)
Via delle Terme di Caracalla
00100 Rome, Italy

Mr. J. O'HAGAN
Chief, Global Perspective Studies Service
Policy Analysis Division

World Meteorological Organization (WHO)
41 Ave. Giuseppe Motta
1211 Geneva, Switzerland

Professor C.C. WALLEN
Chief, Environmental and Special Applications Division
of the Meteorological Applications and
Environment Department

<u>International Atomic Energy Agency (IAEA)</u>
Kärntner Ring 11
1010 Vienna, Austria

Dr. J.-P. CHARPENTIER

Dr. A.F.V. FISCHER
Assistant Director General for
External Relations

Mr. Hellmut GLUBRECHT
Deputy Director General
Department of Research and Isotopes

Mr. Rurik KRYMM
Senior Officer, Section Head
Economic Studies Section

Mr. Vinay MECKONI
Project Leader
Regional Fuel Cycle Centres Study Project
Department of Technical Operations

Dr. F. NIEHAUS

Dr. Harry OTWAY

Mr. A.-J. POLLIART
Director
Division of Nuclear Power and Reactors

Mr. Ivan D. ZHELUDEV
Deputy Director General

<u>International Federation of Automatic Control (IFAC)</u>

Mr. U.A. LUOTO
President of IFAC
c/o EKONO
P.O. Box 27
00131 Helsinki, Finland

<u>International Federation for Institutes of Advanced Study (IFIAS)</u>
The Nobel House
Sturegatan 14
P.O. Box 5344
10246 Stockholm, Sweden

Dr. Sam NILSSON
Executive Secretary

<u>International Federation for Information Processing (IFIP)</u>

Mr. Jan ROUKENS
Director
c/o SAZZOG Foundation
GA van Nispenstraat 37
Arnhem, The Netherlands

International Energy Agency (IEA)
2, rue André Pascal
75775 Paris - Cedex 16, France

Mr. J. Wallace HOPKINS, Jr.
Deputy Executive Director

Organisation for Economic Cooperation and Development (OECD)
2, rue André Pascal
75775 Paris - Cedex 16, France

Mr. Koichi OSHIMA
Director for Science, Technology and Industry

Mr. Remy PRUDHOMME
Deputy Director of Environment

United Nations Economic Commission for Europe (ECE)
Palais des Nations
1211 Geneva 10, Switzerland

Mr. A. LACKNER
Technical Advisor on Data Processing
Statistical Office

Mr. Janez STANOVNIK
Executive Secretary

Organization of Petroleum Exporting Countries (OPEC)
Dr. Karl Lueger Ring 10
1010 Vienna, Austria

Mr. W.F. DUBLIN-GREEN
Senior Exploration Officer

Mr. M.O. OLORUNFEMI
Senior Financial Analyst

Mr. J.M. TINEO
Senior Economic Analyst

International Federation of Operational Research Societies (IFORS)

Professor Takehiko MATSUDA
President of IFORS
c/o Tokyo Institute of Technology
Department of Management Engineering
2-12-1 O-okayama Meguru-ku
Tokyo 152, Japan

IIASA Participants

Council Members

Professor Jermen GVISHIANI (Chairman of the Council and Executive Committee)	The Academy of Sciences c/o State Committee for the USSR Council of Ministers for Science and Technology 11 Gorky Street Moscow, USSR
Professor Leopold SCHMETTERER	The Austrian Academy of Sciences Institute of Research for Socio-Economic Development Fleischmarkt 20/1/1/4 1010 Vienna, Austria
Dr. Rennie WHITEHEAD Dr. Michael J.L. KIRBY*	The Committee for the International Institute for Applied Systems Analysis c/o Mrs. Janice Hayward Institute for Research on Public Policy Suite 514, 3535 Queen Mary Road Montreal, Quebec H3V 1H8, Canada
Dr. Tibor VAŠKO	The Committee for the International Institute for Applied Systems Analysis of the Czechoslovak Socialist Republic Slezska 9, Vinohrady Prague 2, Czechoslovakia
Mr. Jacques LESOURNE (Vice Chairman of the Council)	The French Association for the Development of Systems Analysis 35, rue St. Dominique 75700 Paris, France
Professor Karl BICHTLER (Vice Chairman of the Council)	The Academy of Sciences of the German Democratic Republic Otto-Nuschkestrasse 22/23 108 Berlin, GDR
Professor Koichi MIYASAWA (representing Dr. Hiromi ARISAWA)	The Japan Committee for the International Institute for Applied Systems Analysis Institute of Information Technology World Trade Center Building 7F, 2-4-1 Hamamatsucho Tokyo 105, Japan

---

*Dr. Kirby replaced Dr. Whitehead in his function as Council member as of May 13, 1976.

Dr. Friedrich SCHNEIDER	The Max Planck Society for the Advancement of Sciences P.O. Box 647 8000 Munich 1, FRG
Professor Hinko HINOV	The National Centre for Cybernetics and Computer Techniques Slavjanska 9 Sofia, People's Republic of Bulgaria
Professor George HAMMOND (Chairman of the Finance Committee)	The National Academy of Sciences c/o Office of the Foreign Secretary 2101 Constitution Avenue Washington, D.C. 20418, USA
Professor Alberto ISIDORI (representing Professor Alessandro FAEDO)	The National Research Council Piazzale delle Scienze Rome, Italy
Professor Roman KULIKOWSKI	The Polish Academy of Sciences P.O. Box 22 00-901 Warsaw, Poland
Sir Kingsley DUNHAM (Chairman of the Membership Committee)	The Royal Society 6 Carlton House Terrace London S.W.1, UK
Dr. Sandor GANCZER	The Hungarian Committee for Applied Systems Analysis Orszagos Tervhivatal elnökhelyettes V. Arany Janos u.6-8 1370 Budapest, Hungary
Dr. Roger LEVIEN	Director, IIASA
Professor Wolf HÄFELE	Deputy Director Leader of the Energy Program IIASA
Dr. Andrei BYKOV	Secretary, IIASA

IIASA Scientific Staff

Research Programs

Energy Systems Program Core

Charles Bell	USA
Michel Grenon	France
Wolf Häfele	FRG
C.J. Huang	USA
Fredy Jäger	FRG
Cesare Marchetti	Italy
Wolfgang Sassin	FRG
Plamen Tsvetanov	Bulgaria

IRD Program Core

Michel Balinski	USA
Wesley Foell	USA
Zdzislaw Kaczmarek	Poland
Hans Knop	GDR
Roger Levien	USA

Research Areas

Resources and Environment

Alexandre Bazykin	USSR
Jacqueline Buehring	USA
William Buehring	USA
Bernard Chaix	France
Robin Dennis	USA
Wesley Foell	USA
Ilya Gouevsky	Bulgaria
Zdzislaw Kaczmarek	Poland
Michiel Keyzer	Netherlands
Roman Kulikowski	Poland
Bruno Lapillonne	France
William Matthews	USA
Kirit Parikh	India
Todor Popov	Bulgaria
Ferenc Rabar	Hungary
Jürgen Schmidt	GDR
Richard Seidl	Austria
András Szöllösi-Nagy	Hungary
Kuniyoshi Takeuchi	Japan
Eric Wood	Canada

Human Settlements and Services

Jean-Michel Beaujean	France
Edward Blum	USA
Peter Fleissner	Austria
Niles Hansen	USA
Alexandr Kiselev	USSR
Alexandre Klementiev	USSR
Dagmar Maurer	Austria
John Miron	Canada
Philip Pahner	USA
Andrei Rogers	USA
Horst Strobel	GDR

Human Settlements and Services (con't.)

Elizabeth Swaton	Austria
Dimitrii Venedictov	USSR
Willy Weisz	Austria
William Welsh	USA
Frans Willekens	Belgium

Management and Technology

Abel Aganbegyan	USSR
Cyril Davies	UK
F.G. de Jong	Canada
Ada Demb	USA
Raul Espejo	Bolivia
Saburo Ikeda	Japan
Hans Knop	GDR
Bohumil Mazel	CSSR
Roman Ostrowski	Poland
Jan Owsinski	Poland
Kurt Schaffir	USA
Andrej Straszak	Poland
German Surguchev	USSR
Detlof von Winterfeldt	FRG

System and Decision Sciences

Michel Balinski	USA
Lev Belyaev	USSR
Hermann Bodenseher	Austria
Alexandre Butrimenko	USSR
John Casti	USA
Valeri Dashko	USSR
Jacques Gros	USA
Hans-Richard Grümm	Austria
Ralph Keeney	USA
Yuri Kononov	USSR
Johannes Ledolter	Austria
Joanne Linnerooth	USA
Yoshifumi Masunaga	Japan
Morris Norman	Canada
William Orchard-Hays	USA
Vaclav Peterka	CSSR
Andrzej Radzimiński	Poland
Gerhard Rahmstorf	FRG
Norbert Rozsenich	Austria
Leo Schrattenholzer	Austria
John Sexton	UK
Peter Sint	Austria
Fernanda Toueg	Italy
Peyton Young	USA
Igor Zimin	USSR

General Research

Gerhart Bruckmann	Austria
Roger Levien	USA
Giandomenico Majone	Italy
Edward Quade	USA
Vil Rakhmankulov	USSR

Appendix 3: Table of Contents of Volume 2

RESOURCES AND ENVIRONMENT

Z. Kaczmarek
Tisza and Vistula River Basins: Case Studies

E.F. Wood
Applying Multiattribute Utility Theory to Evaluation of Tisza River Basin Development Plans

A. Szöllösi-Nagy
Application of On-Line Prediction Techniques to Forecasting Short-Term Agricultural Water Demand

L. Dávid
Development of the Tisza River Basin

Discussion
(R. Dennis and I. Gouevsky, Rapporteurs)

HUMAN SETTLEMENTS AND SERVICES

H. Swain
Introduction

N. Hansen
Systems Approaches to Human Settlements

A. Rogers
Migration and Settlement

J.R. Miron
Regional Development and Land-Use Models

W.A. Welsh
Interregional Variations in Public Goods and Services

H. Strobel
Transportation, Automation and Urban Development

E.H. Blum
Urban Emergency Services

D.D. Venedictov
Modeling of Health Care Systems

Discussion
(J.R. Miron and A. Klementiev, Rapporteurs)

MANAGEMENT AND TECHNOLOGY

H. Knop
Introduction

C. Davies, A. Demb, R. Espejo, and R. Ostrowski
An Organizational Approach to Regional Development

J. Owsinski and D. v. Winterfeldt
Models and Decision-Making in Integrated Regional Development

Discussion
(R. Ostrowski, Rapporteur)

I. Lefkowitz
The Steel Case: Conceptual Framework and Hierarchical Control

Discussion
(G. Surguchev, Rapporteur)

SYSTEM AND DECISION SCIENCES

M.L. Balinski
Introduction

G.B. Dantzig
A PILOT Linear Programming Model for Assessing Physical Impact on the Economy of a Changing Energy Picture

A. Butrimenko
Computer Networking

R.L. Keeney
Aspects of Multiple-Objective Evaluation at IIASA

H.R. Grümm
Resilience and Related Mathematical Concepts

V.M. Glushkov
Computer Networks: Comment on a IIASA Research Activity

Discussion
(H.P. Young and F. Toueg, Rapporteurs)

APPENDIXES

Appendix 1: About the Authors

Appendix 2: Table of Contents of Volume 1

IIASA Conference '76

VOLUME 2
10-13 MAY 1976

IIASA CONFERENCE '76

10–13 May, 1976

Volume 2

PREFACE

The IIASA Conference '76 was the first General Conference of the International Institute for Applied Systems Analysis. It provided a major forum for review of the creation, development, research, and future role of IIASA. Thus, these proceedings provide a comprehensive report on the first three years of the Institute.

The proceedings appear in two volumes. Volume 1 contains presentations, comments, and discussions on the concept of IIASA, its creation and research strategy, its studies of global issues (including energy, food, and global development), its work on regional issues, the relationship between analysis and policy-making, and the role of policy analysis in an international setting. The invited comments of the National Member Organizations on the development of the Institute and on the Conference also appear in Volume 1. A list of participants and the table of contents for Volume 2 are appended.

Volume 2 contains presentations, comments, and discussions of the research areas: Resources and Environment, Human Settlements and Services, Management and Technology, and System and Decision Sciences. The table of contents of Volume 1 is appended.

Each volume contains brief biographies of the authors of presentations in that volume.

Recognition is due to the Council of the Institute and the Austrian Government for their significant contribution to the development of the Institute; to the participants of the Conference for their support and guidance; and to the IIASA staff for the spirit and effort devoted to the Conference and the preparation of the proceedings.

Table of Contents

RESOURCES AND ENVIRONMENT

Z. Kaczmarek
Tisza and Vistula River Basins: Case Studies 3

E.F. Wood
Applying Multiattribute Utility Theory to Evaluation of Tisza River Basin Development Plans 9

A. Szöllösi-Nagy
Application of On-Line Prediction Techniques to Forecasting Short-Term Agricultural Water Demand 19

L. Dávid
Development of the Tisza River Basin 25

Discussion
(R. Dennis and I. Gouevsky, Rapporteurs) 31

HUMAN SETTLEMENTS AND SERVICES

H. Swain
Introduction 35

N. Hansen
Systems Approaches to Human Settlements 37

A. Rogers
Migration and Settlement 43

J.R. Miron
Regional Development and Land-Use Models 69

W.A. Welsh
Interregional Variations in Public Goods and Services 75

H. Strobel
Transportation, Automation and Urban Development 85

E.H. Blum
Urban Emergency Services 93

D.D. Venedictov
Modeling of Health Care Systems 101

Discussion
(J.R. Miron and A.A. Klementiev, Rapporteurs) 115

MANAGEMENT AND TECHNOLOGY

H. Knop
Introduction 119

C. Davies, A. Demb, R. Espejo, and R. Ostrowski
An Organizational Approach to Integrated Regional Development 123

J. Owsinski and D. v. Winterfeldt
Models and Decision-Making in Integrated Regional Development 135

Discussion
(R. Ostrowski, Rapporteur) 151

I. Lefkowitz
The Steel Case: Conceptual Framework and Hierarchical Control Approach 155

Discussion
(G. Surguchev, Rapporteur) 173

SYSTEM AND DECISION SCIENCES

M.L. Balinski
Introduction 177

G.B. Dantzig
A PILOT Linear Programming Model for Assessing Physical Impact on the Economy of a Changing Energy Picture 183

A. Butrimenko
Computer Networking 201

R.L. Keeney
Aspects of Multiple-Objective Evaluation at IIASA 215

H.R. Grümm
Resilience and Related Mathematical Concepts 225

V.M. Glushkov
Computer Networks: Comment on a IIASA Research Activity 235

Discussion
(H.P. Young and F. Toueg, Rapporteurs) 239

APPENDIXES

Appendix 1: About the Authors 245

Appendix 2: Table of Contents of Volume 1 249

RESOURCES AND ENVIRONMENT

Tisza and Vistula River Basins: Case Studies

Z. Kaczmarek

The IIASA Water Resources group concentrates on methodological and applied problems of optimal water resources management. Although each of the activities undertaken for the development and optimal operation of water resources must be tailored to the social, economic and physical conditions in a given area, there are universal, generally applicable techniques that are of interest to the group. The optimal use of water resources is a task that in recent decades has often taken the form of integrated river basin development. This is essential because of the complexity of the present social and economic patterns of water demand, and the usually severe disparities between water resources as provided by nature, and the time and place of man's need for water supply.

The current emphasis of systems analysis is on describing physical, social and economic systems by means of mathematical models. The first step (Figure 1) in any systems analysis study is realistically formulating the problem; the next step involves constructing the models; and the last step could be described as linking different models in one complex water resources system.

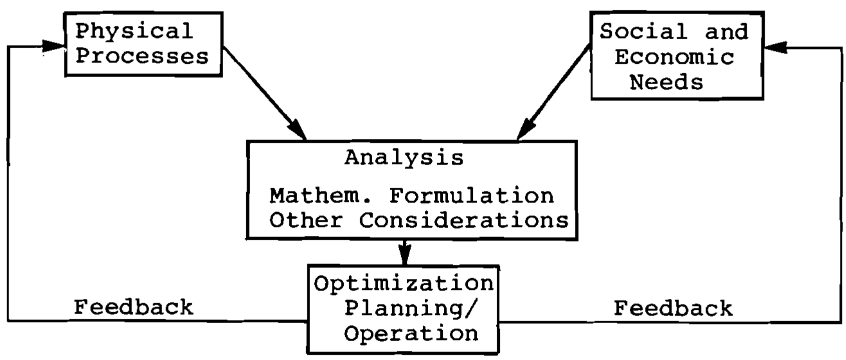


Figure 1. Systems analysis in water resources.

Figure 2 presents an example of a typical scheme, often used for the optimal planning and operation of water resources systems. In most cases, the following types of models must be included in such a scheme: hydrologic models, hydrodynamic models, models of transportation, dispersion, and self-purification of wastes, and models of water demands. In addition, different optimization techniques are used for both the planning and day-to-day management of water resources systems.

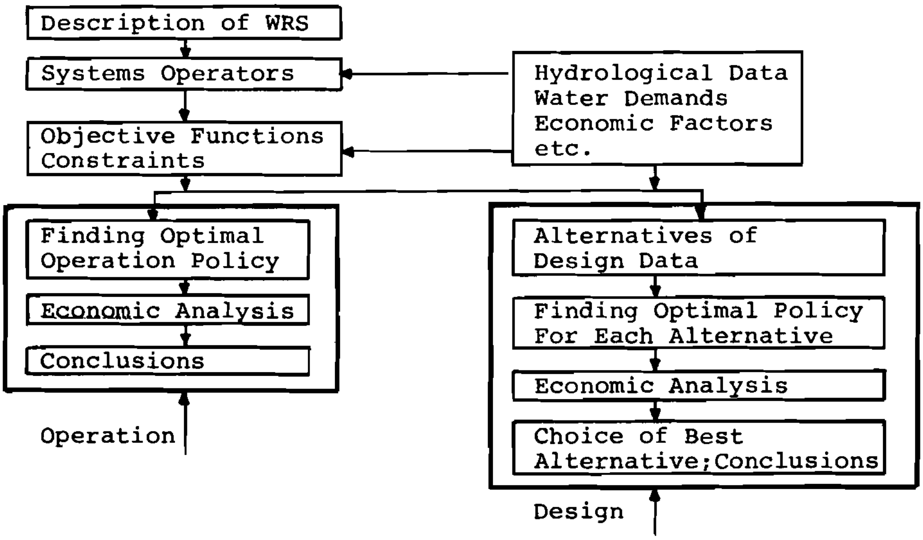


Figure 2. General scheme of river basin management (RBM).

Let me now turn to the question of how to relate the concepts of systems analysis to the problems of regional water resources management. Two major areas of application are the optimal planning and operation of water resources systems. Planning for the integrated development of a river basin or an economic region consists in collecting a hydrologic, technical, social and economic data base, followed by analyzing the investment alternatives and nonstructural measures needed to meet a certain set of water management objectives. The techniques of systems analysis are employed here for selecting from all possible alternatives that particular set of activities which will best accomplish the water management objectives as well as the overall objectives of the decision makers. Operation of a water resources system, on the other hand, is concerned with the decisions needed to best accomplish the objectives of an existing system.

During the past two years, IIASA collaborated with planners from Hungary, Poland and Bulgaria, working on long-term water resources development plans in the Tisza, Vistula and Iskar River basins, respectively. In this presentation I will concentrate on the case studies of the Tisza and Vistula River basins. Compared with basins in many other European regions, these two basins are characterized by limited water resources and great variability in their occurrence. Major water uses in the Tisza and Vistula River basins are for domestic and municipal supply, industry, and irrigated agriculture. Other beneficial uses of water include hydroelectric power generation, navigation, and recreation. It was imperative to consider in these plans also flood control, drainage, and water quality management as well as many intangible values derived from the preservation of the natural environment. Such a situation calls for a comprehensive analysis, and evidently optimal solutions can be found only if each of the sites and facilities is developed on a multi-purpose basis.

Let me relate briefly an experience gained in Poland with respect to water resources planning. The first draft of the national plan for water resources development for 1955-1975 was prepared over the period 1953-1956 by the Polish Academy of Sciences. Since then, universities and scientific research organizations have conducted research intended to provide a more accurate assessment of the water resources of the country and the water needs of individual groups of consumers. At the same time, special attention has been paid to developing techniques for the optimal design and operation of the water resources system. The second version of the water resources development program, for 1960-1985, was prepared in the 1960s at the Water Management Research Institute in Warsaw. Finally, with the assistance of the United Nations Development Programme, a project for the comprehensive development of water resources in the Vistula River basin was prepared over the period 1969-1971. Operation of the Vistula River system over the years 1985-2000 has beeen simulated by the mathematical modeling technique. A similar project is now being prepared for the Odra River basin. From the scientific point of view, one main purpose of the abovementioned activities was to develop a mathematical model of the water resources system, allowing for the optimization of the investment program and the analysis of the system's operation. The main objectives of water resources management in the Vistula River basin are: reliable municipal water supply, industrial water supply, flood protection, and improvement of water quality. To meet these objectives several investment variants were analyzed, using mathematical models and optimization techniques.

The assumptions on which the model of the Vistula River system is based are outlined below.

Assuming that there can be several possible variants of a specified system of storage resources and facilities for the long-distance transfer of water, investigations were made of a number of variants of the water resources system. It was also assumed that for a given variant the project parameters, e.g., capacities of the reservoirs, were known. Optimization of the investment program was taken to mean the choice of the best variant, effected on the basis of economic criteria.

In view of its size and complexity, the system was broken down into subsystems each encompassing areas of less than 50,000 km^2. Each subsystem was analyzed and optimized separately, with due account taken of their mutual interaction, particularly the influence of the upper subsystem on the lower subsystem from the point of view of hydrological conditions.

The water demands of all users in the years 1985 and 2000 were determined by the relevant research and design organizations on the basis of appropriate future analyses. Except for agriculture, the stochastic variability of water demands was not investigated.

The main model included the tasks related to water supply for the population, industry and agriculture, and also made provision for the maintenance of certain minimum flow rates that are indispensable for diluting wastes and meeting various local needs. The investment variants chosen on the basis of the main model were then analyzed from the point of view of additional tasks, e.g., flood protection.

In view of the stochastic variability of water resources, the computations were repeated several times, using hydrological data recorded for the period 1951-1965. Stochastic dynamic programming was also used to analyze the operation of individual water reservoirs.

The purpose of optimization carried out for each of the investment variants was to minimize water shortages. The comparison of the individual variants was based on their costs and operational effects.

A *Comprehensive Program of Water Resources Management* for Poland was prepared on the basis of these analyses. It envisages a substantial development of water engineering projects. The total usable capacity of storage reservoirs, apart from those of purely local significance, will increase over the next 27 years by 2.5 to $3.5 \cdot 10^9$ m^3. This means that almost all potential reservoir sites will have been developed by the year 2000. The significant growth of the reservoir capacity will considerably reduce the volume of floods, and will increase the water resources available during deficit periods. Projects that enable water to be transferred between particular regions of the country will be especially important in the water resources system of Poland. First and foremost among these will be the Central Canal serving to recirculate the Vistula River flow as well as canals and pipelines supplying industrial agglomerations with water from mountain streams.

Some methodological problems of the optimal development of the Tisza River basin will be discussed by Eric Wood and by Laszlo Dávid elsewhere in this volume. The main objectives in this case are water supply for agriculture, flood protection, municipal water supply, and water quality protection. Wood's presentation will also cover the application of multiattribute utility theory for choosing the best design solutions.

The most significant conclusion of the Vistula and Tisza River basin projects is that the techniques developed and tested within the framework of these projects proved to be feasible and technologically workable. The attempt to incorporate in the planning process a specific computational capability to screen, simulate and optimize alternative water resources development programs has demonstrated the merits of the systems approach. This approach should be viewed not merely as a technique or a group of techniques such as mathematical programming, optimization, and probability theory. Rather, it should be thought of as a broad planning strategy that involves the use of various mathematical techniques for solving highly complex problems of water management. It is a framework of thought designed to help decision makers choose a desirable course of action. Although the plans I am referring to have been developed primarily by the national teams, they have often been discussed with members of the Water Resources group, who have contributed to their development. Clearly, many elements of the planning strategy and the tools that may be used effectively for the regional management of water resources are subject to continuing development.

Applying Multiattribute Utility Theory to Evaluation of Tisza River Basin Development Plans

E.F. Wood

INTRODUCTION

Planning for water resources development is a complicated public investment problem. Components contributing to this complexity include multiple conflicting objectives involving economic, environmental, social, and technical considerations; difficult-to-quantify consequences that are crucial in selecting an alternative; and uncertainties about the overall impact of a particular alternative.

Taking these considerations into account, the IIASA Water Resources group, in conjunction with the Methodology group, initiated a cooperative study with the Hungarian National Water Authority. The purpose of the study was two-fold: to investigate the usefulness of multiattribute utility theory for evaluating alternative water resources development plans; and to illustrate the technique for planners and decision makers who influence decisions concerning long-range water resources planning. The Tisza River basin, with five alternative development plans studied earlier [1], was used for the case-study application. The present report highlights the IIASA-Hungarian study; a more detailed report can be found in [2]. The work was not undertaken to influence any decision directly; the analysis was too rough for that.

MULTIOBJECTIVE WATER RESOURCES PLANNING

While procedures for project evaluation have been formulated [3], the applications of multiobjective water resources planning have been limited. Most applications have focused upon formulating the problem as a linear programming, vector optimization problem. The multiple objectives are often represented as a weighted linear function [4,5,6], or by a constraint formulation [7,8].

Structuring the decision problem as a mathematical optimization problem can lead to a number of difficulties. One such difficulty is that the optimization model may focus upon an objective that has little impact on the final decision problem. This often happens when the objective has a small range over the alternatives, even though the objective per se is important. For example, cost may be an extremely important objective, but if the costs for alternative systems were all within one percent of each other, then other objectives would have more influence on the decision.

This and other related problems provide the motivation to consider applying multiattribute utility theory, even though we recognize that this technique has its own set of difficulties.

Multiattribute utility theory tends to focus much effort upon the objective function of the decision problem, which can then be used to assist in building models (either optimization or simulation models) that can best address the issues.

The procedure consists of three steps:

- Assessing a multiattribute utility function over the attributes that describe the planning goals;

- Evaluating the attribute levels for each of the planning alternatives;

- Calculating the utility values for each alternative, resulting in a cardinal evaluation of the alternatives.

Case Study: Problem Description

Figure 1 presents a map of the Hungarian part of the Tisza River basin. In all, the basin is shared by five countries and has an area of 130,000 km^2.

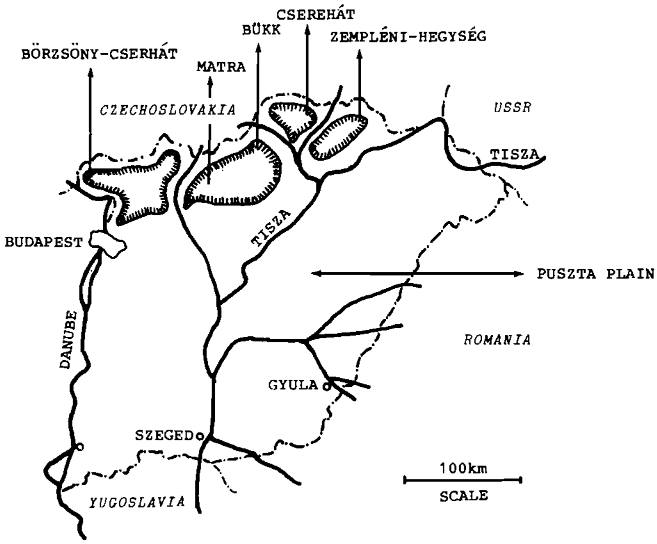


Figure 1. Schematic map of the existing water resources system of the Tisza River basin.

The main demand for water in the Tisza River basin is due to agricultural and industrial uses. The water has been supplied to these activities by a gradually growing water resources system on which development started in the middle of the nineteenth century. In recent years the increased use of water has led to a deterioration of water quality. Further development of the water supply, especially its reliability, is important for planned regional development.

There are five district planning alternatives, one of which could be chosen for development over the next 55 years. These systems are:

System I. Danube and Tisza Rivers inter-basin transfer using a multi-purpose canal-reservoir system via a gravity canal in the flatland area, and a pumped canal reservoir system in the Börzsöny-Cserhát Mountains.

System II. Pumped reservoir system in the northeastern part of the region, to be developed in the hilly region of the Sátoros and Bükk Mountains.

System III. Flatland reservoir system, composed of reservoirs of two to four meters deep, to be developed in the flatland area of the basin.

System IV. Mountain reservoir system in the upper Tisza River basin, which involves building reservoirs in this part of the basin (located outside Hungary).

System V. Groundwater storage system, to be developed in the eastern part of the basin as part of a conjunctive surface groundwater system utilizing the Tisza River water for both water supply and groundwater recharge.

Planning Objectives

The basic aim of these systems is to develop the natural supply of water resources by comprehensive runoff regulation, including quantity and quality regulation over space and time, while simultaneously trying to fulfill other objectives that reflect economic, environmental, and social aims. Thus, the following planning goals were established: water demand, flood protection, drainage and used water disposal, utilization of resources, environmental impact, and flexibility. The last goal implies that the proposed system should be sufficiently flexible to meet a broad spectrum of future requirements, most of which cannot be foreseen at the present time.

ASSESSING THE UTILITY FUNCTION

In this study, we used the assessment of L. Dávid of the Hungarian National Water Authority. The assessment process consisted of four separate steps: familiarization with utility theory, investigation of the qualitative preference structure, assessment of the component utility function, and assessment of the scaling factors. Throughout the assessment process, there were several consistency checks. Now that we have a preliminary utility function to work with, more consistency checks and adjustments can and should be conducted.

Step 1: Familiarization with Utility Theory

The first part of a utility assessment involves discussing the concepts of the approach within the context of the problem being addressed. For this problem, the manner in which utility theory considers uncertainties, multiple objectives, and subjective factors was considered.

The other important aspect of the initial examination is to structure the problem. As a result, we obtained a set of attributes and their ranges to be used in evaluating alternatives. The attributes serve to indicate the degree to which the objectives are met. A summary of these attributes, labelled $X_1, \ldots, X_{12}$, is given in Table 1.

Table 1. Attributes for the Tisza River problem.

	Attribute	Measure	Range Worst	Range Best
X_1	$\equiv$ Total costs (20 ft $\approx$ US$1)	10^9 ft/year	110	80
X_2	$\equiv$ Probability of water shortage	percent	60	0
X_3	$\equiv$ Water quality	subjective	0	100
X_4	$\equiv$ Energy (re-use factor)	$\alpha \equiv \frac{\text{energy produced}}{\text{energy used}}$	0	1.0
X_5	$\equiv$ Recreation	subjective	0	100
X_6	$\equiv$ Flood protection	recurrence interval	40	500
X_7	$\equiv$ Land & forest use	1000 ha	100	50
X_8	$\equiv$ Social impact	subjective	0	100
X_9	$\equiv$ Environment	subjective	0	100
X_{10}	$\equiv$ International cooperation	subjective	0	100
X_{11}	$\equiv$ Development possibilities	subjective	0	100
X_{12}	$\equiv$ Flexibility	subjective	0	100

Step 2: Investigation of the Qualitative Preference Structure

Before one assesses a utility function, it is important to determine the qualitative structure that indicates functional forms appropriate for quantifying the actual function. To do this, one attempts to verify various preference and utility-independence assumptions. As it turned out, it seemed appropriate to assume the conditions necessary for the multiplicative utility function. Complete details of the verification procedure used are explained in a different context in [9].

The analysis showed that a multiplicative form of the multi-attribute utility function was the appropriate form; that is, a utility function in the form

$$1 + ku(x_1, x_2, \ldots, x_{12}) = \prod_{i=1}^{12} \left[1 + kk_i u_i \ (x_i) \right] , \qquad (1)$$

where u is scaled 0 to 1, the component utility functions $u_i, i = 1, \ldots, 12$, are scaled 0 to 1, the scaling constants $k_i, i = 1, \ldots, 12$, are positive and less than 1, and k is a constant calculated from the k_i.

Step 3: Assessment of the Component Utility Functions

The assessment of the component utility functions is described in [2]; these functions are presented in Figure 2.

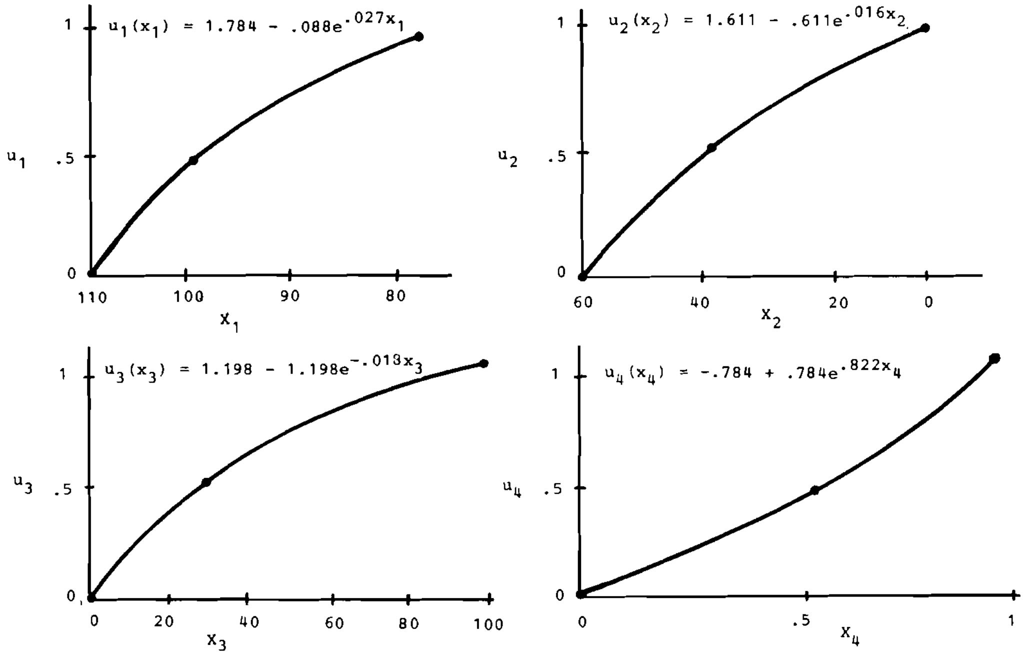


Figure 2. Component utility functions.

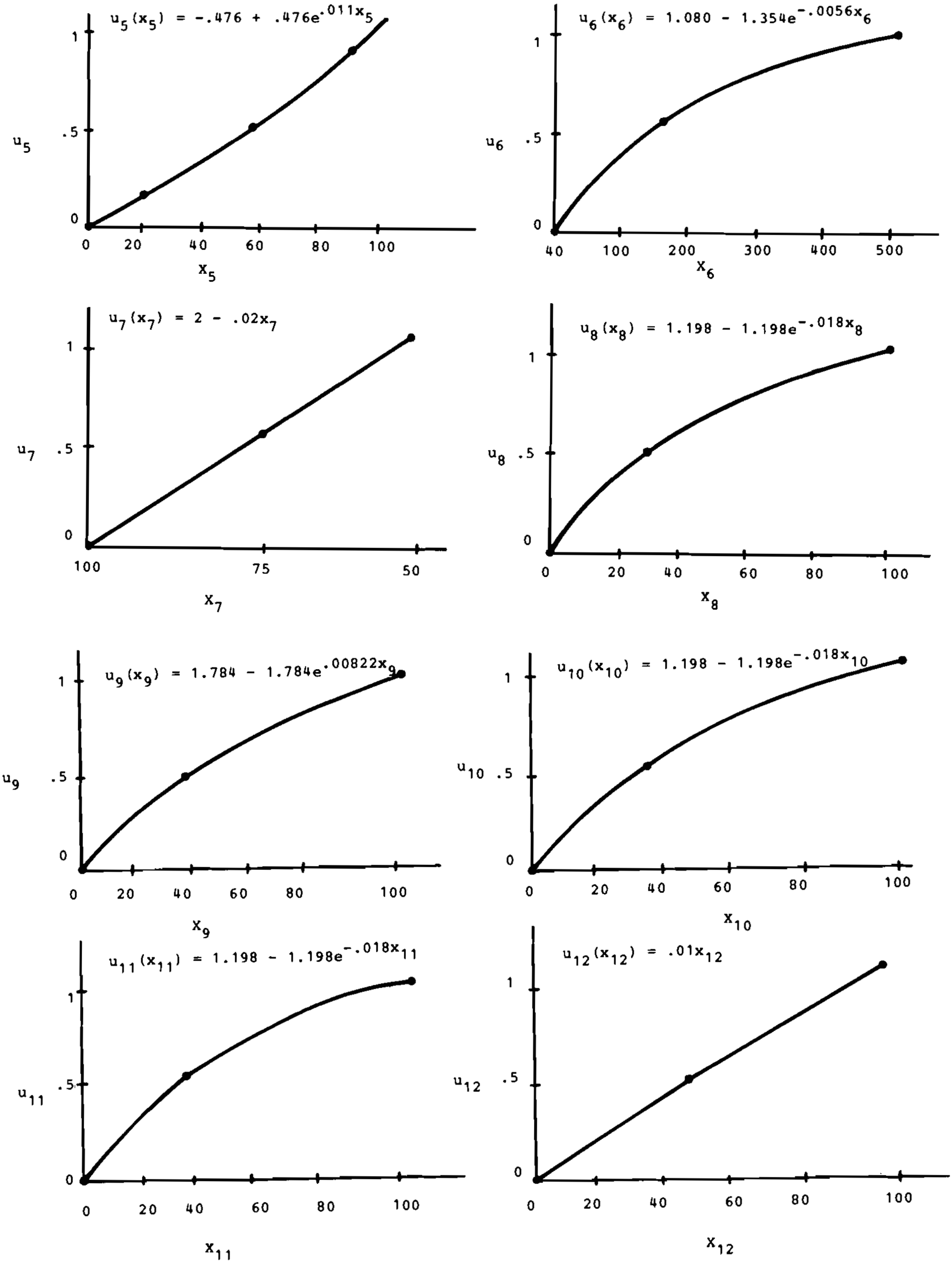


Figure 2. Component utility functions (cont'd.).

Step 4: Assessment of the Scaling Factors

The first step in assessing the k_i is to order their magnitude. To do this, we set all 12 attributes given in Table 1 at their worst levels, and asked, "if only one could be raised to its best level, which one would be preferred"? The response was attribute X_2. This implied that k_2 must be the largest of the k_i. Had there been indifference between moving either X_i or X_j to its best level, then k_i would equal k_j. After several adjustments, this resulted in the order

$$k_2 > k_6 > k_3 = k_{10} > k_8 > k_1 > k_5 > k_9 > k_4 > k_7 > k_{11} = k_{12} \quad . \tag{2}$$

After relative scaling factors had been established among the k_i, their numerical values were calculated along with k. The results are:

$$k_1 = .15,\ k_2 = .243,\ k_3 = .189,\ k_4 = .090,\ k_5 = .132,$$
$$k_6 = .200,\ k_7 = .090,\ k_8 = .165,\ k_9 = 1.32,$$
$$k_{10} = .189,\ k_{11} = .034,\ k_{12} = .034, \tag{3}$$

and

$$k = -.715 \quad . \tag{4}$$

The component utility functions in Figure 2 plus equations (3) and (4) specify the preliminary utility function represented by the multiplicative form (1).

EVALUATING ATTRIBUTE LEVELS FOR EACH ALTERNATIVE

The attribute levels, or the degree to which a particular alternative fulfills a planning objective, are usually determined by detailed hydrologic and economic analysis, often with the aid of models. In this study, we utilize the results of Dávid and Duckstein [1] who earlier had studied these five alternatives. The attribute levels are given in Table 2.

Table 2. Attribute levels for alternative systems.

	Objective	Measure	Alternative System I	II	III	IV	V
1.	Total cost (20 ft ≈ US$1)	10^9 ft/year	99.6	85.7	101.1	95.1	101.8
2.	Probability of water shortage	percent	4	19	50	50	50
3.	Water quality	subjective	80	60	20	80	40
4.	Energy (re-use factor)	$\alpha \equiv \frac{\text{energy prod.}}{\text{energy used}}$	0.7	0.5	0.01	0.1	0.01
5.	Recreation	subjective	80	60	40	20	20
6.	Flood protection	recurrence interval	100	200	67	200	50
7.	Land & forest use	1000 ha	90	80	80	60	70
8.	Social impact	subjective	80	80	60	40	40
9.	Environment	subjective	80	60	20	60	40
10.	International cooperation	subjective	80	60	40	20	40
11.	Development possibilities	subjective	80	60	40	20	40
12.	Flexibility	subjective	80	80	20	40	20

CALCULATING THE UTILITY FUNCTION

Table 3 gives the utility values for each of the five alternative systems. Since higher utilities are desired, these preliminary results imply that system I is somewhat better than system II, which is considerably better than system IV, which in turn is better than system V; system III is the least desirable. To help interpret how much better system I is than system II, we increased the cost of system I in Table 2, holding all other factors fixed, until the utility equaled the current utility 0.821 of system II. This occurred at $x_1 = 104.2 \cdot 10^9$ forint per year, so that system I is essentially better than system II by $4.6 \cdot 10^9$ forint per year. Similarly, system II is better than system IV by at least $24.3 \cdot 10^9$ forint per year because even if the cost of system II increases to $110 \cdot 10^9$ forint per year, the utility of system II is greater than the current utility of 0.648 of system IV. Since systems III and V are even less desirable, it appears that subject to the data of Table 2 and the utility function being used, systems I and II are the only real contenders.

Table 3. Utility value for alternative systems.

System	Utility Value
I	.832
II	.821
III	.503
IV	.648
V	.521

CONCLUSIONS AND RECOMMENDATIONS

This study was a first cut at solving a problem of water resources planning using multiattribute utility theory. A planning problem in the Tisza River basin of Hungary was used to illustrate the usefulness of the technique. A utility function over 12 objectives was assessed, and preliminary results indicate that building inter-basin water transfers from the Danube River or from small reservoirs in the northeast part of the basin is to be preferred to developing three other planning alternatives.

One purpose of the work was to appraise the reasonableness of the approach. The assessed utility function should be interpreted as a preliminary one. Nevertheless, it does indicate the feasibility of making such assessments to water resources planners. The brief analysis was included to fulfill a second purpose: to illustrate the use of a multiattribute utility evaluation model. It was not done to suggest alternatives that should be chosen. For the latter purpose, a more sophisticated and careful analysis would be needed. It is of primary importance to such an effort that one extend this work in the following ways:

- Improved articulation of the system objectives and better attributes for these objectives;

- Formal inclusion of uncertainty;

- A more thorough assessment of the utility function over the revised set of attributes;
- Expansion into a dynamic decision problem.

References

[1] Dávid, L., and L. Duckstein, *Long-Range Planning of Water Resources: A Multi-Objective Approach*, UNDP/UN Interregional Seminar on River Basin and Interbasin Development, Budapest, Hungary, September 16-26, 1975, United Nations, Department of Economic and Social Affairs, New York, 1975.

[2] Keeney, R.L., E.F. Wood, L. Dávid, and K. Csontos, *Evaluating Tisza River Basin Development Plans Using Multiattribute Utility Theory*, CP-76-3, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[3] Water Resources Council (US), Water and Related Land Resources: Establishment of Principles and Standards for Planning, *Federal Register*, 38, 174, Part III (September 10, 1973) 24,778-24,869.

[4] Maass, A. et al, *Design of Water Resource Systems*, Harvard University Press, Cambridge, Mass., 1962.

[5] Major, D.C., Benefit-Cost Ratios for Projects in Multiple Objective Investment Programs, *Water Resour. Res.* 5, 6 (1969), 1,174-1,178.

[6] Marglin, S.A., *Public Investment Criteria*, MIT Press, Cambridge, Mass., 1967.

[7] Cohen, J.L., and D.H. Marks, Multiobjective Screening Models and Water Resources Investment, *Water Resour. Res.*, 9, 4 (1973), 826-836.

[8] Miller, W.L., and D.M. Byers, Development and Display of Multi-Objective Project Impacts, *Water Resour. Res.*, 9, 1 (1973), 11-20.

[9] Keeney, R.L., *Energy Policy and Value Tradeoffs*, RM-75-76, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Application of On-Line Prediction Techniques to Forecasting Short-Term Agricultural Water Demand

A. Szöllösi-Nagy

As Kaczmarek already mentioned, one of the urgent problems in the Tisza River basin is the short-term control of the basin's irrigation systems. The middle Tisza valley irrigation system covers an area of approximately 3,000 km^2 on the east side of the Tisza River, hence the related control problems are of great economic significance. The first step toward establishing a dynamic on-line control system is to find a real-time prediction algorithm for forecasting the irrigation demand. Most existing demand-forecasting procedures use curve fitting or extrapolation techniques in conjunction with static regression models involving the appropriate variables [1]. Clearly, for dynamic control we would need a dynamic forecasting model that takes into account the random effects related to demand.

This paper discusses a proposed discrete, dynamic recursive prediction algorithm that is based on the state space description of the processes involved. The algorithm can readily be embedded in an on-line control scheme. Obviously, to implement a control scheme, one needs a centralized computer with comprehensive access to the system for data collection and control.

The daily demand for irrigation water depends on many factors, such as soil moisture content, precipitation, temperature, humidity, wind velocity, cloud cover, and wastage in the network. It is therefore reasonable to assume that the daily demand, at a certain point in the system, is a random variable. Moreover, the irrigation season (which corresponds to the growing season) can be divided into three distinct periods: pre-irrigation, actual irrigation, and post-irrigation (Figure 1). The demand in each of the irrigation periods can be described by the simple model

$$D(t) = D_p(t) + D_r(t) \quad , \tag{1}$$

where $D_p(t)$ is a periodic component due to the periodic (daily, weekly) operation schedule of the irrigation plant, and $D_r(t)$ is a random residual component representing short-term fluctuations in demand due to changes in the weather patterns. As

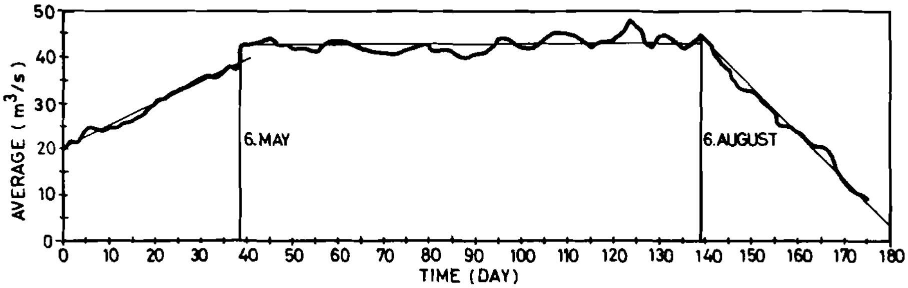


Figure 1. Daily water consumption time series, middle Tisza valley irrigation system.

demonstrated in [2], the demand in each of the irrigation periods is a normally distributed random variable (Figure 2).

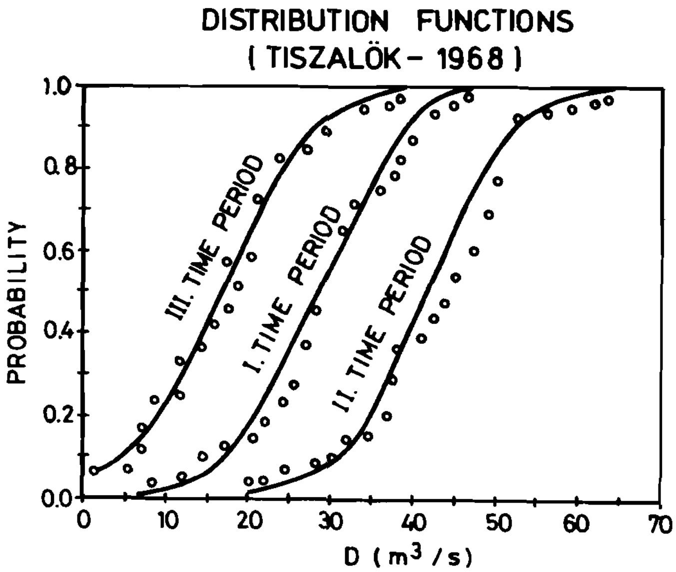


Figure 2. Probability distribution functions for different irrigation periods.

Source: [2]

The periodic component of equation (1) can be represented by a harmonic series model

$$D_p(t) = a_o + \sum_{i=1}^{N} (a_i \cos i\, \omega_o t + b_i \sin \omega_o t) \quad , \qquad (2)$$

where the fundamental frequency, ω_o, equals $2\pi/T$, N is the number of significant harmonics, and the parameters a_i and b_i are the Fourier coefficients identified from past consumption data. Defining the vectors

$$A_p = [a_o, a_1, \ldots, a_n, b_1, \ldots, b_n]^T \quad ,$$

$$B_p(t) = [1, \sin \omega_o t, \ldots, \sin N\omega_o t, \cos \omega_o t, \ldots, \cos N\omega_o t]^T \quad ,$$

the periodic component becomes

$$D_p(t) = B_p^T(t)\, A_p \quad . \qquad (3)$$

For the residual component, the following stochastic difference equation model is proposed:

$$D_r(t) = \sum_{i=1}^{n} \phi_i D_r(t-i) + \sum_{j=0}^{m} \psi_j u(t-j) + \sum_{k=0}^{p} \Theta_k w(t-k) \quad . (4)$$

This is a type of auto-regressive moving-average (ARMA) representation of the residual process, where the model order (n,m,p) as well as the parameters (ϕ, ψ, θ) must be identified using past consumption data. (For technical details see [3].) In equation (4) $u(\cdot)$ is the deviation in the soil moisture content from the nominal value desirable for the plants and, in fact, represents the explicit control of the forecasting scheme. On the other hand, the last term in equation (4) represents the implicit control due to precipitation, temperature deviation and so on; $w(\cdot)$ represents a white Gaussian noise (WGN) sequence with the usual properties. (Though $w(\cdot)$ is a WGN process, the last term of equation (4) is a moving average, hence the residual model considers the correlation in the implicit control.) By applying the standard canonical transformation for the residual model (4), one obtains a state space formulation as follows:

$$x_r(t+1) = \Phi_r x_r(t) + \Psi_r u(t) + \theta_r w(t)$$

$$D_r(t) = H_r^T x_r(t) \quad , \tag{5}$$

where the state vector $x_r(t)$ represents the deviation between the residual values and the explicit control, and the matrices Φ_r, Ψ_r and θ_r contain the parameters. (For details, see [4].)

Since there are uncertainties associated with determining the parameters of the periodic component, we specify a random walk model for the harmonic coefficient in equation (3). That is,

$$A_p(t+1) = A_p(t) + \xi(t) \quad , \tag{6}$$

where $\xi(t)$ is a WGN process with given statistics (or rather, statistics should be adaptively updated during the estimation procedure). By defining an augmented state vector $x(t) = [A_p(t) \vdots x_r(t)]^T$, we have a unified state model

$$\Sigma \begin{cases} x(t) = \Phi\ x\ (t) + \psi\ u\ (t) + \theta\ \omega\ (t) & \text{(7a)} \\ D(t) = H^T\ x\ (t) & \text{(7b)} \end{cases}$$

that includes both the periodic and residual components. The matrices ϕ, Ψ, and θ are readily obtained from those of equation (5) by considering the simple transformation of state augmentation. In fact, using the terms of estimation theory equation (7a) can be considered a state equation, while equation (7b) is a measurement equation.

The problem of recursive demand prediction is formulated as follows: given measurements $D_t = \{D_\tau : \tau=0,1,2,\ldots,t\}$ on the past consumption up to time t, find an unbiased minimum variance estimate $\hat{D}(t+\nu|t)$ of the demand $\nu>o$ steps ahead, subject to the system dynamics Σ. It is obvious from equation (7b) that where there is an unbiased minimum variance estimate $\hat{x}(t+\nu|t)$ on the states, the ν-steps-ahead optimal demand prediction is

$$\hat{D}(t+\nu|t) = H^T\ \hat{x}(t+\nu|t) \quad . \tag{8}$$

Actually, we do have an estimate

$$\hat{x}(t+\nu|t) = \mathcal{E}\{x(t+\nu)|D_t\}$$

on the states that is given by the recursive Kalman filter algorithms [5]. At the same time we also have confidence limits around the predicted demand values.

Summing up, let us mention some of the merits of this short-term demand prediction scheme. Due to the state space formulation of the process, it is easy to handle from a mathematical point of view. The inherent random nature of short-term demand is considered. Moreover, because of the recursiveness, the scheme is easy to implement even for small process computers. It is easily adapted to suit the changing environment, and the algorithms might be embedded without any change in the optimal control scheme for the irrigation system.

Additional problems exist that are worthwhile discussing as, for example, aggregating short-term strategies into long-term ones (i.e., forecasting/control versus projection/planning), and problems of short-term versus long-term reliability in water demand prediction.

References

[1] Gearing, H.W.G., Forecasting Demand, *Statistician*, 20, 3 (1970), 23-28.

[2] Dávid, L., A. Bàràsz, and M. Kropf, Investigation on the Water Demand Distribution Concerning the Irrigation Systems in the Tisza Valley, in *Inventory Control and Water Storage*, A. Prekopa, ed., North-Holland, Amsterdam-London, 1971.

[3] Eykhoff, P., *System Identification*, Wiley, London, 1974.

[4] Lee, R.C.K., *Optimal Estimation, Identification, and Control*, The MIT Press, Cambridge, Mass., 1970.

[5] Meditch, J.S., *Stochastic Optimal Linear Estimation and Control*, McGraw-Hill, New York, 1969.

Development of the Tisza River Basin

L. Dávid

The purpose of the Tisza River basin development is the optimal use of natural water resources, taking into account the constraints of socio-economic growth. The man-made development process of the basin must therefore consider social, economic, technical, environmental and natural elements, and should be a planned, interdisciplinary and controlled process based on systems analysis.

The development process of river basins can be divided into three stages: *natural, developing, and developed* (see Figure 1). In *the natural stage,* there is no significant human interference in the water management activities of the river basin--the water resources practically conform with natural conditions. Water projects in this stage are generally simple, with one purpose, one objective, and insignificant capacities.

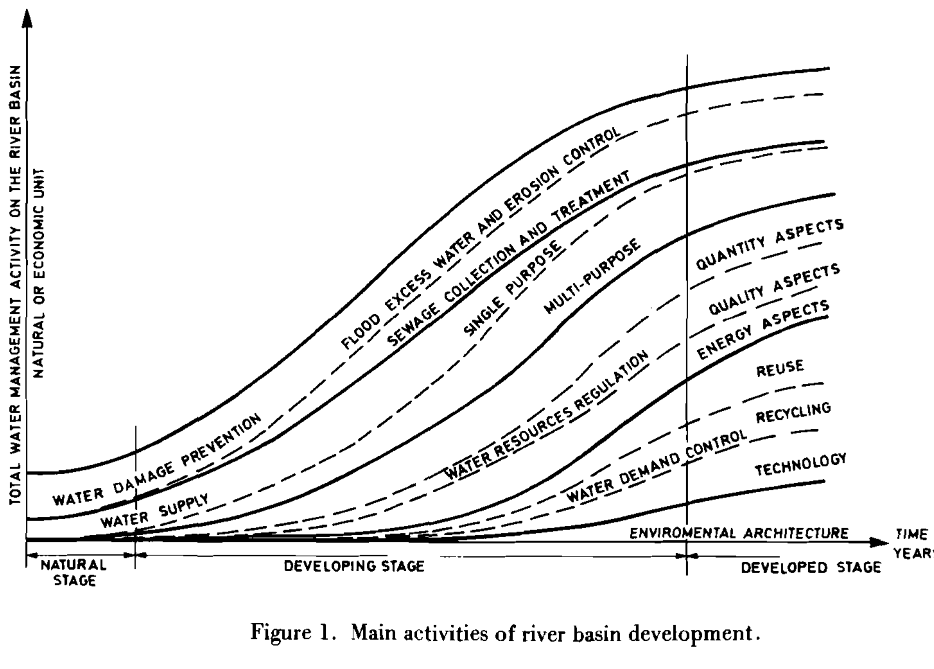


Figure 1. Main activities of river basin development.

In *the developing stage*, deliberate human interference is of a local and regional character, and ultimately becomes basin wide. At this stage, the natural runoff system is gradually changing, thereby becoming more regulated. Multi-purpose, multi-objective integrated water resources systems are constructed with increasingly significant capacities. The storage space and the role of water transfer increase.

In *the developed stage*, the river basin is completely regulated and redistribution of regulated water resources among the users is continuously undertaken. Further development of the basin is based on water demand control and large interbasin transfers.

The objectives, the means, and the activities for the development of a river basin in each of the stages will differ depending on local, sub-basin, regional, national and international interests in socio-economic growth. The development of the Tisza River basin also has to be done on the basis of these three stages.

The Hungarian part of the Tisza River basin is flat, with about 30 percent of the basin's total catchment area (157,000 km^2); the other countries sharing the basin and their portion of the area are: the USSR with 8 percent, Czechoslovakia with 10 percent, Romania with 46 percent, and Yugoslavia with 6 percent. The potential water resources of the basin (the average runoff over several years) is 25 km^3/year at the southern border of Hungary. To completely regulate this volume of water over several years, a storage capacity of 75 km^3 is needed.

Development of the Tisza River basin began in the middle of the nineteenth century; after 150 years of Turkish occupation and the subsequent struggles for independence, Hungary gained sufficient economic strength to undertake this ambitious venture. In its *natural stage*, the basin area was a vast marshland, much of which was covered permanently by water or inundated annually (Figure 2). Over the last 140 years, the development of the basin made the area accessible to cultivation and human settlements, thereby creating opportunities for flourishing economic activities.

The development of the basin began with the control of floods and the regulation of the River. This was followed by the provision of drainage from the basin to the stagnant surface waters accumulating in the plains. These efforts laid the foundations for agricultural and industrial development, and for the increase in the population density (Figure 3).

In the twentieth century, the major objective has been to develop the basin-wide runoff regulation and to regulate the use of water, primarily in agriculture. Attention is increasingly being devoted to the development of industrial and domestic water supply systems, to navigation and to recreational activity.

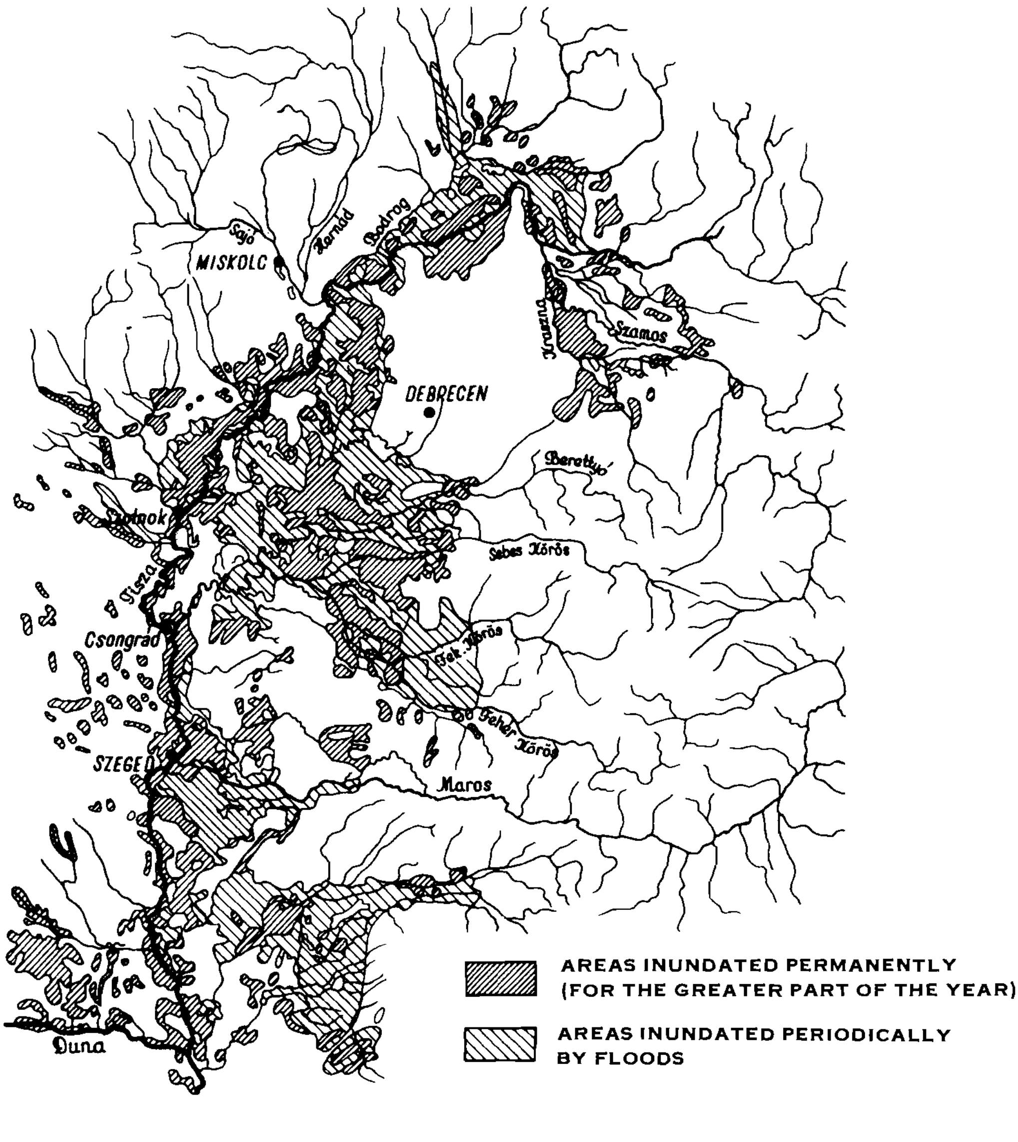


Figure 2. Hydrographic situation in the Tisza River basin before river basin development.

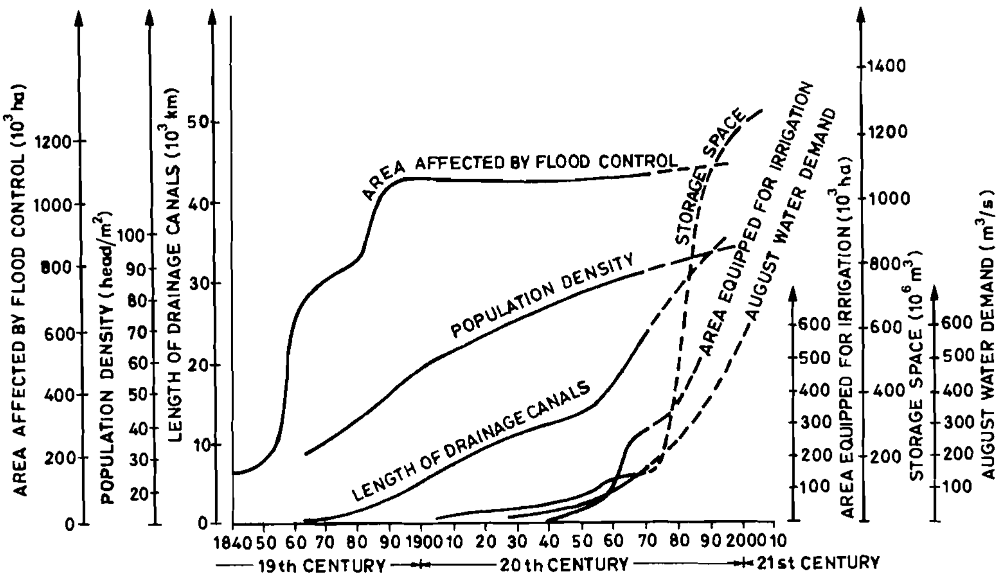


Figure 3. Development of water management characteristics in the Hungarian part of the Tisza River basin.

Because of the increased use of water resources, the quality of water has deteriorated, and attention is now focused on pollution control. In recent years there have been regulations with respect to the quantity, quality and energy-related aspects of water resources to increase the usable water resources. At present, the basin is in the *developing stage*. About 15 to 20 percent of the planned regulation has been achieved. The existing water resources system shown in Figure 4 has a flood levee system (2,800 km), drainage and irrigation canals (2,600 km) that serve an agricultural activity of 3.2 million hectares of land, a number of river barrages and storage reservoirs, and water supply systems for hundreds of settlements and industrial plants.

The goal of future activities is to reach the *developed stage* for the entire basin. According to the socio-economic plans, realization of this stage is scheduled for completion by the period 2030-2040. Thus the duration of the present *developing stage* in the Tisza River basin will be about 200 years. Priorities may change with the evolution of time.

The main objectives and strategies for the further development of the Tisza River basin are:

- Regulations on the use of the basin's water resources--quantity, quality and energy-related aspects--including the water imported from the Danube River;

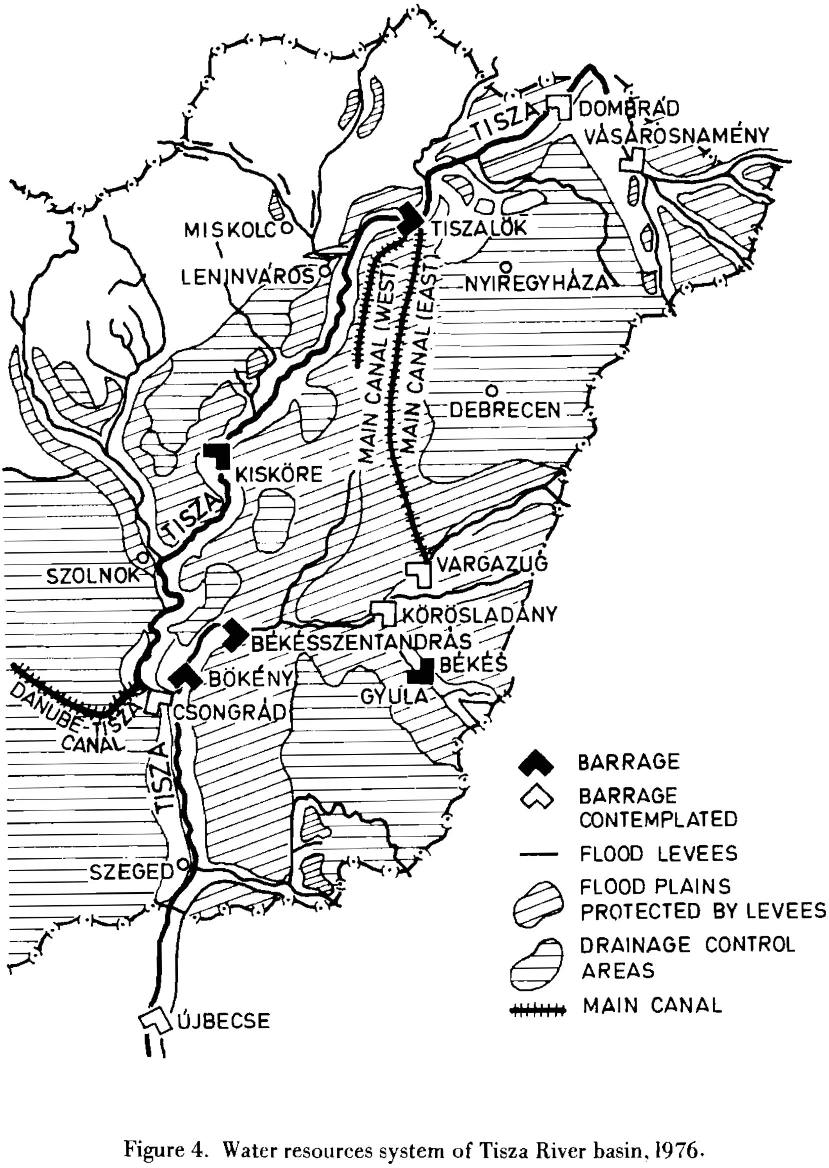


Figure 4. Water resources system of Tisza River basin, 1976.

- Multi-purpose water supply for consumptive and non-consumptive users, and water demand control including the control of re-use and the techniques used;

- Water damage prevention (flood control, drainage, waste water treatment and disposal), in conjunction with water resources regulations. Emphasis should be on waste water treatment and disposal;

- Rational use of natural and socio-economic resources for development (water, land, capital, manpower, energy, etc.);

- Development of international cooperation for water resources regulations among the five countries in the basin, on both bilateral and multilateral bases. A master plan for developing the water resources of the Tisza River basin has recently been prepared by these five countries, within the framework of the Council of Mutual Economic Assistance (CMEA); this plan could serve as the basis for developing such cooperation;

- Environmental architecture by means of water resources development, to serve as a balance between the natural and socio-economic development of the basin;

- Flexibility in the choice and application of methods for developing the basin, so as to avoid problems of uncertainties in natural conditions and in the techniques used as, for example, water demand forecasting.

The application of proper methods and techniques is needed to achieve these objectives. In view of the complex problems involved, the need for rational alternatives, the increasing importance of operation due to the increased regulation of the basin, and the need for long-range planning of development strategies and their impacts, *there is a growing need to apply systems analysis and decision-making techniques in controlling the further development of the Tisza River basin.* There are a number of requisites for the effective use of these techniques: a system for compiling data, in particular economic data; rational alternatives that include measurable and immeasurable factors; a decision-making process and the capability to adapt these new methods.

Discussion

(R. Dennis and I. Gouevsky, Rapporteurs)

The foregoing presentations stimulated an interesting and fruitful discussion.

The view was expressed that a systems analyst needs at least two kinds of models for decision-making: impact models and decision models. The main problem with a decision model is incorporating various objective and subjective goals. Should we continue to use the classical optimization approach? Is there any difference between multiattribute utility analysis and classical optimization? What are the advantages of the multiattribute utility function approach, and how can these be used in resource analysis? Does this approach give too much weight to subjective judgments?

Many of the discussants were in favor of this approach. In their opinion, it differed from classical optimization in several ways. Unlike the latter, it allowed one to characterize the system, and is more closely related to the decision maker's judgments and values. Moreover, the multiattribute utility function can define global objectives that exist only in the mind of the decision maker, and so involves the system analyst in the decision-making process. The use of the multiattribute utility function thus makes it possible to include subjective views and wishes in the model, and is a vehicle not for providing the decision maker with solutions but rather for getting him to decide on the basis of his own thinking.

Another major problem with the decision model concerns selecting and specifying the objective function. If during implementation new objectives become important, how can we change our goals? How do we deal with the objectives and system parameters left out of the model, whether by choice or because they are unknown? Classical systems analysis, having mobilized what is known, can deal with what is left out.

The economic, social and environmental consequences of the decisions made about water resource systems were the main topics discussed. In particular, attention focused on the impact of the international nature of rivers on decisions made in one of the countries sharing the river (multinational conflict resolution); new technologies for water supply such as water transfer, desalination, and watershed management; tradeoffs between upstream and downstream reservoir location and the impact of land use; the tremendous increase in recreational demands and facilities in flatlands (the use of pump-storage reservoirs was suggested as a possible compromise between land use and additional reservoirs); and the impact of water on soil.

One discussant inquired about the impact of applied systems analysis of future water resources development. Have all past cases been fully investigated, and what lessons were learned?

Two IIASA conferences--one on the Tennessee Valley Authority (TVA) in the USA, and the other on the Bratsk-Ilimsk Territorial Production Complex (BITPC) in the USSR--provided valuable information about the problems that can be encountered in large river basis, and also about possible future activities in water resources management.

A general conclusion could be drawn from the discussion. Initially, pure engineering problems characterized man's activities for developing water resource systems. Later, economic issues also became crucial. Today, as in other areas, the complexity of managing water resource systems requires an interdisciplinary problem-solving approach.

There is extensive literature on the theory and application of decision-making techniques. To avoid the type of problems mentioned above, it is essential that both the decision maker and the system analyst be involved in the application of the proposed models, and also understand the consequences of their application.

HUMAN SETTLEMENTS AND SERVICES

Introduction

H. Swain

The research area called Human Settlements and Services had its beginnings in two planning conferences in the summer of 1973, which led in turn to the establishment of two modest research projects at IIASA in 1974. As time progressed the choices of research topics made in each group--away from purely medical topics and toward questions of the planning and management of health care systems in the old Biomedical group, and outwards from macro-level urbanization problems to encompass a variety of service management areas in the former Urban project--made it desirable to combine efforts.

By way of introduction, the fundamental direction of the combined group is toward better tools for and understanding of managing social and economic development. Efforts have been concentrated at two crucial geographic scales, interregional and intra-urban, each corresponding to universal loci of decision-making authority, namely national and big-city governments.

At the level of regional development and the interregional processes that generate it, you will hear Niles Hansen on development strategies and processes in urban-dominated settlement systems, and Andrei Rogers on one of the major problems in that realm, the study of the spatial aspects of population evolution. John Miron is working on models of the development of urban-oriented regions, using the language of optimization theory; and William Welsh, a visiting scholar at IIASA, is studying questions that will arise in later stages of Hansen's international collaborative study, namely, the spatial variation in the provision of public goods and services in a number of European countries.

At the intra-urban scale, there are two more speakers: Edward Blum on the planning and management of urban emergency services, and Horst Strobel on transportation, automation, and urban development, an area where a workshop held in February, building on Strobel's work on automated traffic guidance, has opened some promising avenues for future work of broad interest across the Institute. Blum's work, insofar as it involves emergency medical services, provides a nice bridge to the presentation by Dmitrii Venedictov on the modeling of national health care systems.

That, roughly, is the program. Its origins and early progress have been documented elsewhere,* and my colleagues will doubtless keep you spellbound with accounts of their recent accomplishments and visions of the near future. As an alumnus, I may perhaps be permitted the luxury of philosophizing a little about the place of this research area within the broad spectrum of IIASA concerns.

I think our founders were right: this is the time for transnational and transcultural attempts to apply scientific methods to the problems that afflict mankind. I think further, given the immensity and diversity of those afflictions, that this young Institute supported by all its National Member Organizations has to take some difficult decisions about research priorities and the allocation of its slender resources. I think we have to filter the list of the most pressing and threatening of global problems through twin screens of political realism and scientific ripeness. The problems of choice for IIASA become acute as the participants wrestle with the understanding that all the interesting problems, all the ones that truly matter, are human ones, therefore value-laden, therefore likely to lead to various rumpled feathers. Here the canons of civility and scientific objectivity that have distinguished IIASA's first years will play the crucial role.

Of those problems which are do-able at IIASA at all, few deal more directly with the values, preferences, aspirations, and quality of everyday life of individual human beings than the congeries of issues wrapped up in human settlements and services. The centrality of these issues, however, has only recently surfaced in the competition for a place in the scholarly sun. In June, Habitat, the first-ever United Nations Conference on Human Settlements, begins in Vancouver. It will have important consciousness-raising effects, but as with most one-shot efforts, its usefulness will be measured in the long term only by the redoubled dedication with which national and international communities treat the underlying issues. I am convinced that IIASA should play a unique and leading role in that follow-through, that it is a concern that permeates each of IIASA's research areas, and that the beginnings we report to you here constitute a hopeful start.

***The IIASA Project on Urban and Regional Systems: A Status Report*, SR-75-1, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Systems Approaches to Human Settlements

N. Hansen

In the past two decades governments increasingly have attempted to influence patterns of spatial resource allocation and population distribution. These efforts usually have been prompted by two concerns. First, there is a widespread feeling in many countries that one or more of the largest cities are too big, in the sense that the social costs of further growth exceed the social benefits. It is also felt that assistance should be given to promote the growth of lagging regions. These regions are usually rural and tend to have a relatively high proportion of their employment in the primary sector, but in some instances they are old industrial areas that need modernization. Obviously the problems of big cities, lagging regions, and other parts of any given country are not independent of one another, because the various areas are linked by flows of goods and services, migration, information, etc. Regional and urban policies always have consequences for the whole of the national territory, whether or not they were intended to do so. Thus policy makers should have a reasonably good grasp of the structure of human settlement systems and of the nature of the processes that underlie evolving settlement patterns.

Many traditional approaches to human settlements are being used despite their limitations. Examples include central place theory, export base theory, and input-output analysis. Despite elegant modifications that have been made to such schemes, their usefulness for human settlement policy is severely limited.

Recent changes in human settlement patterns in a number of industrially advanced countries have represented dramatic shifts from past patterns. Cities have grown primarily because they have made it possible for interdependent specialists to interact frequently or intensively with one another. On the other hand, proximity also gives rise to pollution, congestion, and other undesirable external diseconomies that make cities unattractive. In addition, modern transportation and communication technologies have reduced the need for spatial concentration of many kinds of economic activities and household amenities.

The data in Table 1 show that, whereas in the United States in the 1960s the annual average growth rate in metropolitan areas led the corresponding nonmetropolitan rate by 1.6 percent to 0.4 percent, there was a reversal between 1970 and 1973 (0.9 percent versus 1.3 percent, respectively). One in every three metropolitan residents now lives in a declining area. This

Table 1. Population change for groups of metropolitan and nonmetropolitan counties, 1960-1970 and 1970-1973.

Population Category	Provisional (1973) Population (000's)	Annual Population Growth Rate (in %)	
		1970-1973	1960-1970
USA	209,851	1.0	1.3
Inside SMSAs* (Metropolitan)	153,350	0.9	1.6
Outside SMSAs (Nonmetropolitan	56,500	1.3	0.4
In counties from which:			
≥ 20% commute to SMSAs	4,099	1.9	1.0
10%-19% commute to SMSAs	9,683	1.4	0.7
< 10% commute to SMSAs	42,719	1.2	0.3
Entirely rural counties not adjacent to an SMSA**	4,401	0.9	-0.4

Source: [1], based on data given in [2,3].

*SMSAs defined as of December 31, 1974, except in New England, where definitions in terms of entire counties have been substituted.

**"Entirely rural" means that the counties contain no town of 2,500 or more inhabitants.

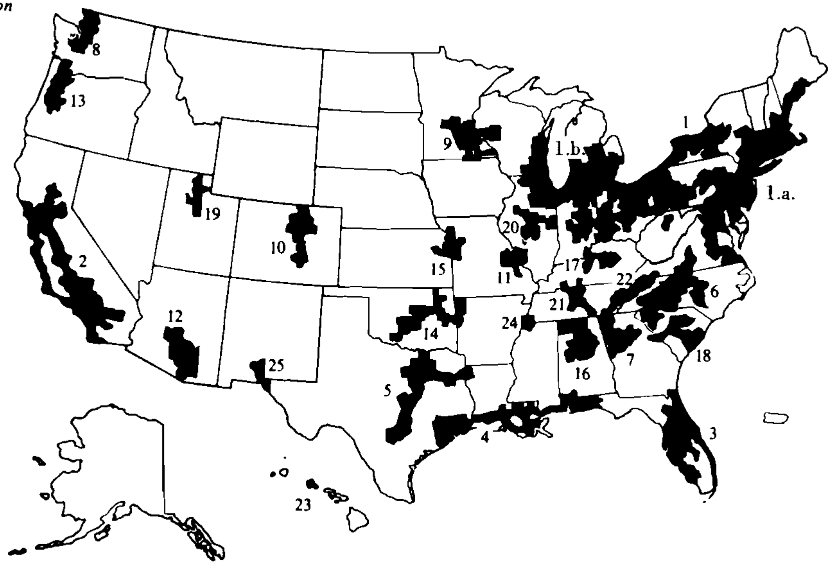
unprecedented reversal is not simply the latest manifestation of urban sprawl around metropolitan areas. Referring to the data in Table 1, a leading demographer points out that the most dramatic net migration changes have taken place "in those counties with the *least* commuting to metropolitan areas and in those classified rural nonadjacent; the more remote kinds of places--those that as a group used to be regarded as 'nowhere' have today become 'somewhere' in the minds of many migrants". Regional employment-change data lend further support to this position.

The nineteenth-century nodal city has given way, in varying degree, to the metropolitan area, the urban field, and the mega-region (see map for US example). Yet spatial-temporal development processes are still imperfectly understood. This in itself explains why, even though many countries feel a need for some form of human settlements policy, few are able to elucidate clearly what the problems really are.

Any major effort to gain better understanding of spatial-temporal development processes should have at the outset a framework of functional economic areas. It should reflect the fact

Based on 2-child family projection

1. Metropolitan Belt
   1.a. Atlantic Seabord
   1.b. Lower Great Lakes
2. California Region
3. Florida Peninsula
4. Gulf Coast
5. East Central Texas—Red River
6. Southern Piedmont
7. North Georgia—South East Tennessee
8. Puget Sound
9. Twin Cities Region
10. Colorado Piedmont
11. Saint Louis
12. Metropolitan Arizona
13. Willamette Valley
14. Central Oklahoma—Arkansas Valley
15. Missouri—Kaw Valley
16. North Alabama
17. Blue Grass
18. Southern Coastal Plain
19. Salt Lake Valley
20. Central Illinois
21. Nashville Region
22. East Tennessee
23. Oahu Island
24. Memphis
25. El Paso—Ciudad Juarez



Projected megaregions in the year 2000, United States.

Source: [4]

that these processes are increasingly international in character. Also it should be sufficiently flexible to take into account differences in degree of development among national (and even subnational) economies as well as differences in degree of national economic planning.

Such a study is now being undertaken at IIASA, in collaboration with the University of Reading, England. The research, supported in part by a grant from the Ford Foundation, covers the USA, Canada, Japan, and most of Western and Eastern Europe, and involves the close collaboration of relevant institutions in each country. The basic units of analysis are urban regions, which essentially are functional labor-market areas corresponding to regionalizations already made in, for example, the USA, Sweden, and the FRG.

The initial phase of this study is attempting to define the hinterlands of urban core areas and to delineate the boundaries of functional urban areas. However, it may not be possible to make core-hinterland distinctions when dealing with urban fields and megaregions, though in the latter it may be possible to identify multiple cores, e.g., in the Ruhr in the FRG, and in the Atlantic Seaboard metropolitan belt of the USA.

Given this context it should be possible to test the theory that, at least in some settings, innovation and economic growth have a two-fold spatial-temporal character; that is, they trickle down through the urban hierarchy and also spread from urban cores to their respective hinterlands. But the hierarchy may include urban fields, megaregion cores, and perhaps even megaregions rather than just the traditionally defined cities or metropolitan areas. Initially this systems model will be tested by means of shift-share analyses using fairly detailed regional employment data.

It also should be possible to test the theory that urban system development is a function of contact systems and information flows--which frequently must be viewed in an international setting--and that economic growth and innovation diffusion patterns may not correspond to the predictions of the theory of hierarchical filtering and hinterland spread. Thus, for analytic purposes mappings of information flows can be superimposed on urban-region mappings. Several European and American scholars are cooperating in this phase of the research.

In conclusion, I would like to stress that if IIASA did not exist it would be extremely difficult to carry out the research task outlined above. The conceptual framework for this study was developed at IIASA, but much of the work involved is in fact being carried out by collaborating institutions in the East and West, both because they feel that it is in their own interest and because IIASA provides an ideal coordinating mechanism for studying problems common to Eastern and Western countries.

The results of the study may find different applications, depending on the country or countries in question. In planned economies, for example, they may help to bring about a closer correspondence between functional economic areas and administrative regions. In market-oriented settings, they should suggest efficient levers for altering the spatial allocation of resources in favor of patterns deemed more desirable than those that would result from market forces in the prevailing institutional setting.

References

[1] Morrison, P.A., *The Current Demographic Context of National Growth and Development*, Rand Corporation, Santa Monica, Calif., 1975.

[2] Blare, Calvin L., *The Revival of Population Growth in Nonmetropolitan America*, ER5-605, Economic Development Division, Economic Research Service, US Department of Agriculture, Washington, D.C., 1975.

[3] Forstall, Richard L., *Trends in Metropolitan and Nonmetropolitan Population Growth Since 1970* (forthcoming).

[4] US Commission on Population Growth and the American Future, *Population, Distribution and Policy*, S. Mills Mazie, ed., Vol. 5 of Commission research reports, US Government Printing Office, Washington, D.C., 1972.

Migration and Settlement

A. Rogers

INTRODUCTION

Human settlement issues and problems are becoming the focus of increasing concern among national governments in many West and East European countries, in North America, and in parts of the Third World. Programs to encourage the development of economically declining regions, to stem the growth of large urban centers, and to revitalize the central areas of expanding metropolises are parts of national agendas all over the globe. A notable example is the work of the US Commission on Population Growth and the American Future, which devoted one of its eight research reports entirely to the subject of population distribution policy [1].

Although much of the Commission's attention was directed at national population growth and its consequences, for its research report, *Population, Distribution, and Policy*, it commissioned papers that directly addressed issues and problems of human settlement and internal migration [1, pp.XIV-XV]:

> Major national attention and the Commission's primary focus has been on national population growth. But national growth implies local growth as additional population is distributed in the rural areas, small towns, cities and suburbs across the country. And choices we make about national population growth cannot help but have important meaning for local areas....
>
> Where people move inevitably affects the distribution of the population and the growth of local areas. As a result, *any national distribution policy will, to some degree, try to intervene in the migration process* by encouraging people to move to one place rather than another or not to move at all.

Despite the general recognition that migration processes and settlement patterns are intimately related, one nevertheless finds that the dynamics of their interrelationships are not well understood. An important reason for this lack of understanding is that demographers have in the past accorded migration a status subservient to fertility and mortality, and have almost totally ignored the spatial dimension of population growth.* Thus, whereas problems of fertility and mortality long ago stimulated a rich and scholarly literature, studies of migration have only recently begun to flourish. Consequently, one finds today a rather large and growing body of scholarly work on migration awaiting a systematic synthesis (e.g., [2,3,4]). The contributions of sociologists in identifying migration differentials (the "who" of migration), of geographers in analyzing directional migration streams (the "where" of migration), and of economists in examining the determinants and consequences of internal migration (the "why" and "so what" of migration) still have not been systematically synthesized into a unified general theory of internal migration.

Out of the recently growing literature on migration, we at IIASA have identified and isolated four related research subtasks that are of particular relevance to our long-term general interests in national settlement systems and strategies (see Figure 1). They are:

- The study of spatial population *dynamics;*
- The definition and elaboration of a new research area called *demometrics* and its application to migration analysis and spatial population forecasting;
- The analysis and design of migration and settlement *policy;*
- A *comparative study* of national migration and settlement patterns and policies.

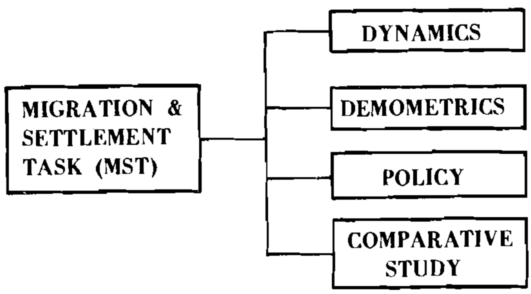


Figure 1. Migration and settlement study.

---

*There are, of course, a few notable exceptions, e.g., the work of Peter Morrison in the USA and that of Leroy Stone in Canada and of V.I. Perevedentsev in the USSR.

THE FOUR PRINCIPAL SUBTASKS

Dynamics

The evolution of every spatial human population is governed by the interactions of births, deaths, and migration. Individuals are born into a population, age with the passage of time, reproduce, and ultimately leave the population because of death or outmigration. These events and flows enter into an accounting relationship in which the growth of a regional population is determined by the combined effects of natural increase (births minus deaths) and net migration (inmigrants minus outmigrants). This subtask focuses on such relationships in order to identify and clarify some of the more fundamental spatial population dynamics involved. In addition to its general concern with the expansion of our knowledge of spatial mathematical demography, the dynamics subtask is also focusing on problems of model schedules and populations, sensitivity analysis, spatial zero population growth and aggregation-decomposition procedures (see Figure 2).

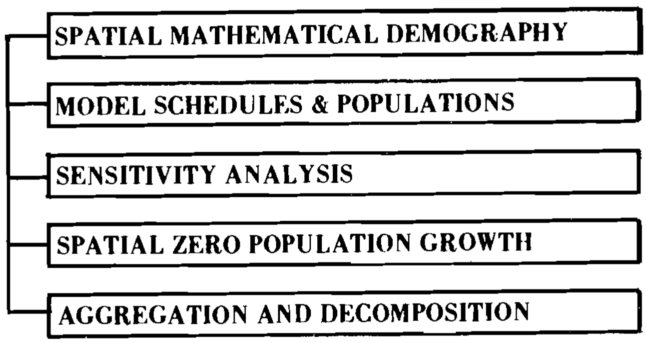


Figure 2. Dynamics.

The age-specific fertility, mortality, and migration schedules of most human multiregional populations exhibit remarkably persistent regularities (see Figure 3). The age profiles of these schedules seem to be repeated, with only minor differences, in virtually all developed and developing nations. Consequently, demographers have found it possible to summarize and codify such regularities by means of hypothetical schedules called *model* schedules.

Model schedules have two important applications: they may be used to infer (or "smooth") empirical schedules of populations, for which the requisite data are lacking (or inaccurate); and they can be applied in analytical mathematical examinations of population dynamics.

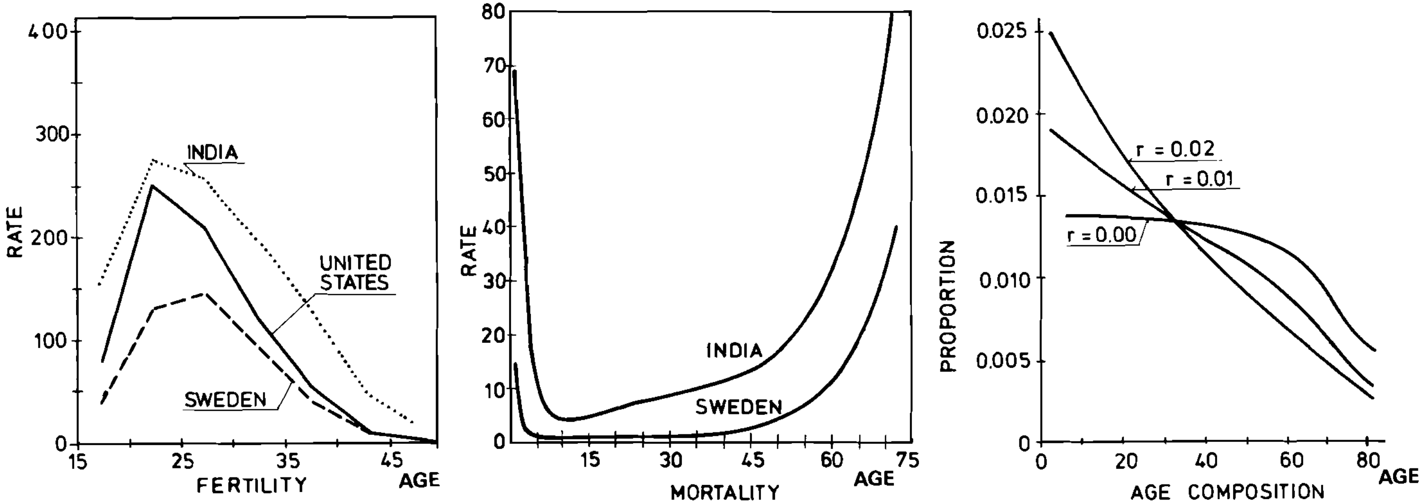


Figure 3A. Non-spatial dynamics.

Sources: [5,6,7]

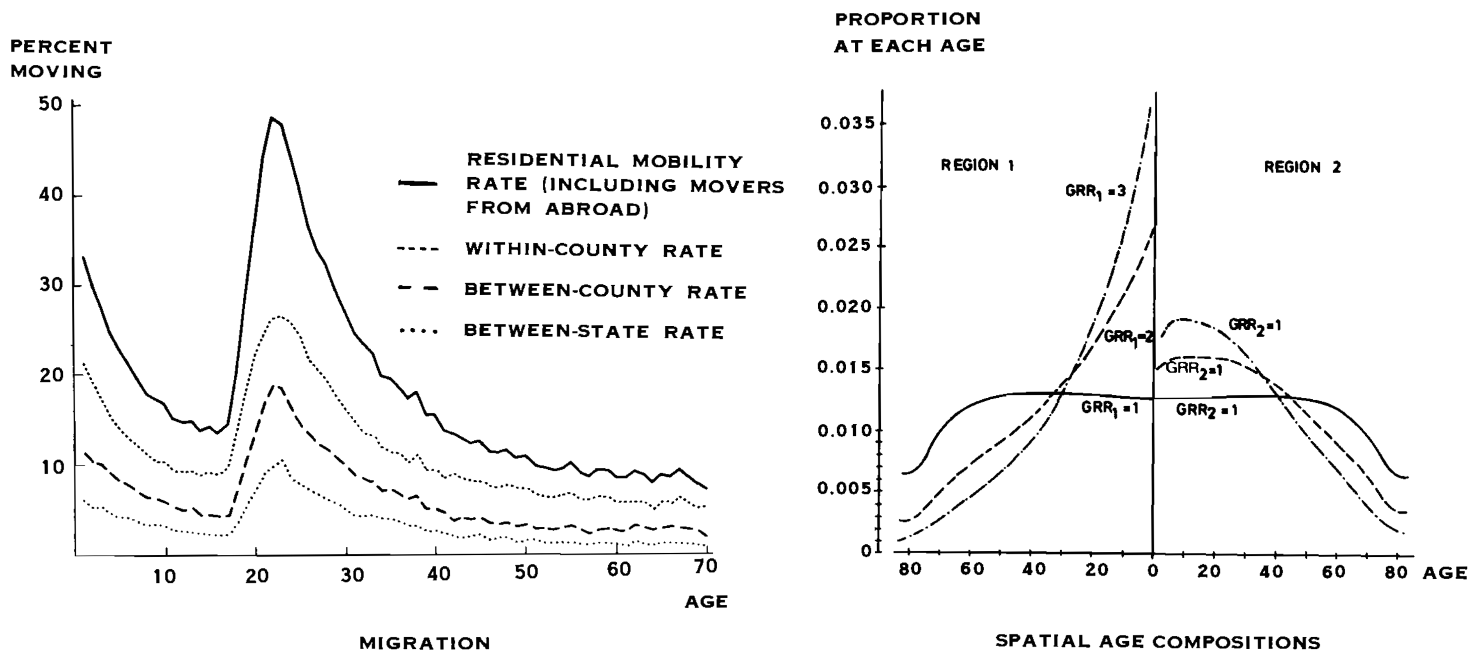


Figure 3B. Spatial dynamics.

Sources: [5,6,7]

The development of model *fertility* and model *mortality* schedules and their use in studies of the evolution of human populations have received a considerable amount of attention [8,9,10,11]. The construction of model *migration* schedules and their application to studies of the *spatial* evolution of human populations disaggregated by region of residence, however, have not. We at IIASA are addressing this latter question, and have been able to show how techniques that have been successfully applied to treat the former problem can readily be extended to deal with the latter.

In the realm of spatial mathematical demography, every demographic change may be traced back to a change in age-specific fertility, mortality, and migration rates. But how do changes in these rates affect the dynamics of the spatial demographic system? This question is the subject of our studies in sensitivity analysis. We have derived a set of sensitivity functions that relate a change in spatial demographic statistics to a corresponding change in component rates. The primary purpose of this analysis is to contribute to the knowledge of spatial population dynamics by presenting a unifying technique of impact assessments. In single-region mathematical demography, ordinary differential calculus is used to perform such sensitivity analysis. In multiregional demography, where we deal with matrix and vector functions, the application of ordinary calculus is very complicated, and matrix differentiation techniques must be applied. We have used such mathematical tools to derive analytical expressions that establish the impacts of changing rates on multiregional life table statistics, population projections, and stable population characteristics. These sensitivity functions reveal how each spatial demographic characteristic depends on age-specific rates and how it reacts to changes in those rates.

Increasing concern about the sizes and growth rates of national populations has generated a vast literature dealing with the socio-economic and environmental consequences of a reduction of fertility to replacement levels and the consequent evolution of national populations to a zero-growth condition called *stationarity*. But where people choose to live in the future presents issues and problems that are potentially as serious as those posed by the number of children they choose to have. The ways in which stabilization of a national population is likely to affect migration and local growth have received very little attention and merit careful study.

We have considered some of the redistributional consequences of an immediate reduction of fertility to bare replacement levels. This analysis has been carried out using the mathematical apparatus developed by demographers to analyze the evolution of national populations to zero growth, with an appropriate extension to include the spatial impact of internal migration. Such an extension shows that stabilization of the regional populations in a multiregional system will alter the relative contributions of natural increase and migration to regional growth. Regional age compositions will also be affected, and in ways that are strongly influenced by the age patterns of migration. Retirement havens, for example, will receive proportionately higher flows of inmigrants as a national population increases in average age, whereas destinations that previously attracted mostly younger migrants will receive proportionately fewer inmigrants. Finally, the redistributional effects of stabilization will depend in a very direct way on the redistributional pattern of total births that is occasioned by fertility reduction.

During the past two decades social scientists have come to model dynamic socio-economic systems of growing size and complexity. Despite a heavy reliance on ever more sophisticated high-speed digital computers, their capacity for handling such systems has not kept pace with the growing demands for more detailed information. Consequently, it is becoming especially important to identify those aspects of a system that permit one to deal with parts of it independently from the rest or to treat relationships *among* particular subsystems as though they were independent of the relationships *within* those subsystems. These questions are, respectively, those of decomposition and aggregation, and their application toward "shrinking" large-scale population projection models is one element of our spatial population dynamics subtask.

Demometrics

In 1938, the US National Resources Committee published a major demographic study which, after adopting a set of "reasonable" assumptions with regard to future fertility, mortality and net immigration, projected the total US population in 1980 to be 158 million, at which time it was also to have reached a state of equilibrium. The US population passed the 158 million mark less than fifteen years later and today exceeds 210 million.

It is difficult to fault such projections, for it is very unlikely that any competent demographer, faced with the same situation, would have come up with a radically different set of projections. How then, can the accuracy of such exercises in social prediction be improved? We at IIASA believe that the development of a discipline called *demometrics* is a necessary first step (see Figure 4).

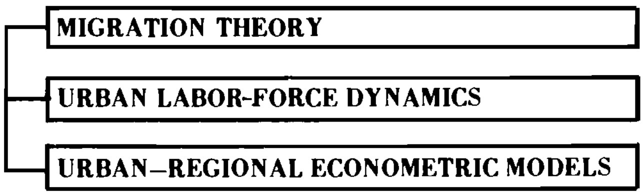


Figure 4. Demometrics.

In the field of economics a division is generally made between the areas of *mathematical economics* and *econometrics*. The former deals principally with abstract mathematical descriptions of economic dynamics and economic growth; the latter treats statistically-estimated relationships between basic economic variables. Analogous distinctions are made to distinguish mathematical psychology from psychometrics, mathematical biology from biometrics, and mathematical sociology from sociometrics. In a similar vein, we at IIASA are distinguishing mathematical demography from demometrics, the development and elaboration of which forms the major focus of the second of the four principal subtasks in the migration and settlement study.

In a broad sense, demometrics is concerned with the unified application of mathematical and statistical methods to the study of demographic phenomena. The principal aim of this discipline is to establish empirically quantitative relationships between demographic and socio-economic variables. It is important not to confuse this activity with mathematical demography and statistical techniques (as does Winkler [12]), or with demographic statistics (as does the layman). Demometrics is distinguished by its fusion of the deductive approach of mathematics, the inductive approach of statistics, and the causal approach of demographic theory.

The 1938 projection by the US National Resource Committee, like most projections today, did not link demographic variables with economic variables. Until very recently, this has been a standard practice in both disciplines. That is, demographers typically have given economic variables only cursory treatment in their models, and economists have accorded demographic variables a similar status. In the words of Hoover [13, p.73]:

> Purely demographic and purely economic models...are multitudinous and often highly complex. This makes even more striking the relatively primitive state of the art that prevails in the linking of demographic and economic variables.

Much of our work in the demometrics subtask is directed toward advancing the state of the art in this fledgling activity. Our fundamental approach has been to couple an economic model with a demographic model by means of linkages through the consumption and labor sectors (see Figure 5). The former linkage appears in the form of a consumption function that demands the economy to produce a certain output for the population to consume. The latter linkage takes the form of a migration labor-force equilibrating model that views the demographic model as the supplier of labor and the economic model as the demander of labor. The two models operate recursively in developing forecasts of demographic and economic growth that are internally consistent.

The consistent-forecasting framework just outlined has led us to consider in some detail two related areas of research: migration theory, and urban labor-force dynamics.

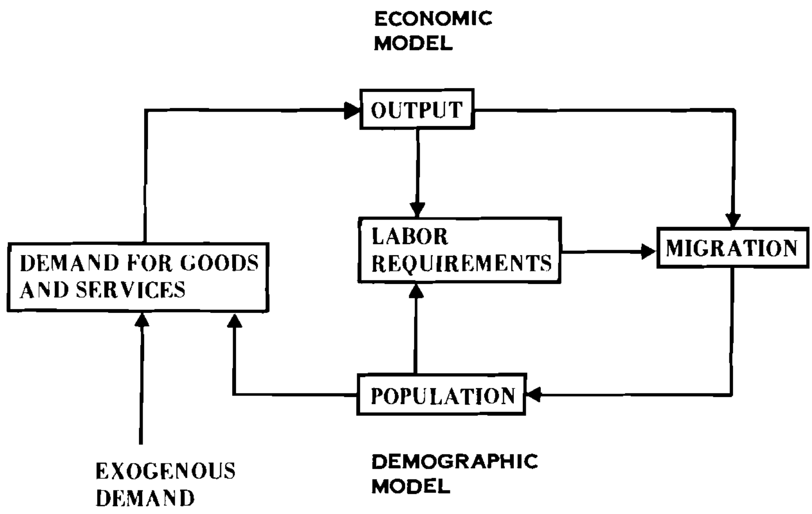


Figure 5. Consistent demographic-economic forecasting.

Theory- and model-building in the field of migration research has both a micro- and a macro-dimension. The former is dominated by the economist's perspective of migration as an investment in human capital--a perspective which holds that "migration may be viewed as a comparison of the present value of the benefits and costs of moving" [14, p.365]. The macrotheory of migration, on the other hand, focuses on aggregate movements and, like macro-economics, generally fails to relate in any precise manner its theories with those concerning individual decision-making (i.e., the microtheory).

Although an economic model forecasts the quantity of labor that will be demanded, it is important to know how much of that labor will be supplied by the resident population and how much by new migrants. Inmigration, for example, implies a larger population, whereas a change in the labor-force participation rate of residents does not. Both sources of labor supply compete for the same jobs, and each introduces a different influence on the ultimate forecast.

A large literature on urban labor-force dynamics is available. In the past, much of it has been concerned with proving or disproving the "added worker" and "discouraged worker" hypotheses [15]. Recently, attention has been directed at the dynamics of the job search process itself [16]. We believe that this body of literature will ultimately provide the connecting link between urban migration and labor-force dynamics; consequently, an increasing amount of our research effort is being directed toward establishing such a connection.

Policy

The policy analysis and design subtask of the migration and settlement study is surveying the fundamental dimensions of current national migration and settlement policies. In particular, it is examining the consequences of migration, those affecting both the origin region and the destination region. And it is evaluating the utility of the "optimal policy" paradigm of Tinbergen that recently has been usefully applied by mathematical economic planners (see Figure 6).

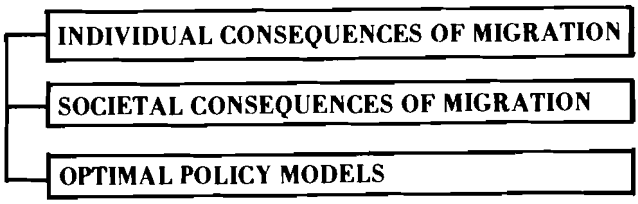


Figure 6. Policy.

A wide variety of countries are striving to channel urban growth to certain regions and to divert it from others. Generally, such national urbanization or human settlement policies have been defended on the grounds of either national efficiency or regional equity. The arguments often are framed in terms of an underlying conceptual framework known as "growth-pole theory" (e.g., [17]). Migration is an important element of this theory [17, pp.149-150]:

> One justification for pursuing a growth-centre policy in a depressed region relates to the supposed ability of major urban centres to generate and to attract migrants. There are three arguments here.... These three arguments relate successively, then, to the generation, interception and attraction of migrants. And so we must look in this chapter not at the *effects* of migration on the fortunes of the growth centre or its hinterland...but at the *causes* and *nature* of migration.

We at IIASA are focusing on the *causes* of migration in the demometrics subtask and on the *consequences* of migration (i.e., its consequence for the individual migrant) in the policy analysis subtask.

Several scholars of internal migration have concluded that the experience of migration affects favorably the personal well-being and satisfaction of the migrant (e.g., [18,19]). However, the societal consequences of migration often fall unequally on different groups.

Migration, as a mechanism for transferring labor from labor surplus areas to labor deficit areas, moves the national economy toward greater efficiency. But this adjustment of the national labor market has local consequences with regard to equity. And it is these negative consequences that often fall on those "left behind", since it is the most productive members of the labor force that are the ones who move away, leaving behind localities increasingly unattractive for industrial investment [19].

The various individual and societal consequences of internal migration have broad implications for national policies dealing with migration and settlement. The built-in conflict between the goals of national efficiency and regional equity is a fundamental "fact of life" in the design of such policies, one that ultimately can be resolved only in the political arena. A potentially useful tool for illuminating some of the tradeoffs is offered by the formal theory of economic policy, first proposed in 1963 by J. Tinbergen [20] in the field of economic planning (see Figure 7, and [21, pp.11-12]):

> The theory of economic policy is concerned with the analysis of decision situations and policy problems, using that part of general economic theory which can be quantitatively applied to economic data in some operational sense....This analytical framework has been used implicitly in other contexts which are not economic in any conventional sense. For instance,

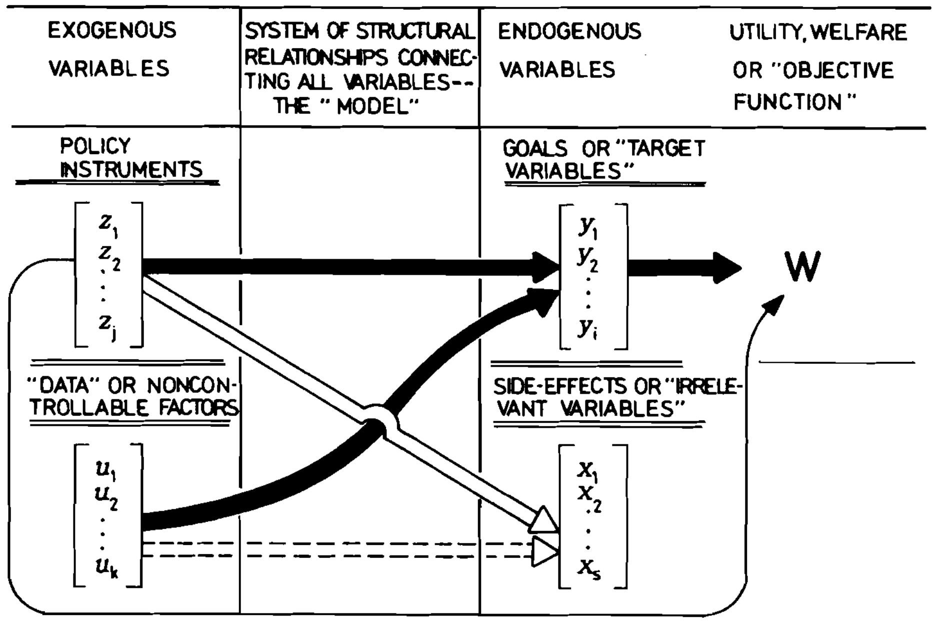


Figure 7. The Tinbergen policy framework.
Source: [21]

> control engineers and communications systems analysts, in developing the theory of servomechanisms and the principles of automatic control of a complex physical system, start by describing the "laws of motion" of the existing physical system by a set of differential or difference equations involving variables which are controlled (inputs) and other variables which are the effects or outputs. Comparisons are made between alternative outcomes over time when the controlled variables are completely absent from the system and when they are present at different assigned levels. A set of optimal controls is then chosen which in some sense provides the best possible outcome, e.g., which optimizes a given performance integral in a feedback control in the servomechanism theory.

As the authors of the above quotation point out, "the logical structures of some problems of economic policy are formally analogous to problems of decision-making and stabilization or 'steering' in other fields". We believe that spatial demography is one such field, and we therefore are actively exploring the utility of this approach for migration and settlement policy analysis and design.

Comparative Study

The comparative study of migration and settlement (Figure 8) has adopted the general framework of two recently published studies carried out in a closely related area. Specifically, the comparative analysis of human *migration* and *redistribution* is being carried out in a manner that is analogous to the procedures used by two studies of human *mortality-fertility* and *reproduction*, namely, the book by Keyfitz and Flieger entitled *Population: Facts and Methods of Demography* [22], and that edited by Berelson entitled *Population Policy in Developed Countries* [23] (see Figure 9).

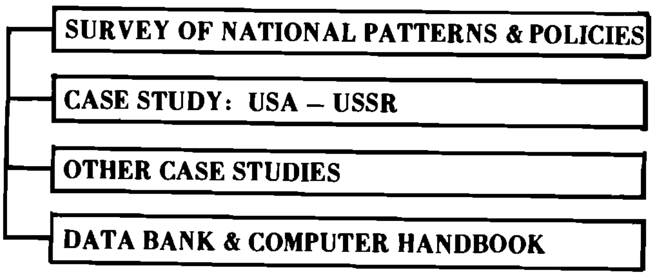


Figure 8. Comparative study.

POPULATION

FACTS AND METHODS OF DEMOGRAPHY

Nathan KEYFITZ
University of California
Berkeley

Wilhelm FLIEGER SVD
University of San Carlos
Cebu City, Philippines

W. H. FREEMAN and COMPANY
San Francisco

PROGRAM LIFE

LIFE

reads input, checks its ...
standard deck for use as input
also calls lif, which com...
and punches 'LL(X).'

input starts with 12 cards...
title card ...
totals card in format...
the year (idate) in ...
total population ...
total deaths ...
total births ...
male births ...
female births ...
the number of years ...
apply (years) in ...
is not punched, ...
male population by age ...
female population by age ...
births by age ...
male deaths by age ...
female deaths by age ...

age groups are ...
(20 categories).

next are the numbers nn and mm
nn cards containing ...
adjustments. ...
with a card punched ...

MAIN TABLES - Countries of Europe

POLAND, 1965

Table 1 DATA INPUT TO COMPUTATIONS

Age Population Births ...
.
.
.

Table 2 LIFE TABLE FOR MALES

Age,x $_nq_x$ l_x $_nd_x$ $_nL_x$ ...
.
.
.

Table 3 LIFE TABLE FOR FEMALES

Age,x $_nq_x$ l_x $_nd_x$ $_nL_x$ ...
.
.
.

Table 4 ...
.
.
.

Figure 9A. The Keyfitz-Flieger Book [22].

POPULATION POLICY IN DEVELOPED COUNTRIES

Edited by

BERNARD BERELSON

A POPULATION COUNCIL BOOK
McGRAW-HILL BOOK COMPANY

CONTENTS

Preface		ix
The Authors		xi
Chapter 1	Introduction	1
Chapter 2	Ireland	8
Chapter 3	Israel	42
Chapter 4	Finland	98
Chapter 5	Sweden	113
Chapter 6	Bulgaria	149
Chapter 7	Greece	171
Chapter 8	Belgium	193
Chapter 9	Hungary	225
Chapter 10	Australia	270
Chapter 11	The Netherlands	294
Chapter 12	Czechoslovakia	319
Chapter 13	Romania	355
Chapter 14	South Africa	385
Chapter 15	Canada	403
Chapter 16	Argentina	427
Chapter 17	Poland	445
Chapter 18	Spain	489
Chapter 19	France	545
Chapter 20	Great Britain	592
Chapter 21	Italy	647
Chapter 22	West Germany	679
Chapter 23	Japan	704
Chapter 24	United States	731
Chapter 25	Soviet Union	760
Chapter 26	Summary	771
Index of Topics		791

THE AUTHORS

Bernard Berelson. President of the Population Council, New York

IRELAND
Brendan M. Walsh

ISRAEL
Dov Friedlander

FINLAND
Paavo Piepponen

SWEDEN
Lena Jonsson

BULGARIA
Ivan Stefanov
Nicola Naoumov

.
.
.

JAPAN
Minoru Muramatsu
Toshio Kuroda

UNITED STATES
Charles F. Westoff

SOVIET UNION
Dmitri I. Valentei

Figure 9B. The Berelson Book [23].

The Keyfitz and Flieger book focuses on observed age- and sex-specific mortality and fertility schedules, and projects the evolution of the populations exposed to these schedules. In order to examine the population trends of the present day, the authors collect together a data bank of population statistics from more than 90 countries and subject these to a standardized analytical process.

If national population growth is the primary *focus* of the Keyfitz and Flieger study, its principal *approach* for examining such growth is embodied in a collection of computer programs that provide the vehicle for analyzing population growth in a consistent and uniform manner. These programs and the mathematical models that underlie them are also presented in the study volume.

Finally, the major *contribution* of the Keyfitz and Flieger study is the uniform application of a consistent methodology to a vast amount of data in order to trace population growth trends in a large number of countries.

The focus, approach, and contribution of the Keyfitz and Flieger study have much in common with those of the comparative study of migration and settlement. The focus of the latter also is population growth, but *spatial* population growth. The approach also relies on a uniform set of computer programs, but these embody the models of *multiregional* mathematical demography [24]. And the expected contribution also is that of linking data and theory, but the data and theory that are linked are *spatial* in character.

There are several important differences between the two study formats:

- A primary concern of the Keyfitz and Flieger study is population *reproduction* and the *demographic transition* from high to low birth and death rates. An important focus of the comparative migration and settlement study is population *redistribution* and the *mobility transition* [25] from low to high migration rates.
- The Keyfitz and Flieger study is the product of two authors; the comparative migration and settlement study requires the collaborative efforts of an international team of scholars residing in various member and non-member nations.
- The Keyfitz and Flieger study identifies trends and the numerical consequences of the continuation of such trends into the future; the comparative migration and settlement study is, in addition, striving to link national trends with explanatory variables.
- Although Chapter 4 of their book is entitled "Policy Dilemmas and the Future", the Keyfitz and Flieger study does not deal with national policies. (Their Chapter 4 is only three pages long.) The comparative migration

> and settlement study, however, explicitly considers the national migration and settlement policies of each country represented. In this respect, the study resembles more the study of population policies coordinated by Berelson [23].

The book edited by Berelson is a review of population policies in 24 developed countries. The individual chapters were written by collaborating scholars residing in the particular countries. Thus, for example, Professor Charles Westoff of Princeton's Office of Population Research wrote the chapter on population policy in the USA, and Professor Dimitri Valentei of Moscow State University's Population Center authored the chapter on population policy in the USSR.

According to Berelson, "the collaborators were given a common outline as a guide to the topics to be addressed, but each author was free to prepare his report in his own manner". It is therefore not surprising that different authors elected to emphasize different aspects of population policy, and drew on different kinds of demographic data to develop their presentations. Thus the book is somewhat uneven in its coverage and in the data and indicators put forward by the various authors.

In the migration and settlement study we are striving to marry the Berelson approach with the Keyfitz-Flieger approach in order to capture the best features of each. Every national analysis in the comparative study of migration and settlement is, as in the Berelson study, being carried out in collaboration with scholars residing in the countries being studied. However, most of the data, projections, and indicators that form the foundation of the analysis are being processed, as in the Keyfitz-Flieger study, by a common set of computer programs. These data and programs will be published.

AN ELEMENT OF THE FIRST SUBTASK: SPATIAL ZERO POPULATION GROWTH

World Zero Population Growth

Most demographers would agree that current rates of world population growth cannot continue for more than a century or two without producing a collapse of the present world system. A much publicized example of the recent wave of concern over the world's "population explosion" is the study sponsored by the Club of Rome entitled *The Limits to Growth*, in which it is asserted that [26, p.23]:

> If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.

A notable effort to examine a range of alternative projections of world population growth is the recent book by Frejka entitled *The Future of Population Growth: Alternative Paths to Equilibrium* [27]. In this book, the author presents several projections of the populations of the developed and less developed regions of the world and its major areas. All the projections ultimately converge to a stationary "zero growth" population and differ only in the paths by which this zero growth is achieved. Five major paths (or projections) are offered. These differ, one from another, by the length of the period of fertility decline to replacement level (0, 10, 20, 50, or 70 years).

According to Frejka, the population of the world in 1970 was approximately 3.6 billion, out of which a total of 1.1 billion were living in the more developed countries and 2.5 billion resided in the less developed nations. The age compositions of these two populations were significantly different: the median age of the former was 31 years whereas that of the latter was 19 years. The most important implication of this difference is simply that the younger population has a proportionately much larger stock of future childbearers and, in consequence, a much larger built-in "momentum" for growth.

Figures 10 and 11 summarize Frejka's principal findings. Figure 10 contrasts the five major growth projections, demonstrating that [27, pp.52-54]:

> Provided the average fertility conditions changed so substantially that the NRR [net reproduction rate] declined from its estimated current (1965-70) level of 1.9 to a level of 1.0 within a few years, the present world population of 3.6 billion would...settle at around 5.6 to 5.7 billion inhabitants. If, however, a world fertility decline were brought about very gradually so that in, say, 70 years an NRR of 1.0 were attained, then... world population would settle at over 15 billion.

Figure 11 disaggregates the population projection of Figure 10 by "more developed" and "less developed" regions of residence. The difference between the two sets of trajectories is striking evidence that "future world population growth will increasingly be determined by the nature of population growth in the less developed regions" [27, p.73].

Frejka's book is part of a vast literature on the social, economic, and environmental impacts of a reduction of fertility to replacement level and the consequent evolution of populations to a zero growth condition. *But where people choose to live in the future presents issues and problems that are potentially as serious as those posed by the number of children they choose to have.* Yet the *spatial* implications of reduced fertility have received relatively little attention, and consequently, we are ill-equipped to develop adequate responses to questions such as the one recently posed by the US Commission on Population

Growth and the American Future* [28, p.13]:

> How would stabilization of the national population affect migration and local growth?

Recognizing the importance of examining the spatial consequences of zero population growth, we at IIASA have applied our models of spatial population dynamics to the study of *spatial zero population growth.*

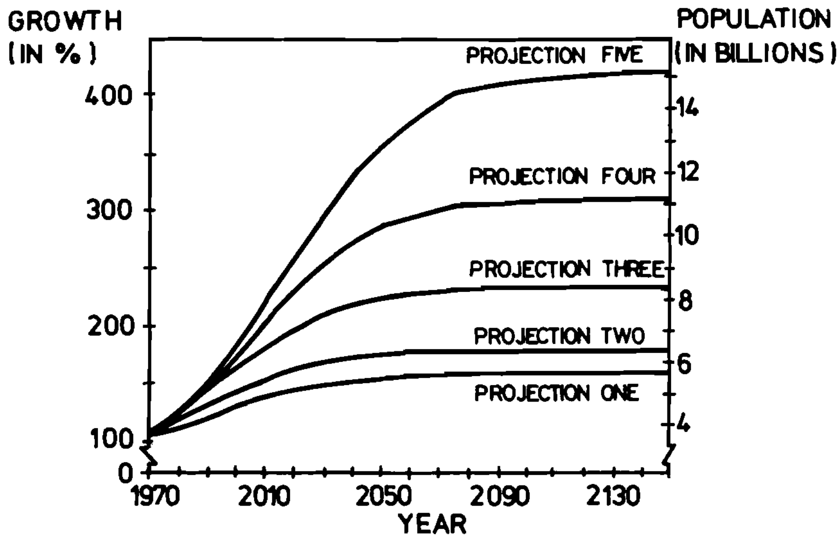


Figure 10. Growth of world population, projections one to five standard set, 1970-2150 (in absolute numbers and in percentages).

Source: [27]

---

*A notable exception is the work of Peter Morrison, who concludes: "...demographic processes interact in subtle and often complex ways, and the mechanisms by which declining fertility would influence population redistribution are only partially understood. Their elucidation can furnish a clearer picture of how and under what circumstances population redistribution can be influenced by public policy" [29, p.547].

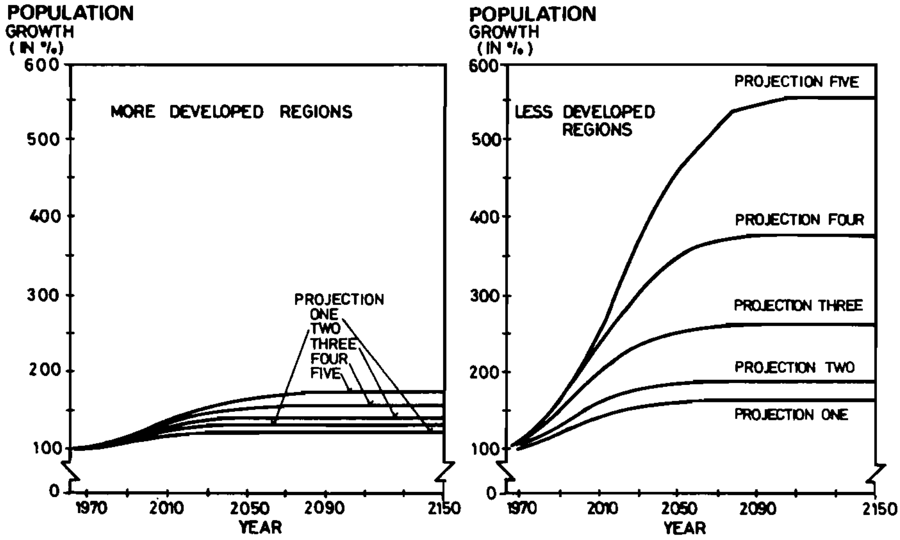


Figure 11. Growth of population of more developed and less developed regions, projections one to five, standard set, 1970-2150 (1970 = 100).

Source: [27]

Spatial Zero Population Growth

Zero population growth for a nation implies an *average* of zero growth for local areas. This, of course, still allows for the possibility of nonzero growth in particular localities. Thus *spatial* zero growth, like *temporal* zero growth, may be viewed either as a condition that ultimately prevails uniformly, or one that exists only because of a fortuitous balancing of regional rates of positive growth, of zero growth, and of decline. Since no obvious advantages arise from the latter case, demographers quite naturally have viewed the attainment of temporal zero growth in the long run in terms of an indefinite continuation of temporal zero growth in the short run. We follow this tradition and view the attainment of spatial zero growth in the long run in terms of temporal zero growth within each region of a closed multiregional population system. In consequence, we confine our attention here to the evolution of a particular subset of stationary populations, called *spatial zero-growth populations*, i.e., stable multiregional populations that have a zero growth rate. Thus we augment the usual twin assumptions of a fixed mortality schedule and a fixed fertility schedule, set at replacement level, with the assumption of a fixed migration schedule.

If age-specific death rates are fixed and replacement level birth rates remain unchanged, a population that is closed to migration will ultimately evolve into a stationary population. The characteristics of such a population are well known. The number of individuals at any age would remain fixed, and the total number of deaths would equal exactly the total number of births. Because mortality risks would be relatively low from just after birth through middle age, the age composition of such a population would be nearly rectangular until ages 50 or 60, tapering much more rapidly thereafter with the increase in death rates among the older population.

The maintenance of a stationary population requires that parents have only as many children as are needed to maintain a fixed number of births every year. This means, for example, that a 1,000 women must on the average produce a 1,000 baby girls during their lifetime. Moreover, since some girls will not survive to become mothers, those who do must have slightly more than 1,000 daughters in order to compensate for those who don't. Hence the *gross* reproduction rate (GRR) must be greater than unity by an amount just sufficient to maintain a *net* reproduction rate (NRR) of unity. For example, about 97 to 98 percent of the women in the United States today survive to the principal ages of childbearing. Consequently, those who do must have approximately 1.027 daughters, on the average, as they pass through the childbearing ages. In other words, the GRR must be 1.027 in order for the NRR to be unity.*

The Momentum of Spatial Zero Population Growth

Differences between most observed population age compositions and those of stationary populations make it virtually impossible to attain zero growth in the near future. A closed population's birth rate and growth rate depend on its fertility schedule and its age composition. Consequently, whether and how long a population continues to grow after achieving a net reproduction rate of unity depends on that population's age composition and its degree of divergence from that of a stationary population. The ratio by which the ultimate stationary population exceeds a current population is the "momentum" of that population, a quantity that recently has been given analytical content by Keyfitz [30] who shows that the momentum of a population numbering K

---

*Because there are usually about 105 baby boys born for every 100 baby girls, mothers in a stationary population of males and females would need to have a total rate of reproduction about three percent more than twice 1.027. In this way we obtain the total fertility rate of 2.11 used, for example, in the US Census Bureau projections [31].

individuals, with an age composition close to stable, may be approximated by the expression

$$\frac{\hat{Y}}{K} = \frac{b\ e(0)}{r\ \mu} \left(\frac{R(0) - 1}{R(0)}\right) \quad , \tag{1}$$

where b is the birth rate, r is the rate of growth, e(0) is the expectation of life, and R(0) is the net reproduction rate--all measured before the drop in fertility--and μ is the mean age of childbearing afterward. Observe that equation (1) also may be expressed as

$$\hat{Y} = e(0)\hat{Q} \quad ,$$

where

$$\hat{Q} = \frac{bK}{r\mu} \left(\frac{R(0) - 1}{R(0)}\right)$$

is the number of births in the (ultimately) stationary population. Note that since the derivation assumes the population to be approximately stable before the decline in fertility, b and r are intrinsic stable rates of the initial (nonstationary) regime of growth.

Straightforward population projection calculations may be used to obtain the future population that evolves from any particular observed or hypothetical regime of growth. Therefore equation (1) is not needed to obtain a numerical estimate of an ultimate stationary population. However, Keyfitz's simple momentum formula gives us an understanding of the population dynamics that are hidden in the arithmetical computations of a population projection. It identifies in an unambiguous way the five parameters of a current population that determine the size of the ultimate stationary population.

We at IIASA have developed a spatial generalization of Keyfitz's momentum formula. We begin by estimating the ultimate size of the total stationary births, $\hat{Q}$, by means of equation (1); next, we distribute that total among the various regions according to the allocation defined by the characteristic vector associated with the unit root of the "reduced" net reproduction matrix $\hat{R}(0)$; then premultiplying the resulting vector by the matrix of expectations of life at birth $\underset{\sim}{e}(0)$, we find the vector of regional zero-growth populations $\{\hat{\underset{\sim}{Y}}\}$, i.e.,

$$\{\hat{\underset{\sim}{Y}}\} = \underset{\sim}{e}(0)\{\hat{\underset{\sim}{Q}}\} \quad , \tag{2}$$

where $\{\hat{Q}\}$ is scaled to sum to $\hat{Q}$, the latter coming from Keyfitz's single-region formula.

Equation (2) may be used to dramatically underscore our earlier assertion that *where people choose to live in the future presents issues and problems that are potentially as serious as those posed by the number of children they choose to have.* Consider, for example, the projection to zero growth of India's population that was recently carried out by Ryder on the basis of the following assumptions [32, p.6]:

> To simplify the task of projecting the population of India, we make the following assumptions: it is a stable population with a growth rate $r = +0.025$ and survival functions corresponding to those labelled "West, level 13" (for which the female and male expectations of life at birth are 50 and 47.114, respectively) in the Coale/Demeny collection; the mean age of (gross) maternity $m = 29$; the ratio of male to female births $k = 1.05$; and the current population size is 600 million.

From these assumptions it follows that the initial number of female births per annum $B(t)$ equals 12.156 million, $R(0)$ equals 2.019, and μ equals 28.672 years. Applying equation (1), Ryder finds a $\hat{Q}$ of 8.558 million and a zero growth population of 851 million. He then shows that if India's survival level rises to $e(0)$ equals 70 years for females and $e(0)$ equals 66.023 years for males, and

> ...if replacement level fertility takes 40 years to achieve and the mean age of gross reproduction declines from 29 to 27, the ultimate female birth cohort size will be...15.029 million. Given that value,...the consequent ultimate population size is 2.094 billion [32, p.7].

Ryder concludes that "the thought of a population of 2.1 billion for India is staggering", and goes on to examine in what respects the components of his projection may be modifiable.

There is no question but that a 2.1 billion population for India is staggering. What is even more mind-boggling, however, is that approximately 70 to 80 percent of this total is likely to be found in that nation's already teeming and over congested urban areas (the current figure is 20 percent). To show this, we need only introduce a few additional assumptions and then apply equation (2). Specifically, assume that life expectancy is 55 years in urban areas and 45 in rural areas, with the migration pattern being such that

$$\underset{\sim}{e}(0) = \begin{bmatrix} {}_u e_u(0) & {}_r e_u(0) \\ {}_u e_r(0) & {}_r e_r(0) \end{bmatrix} = \begin{bmatrix} 50 & 20 \\ 5 & 25 \end{bmatrix} .$$

Assume, further, that the spatial pattern of net reproduction after the drop to replacement fertility is given by

$$\hat{\underset{\sim}{R}}(0) = \begin{bmatrix} 0.85 & 0.45 \\ 0.15 & 0.55 \end{bmatrix} .$$

Then,

$$\{\hat{\underset{\sim}{Q}}\} = \hat{Q} \begin{bmatrix} 3/4 \\ 1/4 \end{bmatrix}$$

and

$$\{\hat{\underset{\sim}{Y}}\} = \begin{bmatrix} \hat{Y}_u \\ \hat{Y}_r \end{bmatrix} = \hat{Q} \begin{bmatrix} 50 & 20 \\ 5 & 25 \end{bmatrix} \times \begin{bmatrix} 0.75 \\ 0.25 \end{bmatrix} = \hat{Y} \begin{bmatrix} 0.80 \\ 0.20 \end{bmatrix} \text{ million.}$$

Thus, under our assumptions, a fertility reduction that allows a woman one baby girl puts roughly 80 percent of India's ultimate zero-growth population into urban areas (Alternative A in Figure 12). A similar calculation using an alternative scheme of fertility reduction (i.e., proportional fertility reduction) gives about 72 percent for the same figure (Alternative B in Figure 12).

Figure 12 summarizes the above results. Note that the "momentum" for urban areas varies from 500 to 1400 percent, depending on the time that it takes for the fertility decline to occur and on the spatial pattern of that fertility reduction.

CONCLUSION

Internal migration and human settlement patterns are increasingly becoming subjects of governmental concern, both in developed countries and in the developing nations of the Third World. Whether the problem is that of ensuring an adequate supply of labor in Siberia or one of stemming the vast flood of migrants from the farms and villages of Latin America to its overcrowded major cities, the need for a well-developed understanding of the relationships between spatial population dynamics and socio-economic development is clear. A stark reminder of this need recently appeared on the editoral page of the International Herald Tribune [in 33, p.4]:

> Bombay - The doors of the jumbo jet swing open and the night air rushes in. The warm stench of industrial waste and human excrement overpowers the smell

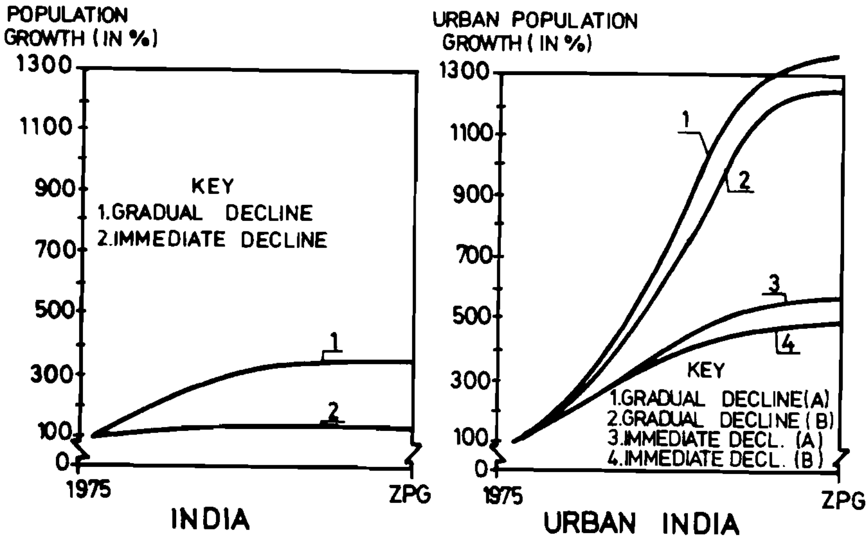


Figure 12. Growth of India's population to zero population growth (ZPG). Source: [34]

of jet exhaust. This is Bombay--city of six million, industrial giant, metropolis of the western seaboard, ringed by forests of chemical plants, textile mills and engineering factories. Inside are the people, crushed together, man on man, woman on woman, child on child. Squeezed between humanity run the open sewers, full of the putrid outpourings of an overwrought civilization.

Bombay at the end of the 17th century had only 10,000 inhabitants. By 1872 it was 644,000. Today, the density of population is higher than Manhattan's and growing steadily. Only economic recession keeps the numbers down. For once the wheels of industrial society move, the people come in their hordes leaving the economic insecurity of the villages for this city where they think there must be hope.

Dr. A. Mehta, chief economic adviser of Tata Industries...estimates the number of under-employed as about 20 million, or 10 percent of the labor force. By AD 2000, he argues, India will have to find jobs for an additional 200 million people....He concludes that the urban-industrial world is not the answer to this problem...[He] believes this great nation...will have to turn its back on its old developmental ideas ...of escaping poverty through industrialization. It will have to begin taking its agriculture seriously and hold its people on the land and in the villages.

References

[1] US Commission on Population Growth and the American Future, *Population, Distribution, and Policy*, S.M. Mazie, ed., Vol. 5 of Commission research reports, US Government Printing Office, Washington, D.C., 1972.

[2] Greenwood, M.H., Research on Internal Migration in the United States: A Survey, *Journal of Economic Literature*, 13 (1975), 397-433.

[3] Price, D.O. and M.M. Sikes, *Rural-Urban Migration Research in the United States: Annotated Bibliography and Synthesis*, US Government Printing Office, Washington, D.C., 1975.

[4] Shaw, R.P., *Migration Theory and Fact: A Review and Bibliography of Current Literature*, Regional Science Research Institute, Philadelphia, Pa., 1975.

[5] Bogue, D.H., *Principles of Demography*, Wiley, New York, 1969.

[6] Long, L.H., New Estimates of Migration Expectancy in the United States, *Journal of the American Statistical Association*, 68 (1973), 37-43.

[7] Rogers, A. and F. Willekens, *Spatial Population Dynamics*, RR-75-24, International Institute of Applied Systems Analysis, Laxenburg, Austria, 1975.

[8] Coale, A.J. and P. Demeny, *Methods of Estimating Basic Demographic Measures from Incomplete Data*, United Nations, New York, 1967.

[9] Coale, A.J. and P. Demeny, *Regional Model Life Tables and Stable Populations*, Princeton University Press, Princeton, N.J., 1966.

[10] Coale, A.J., *The Growth and Structure of Human Populations*, Princeton University Press, Princeton, N.J., 1972.

[11] Rele, J.R., *Fertility Analysis Through Extension of Stable Population Concepts*, Institute of International Studies, University of California, Berkeley, Calif., 1967.

[12] Winkler, W., *Demometrie*, Duncker and Humbolt, Berlin, 1969.

[13] Hoover, E., Basic Approaches to the Study of Demographic Aspects of Economic Development: Economic-Demographic Models, *Population Index*, 37 (1971), 66-75.

[14] Bowles, S., Migration as Investment: Empirical Tests of the Human Investment Approach to Geographical Mobility, *Review of Economics and Statistics*, 52 (1970), 356-362.

[15] Mincer, J., Labor-Force Participation and Unemployment: A Review of Recent Evidence, in *Prosperity and Unemployment*, R.A. Gordon and M.S. Gordon, eds., Wiley, New York, 1966.

[16] Phelps, E.S., ed., *Microeconomic Foundations of Employment and Inflation Theory*, W.W. Norton, Boston, Mass., 1970.

[17] Moseley, M.H., *Growth Centers in Spatial Planning*, Pergamon, Oxford, 1974.

[18] Lansing, J.B. and E. Mueller, *The Geographic Mobility of Labor*, Survey Research Center, Institute for Social Research, University of Michigan, Ann Arbor, Mich., 1967.

[19] Morrison, P.A., *Migration from Distressed Areas: Its Meaning for Regional Policy*, R-1103-EDA/FF/NIH, Rand Corporation, Santa Monica, Calif., 1973.

[20] Tinbergen, J., *On the Theory of Economic Policy*, North-Holland, Amsterdam, 1963.

[21] Fox, L., J. Sengupta, and E. Thorbecke, *The Theory of Quantitative Economic Policy*, North-Holland, Amsterdam, 1972.

[22] Keyfitz, N. and W. Flieger, *Population: Facts and Methods of Demography*, W.H. Freeman, San Francisco, Calif., 1971.

[23] Berelson, B., ed., *Population Policy in Developed Countries*, McGraw-Hill, New York, 1974.

[24] Rogers, A., *Introduction to Multiregional Mathematical Demography*, Wiley, New York, 1975.

[25] Zelinsky, W., The Hypothesis of the Mobility Transition, *Geographical Review*, 46 (1971), 219-249.

[26] Meadows, D.H. et al., *The Limits to Growth*, Universe Books, New York, 1972.

[27] Frejka, T., *The Future of Population Growth: Alternative Paths to Equilibrium*, Wiley, New York, 1973.

[28] US Commission on Population Growth and the American Future, *Population and the American Future*, US Government Printing Office, Washington, D.C., 1972.

[29] Morrison, P.A., The Impact of Population Stabilization on Migration and Redistribution, in *Population, Distribution, and Policy*, S.M. Mazie, ed., US Commission on Population Growth and the American Future, US Government Printing Office, Washington, D.C., 1972.

[30] Keyfitz, N., On the Momentum of Population Growth, *Demography*, 8 (1971), 71-80.

[31] US Bureau of the Census, Illustrative Population Projections for the United States: The Demographic Effects of Alternative Paths to Zero Growth, *Census Population Reports*, Series P-25, No. 480, US Government Printing Office, Washington, D.C., 1972.

[32] Ryder, N.B., Notes on Stationary Populations, *Population Index*, 40 (1974), 3-28.

[33] Power, J., Sense of Helplessness, in *International Herald Tribune* (April 6, 1976), 4.

[34] Rogers, A. and F. Willekens, *Spatial Zero Population Growth*, RM-76-25, International Institute of Applied Systems Analysis, Laxenburg, Austria, 1976.

Regional Development and Land-Use Models

J.R. Miron

INTRODUCTION

In the brief history of IIASA's involvement in urban research, first in the Urban project and now in the Human Settlements research area, emphasis has been placed on mathematical models of urban growth and public policy in a national settlement system (see Figure 1). Commonly, in this kind of research, each city or settlement is treated as a point in a network of urban centers linked by transportation and communication facilities or by some organizational connection. Certain useful kinds of behavioral and policy theorems can be derived from elementary models based on such an abstract conceptualization.

There are, however, a whole class of urban growth processes that operate either in the immediate vicinity of an urban center or in that small subset of the national settlement system representing neighboring cities and towns. The urban network approach

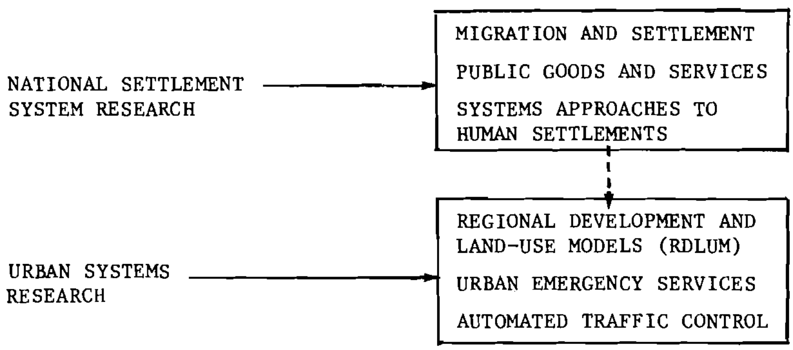


Figure 1. Urban and regional research at IIASA.

used at the national level is not satisfactory at the regional level. Instead of treating cities as abstract points in space, one must put emphasis on the continuity of space. Regional land-use models are preferable because of their specific emphasis on land areas and spatial patterns of land use.

It is toward an examination of these regional growth processes, their controllability and their optimality that the present research has recently been started. The purpose of this short-term project is to undertake a review of the use of mathematical models in analyzing such growth issues. This research is serving to outline some potential research issues to which the Human Settlements and Services area might contribute, within the Integrated Regional Development (IRD) program. In addition to this in-house purpose, the research will contribute to IIASA's clearinghouse role by reviewing recent major advances in these topics.

TOPICS AND LINKAGES

The purpose of this research is to analyze the processes underlying the spatial pattern of regional development. Two topics of research have been identified (see Figure 2). The

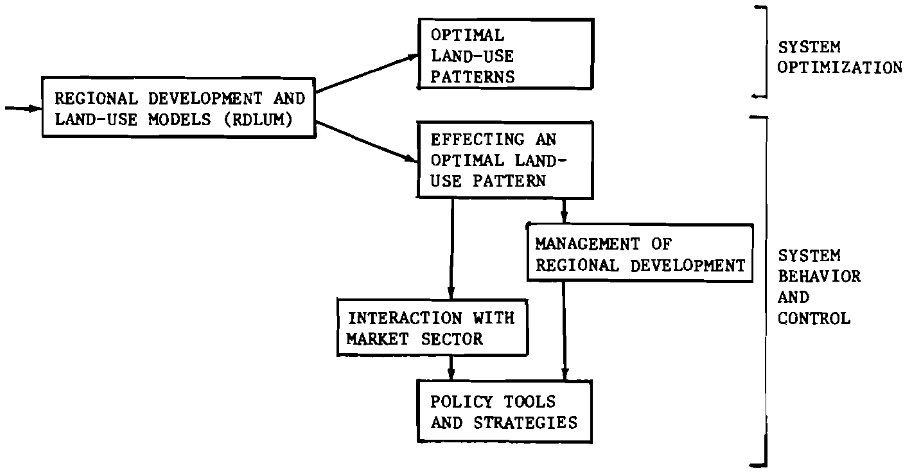


Figure 2. Main research questions in RDLUM.

first is concerned with the problem of designing a spatial arrangement of land uses which, in some sense, "optimizes" regional development from society's point of view. In previous research, the design problem has virtually always been treated abstractly. There has been no attention paid to the questions of how this development is to be managed or how it is to be integrated within the market sector of society, where this exists. The design problem has been to determine where facilities or land uses should be placed, and how much of them there should be to optimize some objective function.

The abstract nature of this design problem makes it applicable to many kinds of societies, both East and West. However, every society operates within a particular institutional structure and its own division between central planning and decentralized or market decision-making. Given that some notion of an "optimal" spatial pattern of regional development can be found, most governments are faced with either of the following problems: they are not able to manage the proposed development, or the market sector behaves so as to thwart the optimal plan. To counter these problems, the government typically has to find policy tools and strategies to shift the regional development process toward the optimal solution. This constitutes a second topic of research, one that has been virtually ignored in previous research.

This research has many potential linkages with other areas and programs at IIASA (see Figure 3). The outputs of this work can be incoporated into the IRD program. The inputs could come

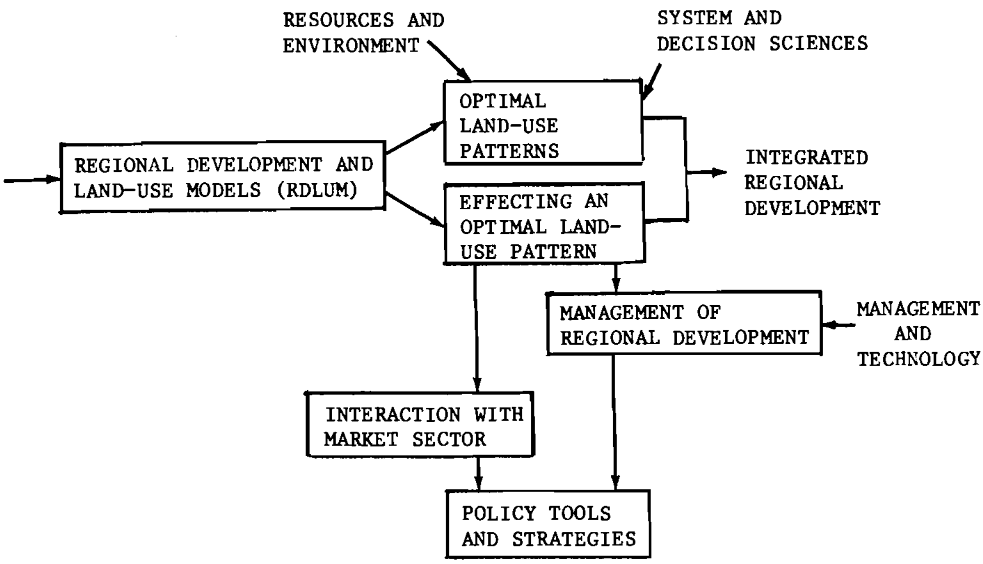


Figure 3. Potential research linkages with RDLUM at IIASA.

from several sources. The Resources and Environment (Ecology) area could, for instance, contribute to an integration of land-use design and air quality management models. The System and Decision Sciences area could contribute toward the research on optimization models. Finally, the current activities of the Management and Technology area could be integrated directly into the development management topic.

To give some detail and flavor to this discussion, let us consider briefly the work that has been done on optimal land-use design models at IIASA.

OPTIMAL LAND-USE DESIGN MODELS

In research to date, progress in the development of optimal land-use design models has been evaluated. In particular, the ways that design problems have been cast previously as mathematical programming models have been studied (see Figure 4). This involves looking at how the instrument variables in such models are designated, what kinds of constraints are allowed for, and how the objective function is formulated.

As an example, Dickey and Najafi* have described an application of their TOPAZ design model to the New Valley Planning District of Virginia in the USA, an area of approximately 120,000 hectares. This region was subdivided into 40 zones. The 200 instrument variables in the TOPAZ model are the assignments of aggregate new development (over the next 20 years) in five different categories of land use (including residential, commercial, industrial, public, and park land uses) among each of the 40 zones. The objective function of the TOPAZ model to be minimized is the sum of the establishment costs (including land purchase and preparation, facility provision, and building construction) for each land use allocated to each site, and the capitalized value of the anticipated resulting transportation flows among zones. In the model, there are constraints which assert that, for each of the 40 zones, the amount of land allocated to each use does not exceed the amount of developable land in that zone. In addition, there are five other constraints. Each asserts that, for a given land-use type, there is a minimum total amount of land which must be allocated among the 40 zones. Although this is only one specific case, the TOPAZ model has several features in common with virtually all other design models: a gross-scale representation of the region as a finite set of homogeneous zones, an orientation toward development cost minimization, a fixed-planning horizon for new development, and

---

*J.W. Dickey and F.T. Najafi, Regional Land Use Schemes Generated by TOPAZ, *Regional Studies*, 7 (1973), 373-386.

OPTIMAL LAND-USE PATTERNS

MATHEMATICAL PROGRAMMING APPROACH:
A TYPICAL LAND-USE DESIGN MODEL

Minimize:

$$Z = f(x_{11}, x_{12}, \ldots, x_{1n}, x_{21}, \ldots, x_{mn})$$

subject to:

$$\sum_{i=1}^{m} x_{ij} \leq S_j \qquad j = 1,2,\ldots,n$$

$$\sum_{j=1}^{n} x_{ij} \geq D_i \qquad i = 1,2,\ldots,m$$

$$g_i(x_{11}, x_{12}, \ldots, x_{1n}, x_{21}, \ldots, x_{mn}) \geq c_i \qquad i = 1,2,\ldots,k$$

$$x_{ij} \geq 0;$$

where:

n = zones,

m = land uses,

k = design standard constraints,

Z = discounted stream of development costs,

S_j = supply of developable land in zone j,

D_i = aggregate land requirement of use i,

x_{ij} = real assignment of land use i to zone j.

Figure 4. Research approach to optimal land-use patterns.

constraints ensuring that no zone's capacity for development is exceeded and no land use's aggregate demand for space goes unmet.

In the brief research to date, several major methodological issues have been raised concerning the theoretical foundations of such models and the transition from a theoretical to an applied planning tool. These issues should form the basis of a next stage of research. They include the following questions. To what extent can the objective function of such models be expanded to include criteria other than cost minimization? To what degree can uncertainty about future social conditions be incorporated to yield a more "robust" or resilient optimum? Can the concept of a fixed planning horizon be replaced by a more dynamic and open-ended design model? Finally, how can the interdependencies among land uses, as for example, those created by air pollution, be incorporated in these models? A main conclusion of the research at IIASA at this stage is that we are a substantial way off from realistic empirical applications of these models. However, research on the above questions can move us considerably closer to that goal.

CONCLUSIONS

The emphasis in this research is on the processes that affect the development of human settlements at the regional level, the extent to which such processes are controllable, and the extent to which an optimal spatial pattern of development can be delineated. Our approach is to use mathematical models to look at these issues. Thus, commitment to a theoretical framework, with a concurrent emphasis on the ultimate empirical applicability of the research, is in keeping with IIASA's potential role in integrated regional development.

Interregional Variations in Public Goods and Services

W.A. Welsh

This research on interregional variations in public goods and services is related to both of the programs that constitute the Human Settlements and Services area at IIASA: the Urban and Regional Systems project, and the Biomedical project. However, the status of my study differs somewhat from that of these programs. I am a guest scholar at IIASA, supported largely by outside funding--in this case, from the Ford Foundation, with supplemental support from the Lilly Endowment and from IIASA.

My status here illustrates the importance of what I believe is one of IIASA's potentially most significant functions--its "outreach" function. My work involves close collaboration with scholars in both Eastern and Western Europe. IIASA's unique capability to facilitate collaborative East-West research is of critical importance to the success of this work. I believe that IIASA's central role in East-West research can be further enhanced by its ability to provide an institutional home for such research that already receives outside funding.

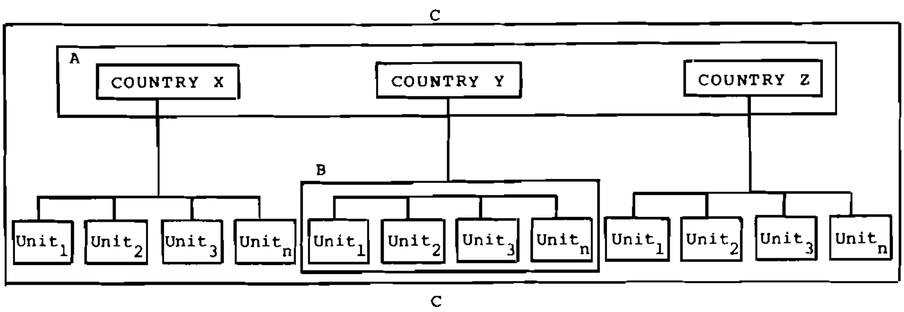
FOCUS OF THE STUDY

The basic question dealt with in this research is: *what are the sources of variations among localities in the levels and quality of public goods and services made available to citizens?* The study focuses on service areas as, for example, the provision of health care, educational services, basic communal services such as sanitation and electrification, and public housing. We know that man lives in differing degrees of physical and psychological comfort. Some of the differences in living conditions can be traced to inequalities in access to economic and other resources. Some of these differences are due to the weight of tradition or to the capricious impact of historical circumstances. It is also reasonable to assume that some of the variations in these conditions can be accounted for by differences in recent and current government policies. Further, it is widely supposed that effective government action can increase the extent to which human communities can determine their own conditions.

This research is being conducted by three American social scientists, with the active collaboration of scholars in the first four countries being studied: Bulgaria, Hungary, Poland,

and Yugoslavia. The choice of these countries for the initial segments of the research follows the interests of the Ford Foundation; funding is through their program of East European studies. We hope and expect in the next two years to extend this research to a similar number of Western European countries, and we are already consulting with scholars in Western Europe, especially in the Federal Republic of Germany.

Almost all previous cross-national comparative studies of public goods and services have focused at the national level; that is, they have compared such things as public consumption expenditures, social programs, and measures of population well-being for nation-states as a whole, ignoring interregional variations within those nations. (This strategy is represented by box A in Figure 1.) Research on within-nation variations has almost always dealt with a single country (box B in Figure 1). We believe that these past research emphases are unfortunate; a basic premise underlying our research is that variations in levels of public goods and services provided to citizens frequently are greater *within* societies than *between* societies--especially for societies that are at roughly similar levels of economic development. Consequently, our research strategy is to examine both *within-nation variations* and *between-nation variations* (box C in Figure 1) by looking at a pooled sample of subnational administrative units from several countries.



A: Usual design for *cross-national* comparative studies

B: Usual design for study of *within-nation* variations

C: Design for *cross-national* comparison of *within-nation* variations

Figure 1. Strategies for examining variance in comparative policy research.

We are not suggesting that there are no inter-societal differences or that they should not be studied; our research will examine such differences, as well. But we believe strongly that more attention should be given to interregional variations within countries, studied in a cross-national comparative context.

RESEARCH ORIENTATION AND BASIC HYPOTHESES

Because this study began only in January of this year, it is still early in the data-gathering process; thus this report will deal primarily with the orientation and design of the research, rather than with any definitive findings. Nevertheless, we have done some preliminary data analysis, which I shall mention for illustrative purposes.

Generally speaking, we are interested in five sets of variables. These sets of variables and their basic interrelations are shown in Figure 2. The variables are:

- *Economic* characteristics of subnational units of government;

- *Demographic* processes characterizing and affecting these units;

- The *expenditure of funds* (both current operating funds and capital investments) made by these units for basic public goods and services;

- Indicators of the *intermediate outputs* of government (i.e., measures of *public goods and services* actually provided);

- Measures of the *impacts* of these policy activities (i.e., measures of *population well-being* in areas of relevance to government service programs).

For example, in looking at the area of public health, we are interested in not only the resources available to local decision makers, the demographic structure of the population, the expenditures made for health care services, and the nature of available medical facilities, but also the measures of population conditions such as the incidence of various kinds of disease, the infant mortality rate, and the number of workdays lost as a result of illness.

The data are being analyzed initially through the use of multiple regression techniques. First, economic and demographic variables are used to predict variations in expenditure levels.

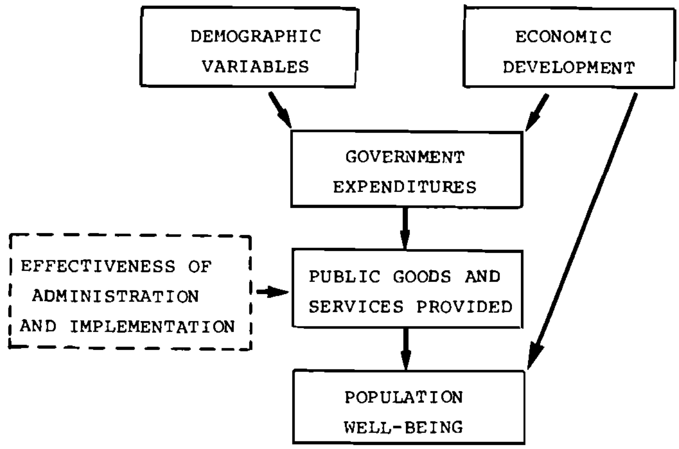


Figure 2. Model for studying the policy process.

Expenditure levels, in turn, are examined as predictors of the intermediate outputs of government (e.g., in hospital beds, health or child-care facilities). Finally, each of these sets of variables is related to measures of population well-being that constitute the variables we ultimately wish to explain.

As a picture of social causation, such a model represents a significant oversimplication. In point of fact, it reflects conventional assumptions as much as our own predispositions and expectations. Our analysis will move in the direction of testing a more complex model, the outline of which is suggested by Figure 3. In this model, we acknowledge that there are other social and political factors that may affect the provision of basic public goods and services. Similarly, we recognize the complexity of the planning and expenditure processes themselves.

While considering data analysis, I should mention briefly that we will go beyond the use of regression models. For reasons that mathematical systems analysts have recognized for a long time--but that most social scientists are only now beginning to acknowledge--regression techniques have real limitations as bases for identifying patterns of causation. In particular: a) regression assumes that the form of causation is *proportional transformation*, which is only one of numerous forms that social relationships can exhibit; and b) regression is based inherently on measures of *covariance* and thus cannot describe relationships where *constancy* in one measure leads to *variation* in another. Mathematical process models can overcome both of these shortcomings of regression techniques.

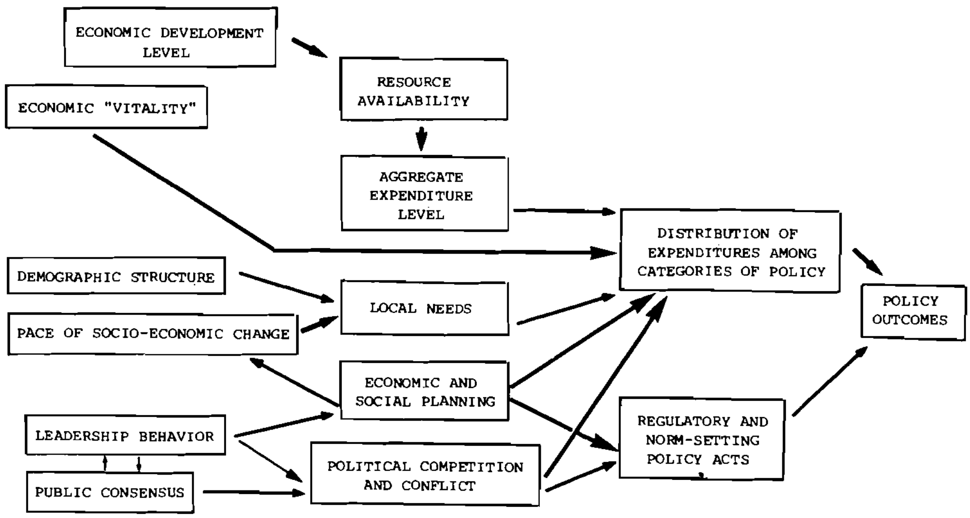


Figure 3. Some possible categories and relationships for the comparative study of public policy.

There are three basic hypotheses that guide our research.

1. *Interregional disparities in social services often tend to remain, and in some cases to grow, even in modern societies where there are nationally uniform norms and standards for such services.*

These social service inequalities persist, whereas in the same societies, interregional differences in economic growth seem to be declining.

For example, Tables 1 and 2 depict the situation in one of the countries being studied. Table 1 shows (for 1969) the extent of variation among subnational units in four measures related to public health: hospital beds per 10,000 population, child-care facilities in towns and in rural settlements (both adjusted for population size of the administrative unit), and rural sanitation (i.e., central water supply systems only). For a relatively small, relatively homogeneous country, the differences seem dramatic.

Table 2 shows the change, since the early 1960s, in the extent of variation in measures of public expenditures and services, and in measures of economic growth and vitality. As a measure of variation, we used the standard deviation; other measures of dispersion showed the same pattern. We found that the standard deviations for expenditures and service activities tended upward, even though the standard deviations for economic measures remained essentially steady, or increased only modestly.

Table 1. Variation among subnational units in health-related measures, 1969.*

	Hospital Beds per 10,000 Pop.	Child-Care Facilities No. of Places per 1,000 Population		Sanitation: % of Rural Settlements with Sanitation (Water Supply Systems)
		Towns	Rural Settlements	
Values for the Respective Subnational Units	4.75	10.4	6.8	55.6%
	4.97	4.9	2.8	70.3
	5.71	4.7	4.5	82.4
	5.83	6.7	4.4	26.7
	6.00	4.8	3.8	55.2
	4.99	4.9	1.2	80.3
	10.28	5.8	0.7	39.3
	3.97	10.3	2.0	32.5
	5.72	8.5	4.6	68.3
	9.57	5.3	2.0	47.7
	6.51	5.7	2.6	51.6
	4.39	6.2	2.9	79.0
	8.67	4.6	1.1	72.5
	5.37	5.9	2.5	86.7
	6.24	6.2	7.9	77.8
	5.06	5.4	3.2	85.6
	6.68	4.8	9.3	96.0
	4.74	9.3	5.5	91.2
	5.40	7.9	4.9	67.5
	5.73	8.9	10.6	83.0
	9.93	5.8	2.4	97.8
	6.80	8.5	2.6	52.8
	8.87	6.6	5.4	74.7
	4.67	5.1	6.2	96.7
	5.63	6.3	3.7	47.6
	6.67	6.4	6.3	48.9
	5.77	8.4	2.1	78.3
	4.66	7.6	3.1	56.6

*The range of values is shown by the circled numbers that indicate the highest and lowest values in each of the columns.

Understanding the sources of these continued variations among localities within a given country seems critical to subsequent efforts to eliminate such differences. A fundamental tenet of essentially every contemporary society is that each citizen is entitled to uniform levels of public goods and services regardless of where he lives. The elimination of interregional inequalities in the provision of basic public goods and services to citizens must be considered one of society's most fundamental social challenges.

Table 2. Changes in standard deviations for economic measures and measures of expenditures and services, 1962-1972.

Economic Measures	Change in Standard Deviation (in percentage)
Profitability of enterprises	0
Industrial wage level	+ 25
Income generated in retail trade	+ 50
Trade turnover	+ 50
Expenditure Measures	
Investment in housing	+ 1,200
Investment in communal economy	+ 900
Investment in education	+ 570
Investment in health	+ 420
Service Measures	
Housing construction	+ 180
Hospital beds	+ 40

2. *Variations in the levels of public goods and services provided to citizens frequently do not correspond to those environmental factors that conventional wisdom tends to associate with locational inequalities in population well-being.*

In particular, the usual assumption that economic development and demographic factors explain a great deal of the variance in government action on behalf of citizens is, in our opinion, dubious and deserves critical attention. In the research to date, we have found that economic and demographic variables explain substantially less than one half of the variance in many measures of government services, and less than one half of the variance in many indicators of population well-being.

More specifically, we believe that social and economic measures are, to some extent, related to government expenditures and services *only for those policy areas where physical construction activity consumes a large proportion of total investment.* This is because access to basic financial resources can be translated with relative effectiveness into physical plant construction. But for those policy areas where a higher proportion of total investment goes to salaries, service programs, and the training of skilled personnel--*in areas where human resources are more critical*--social and economic measures are related only in a more limited way to levels of government expenditures and services.

Table 3 illustrates this point. It summarizes the results of a time-series regression analysis of data for one of our subject countries over an 11-year period (1962-1972). A regression model including eight measures of economic and social context was used to predict levels of investment in certain basic goods and services. The R^2's--indicating the amount of variance explained--are not particularly high in any case; they are especially low for investments in health and education, where a much higher proportion of total investment in this country goes to human resources development.

Clearly, in addition to economic and demographic factors, there are other factors that operate to create these interregional differences. Identifying these factors is the principal purpose of this research.

3. *One of the sources of these interregional variations in public goods and services is the difference in basic budgetary and fiscal relations between the central government and the subnational units of the government.*

Table 3. Relevance of measures of social and economic context* to subnational expenditures, 1962-1972.

Dependent Variable	R^2 (Amount of Variance Explained)
Capital investment, housing	.59
Operating funds, housing	.50
Capital investment, communal economy	.58
Operating funds, communal economy	.49
Capital investment, education	.29
Operating funds, education	.18
Capital investment, health	.31
Operating funds, health	.32

*Predictor variables used: population density; industrial wage level; industrial workers as % of work force; workers in government administration as % of work force; number of "specialists" (specialized training in higher technical schools) per capita; index of industrial production; % of population living in towns and cities, "urbanization"; trade turnover per capita.

We do *not* believe, as has been commonly assumed, that most of the variance in such relationships can be attributed to decisions made at the center. Rather, we believe that budgetary relations among levels of government--even in relatively centralized societies--have developed in a much more complex way than has been commonly assumed, and a good deal of this complexity can be traced to institutionalized budgetary strategies being pursued by subnational government units.

To understand such phenomena, we are developing mathematical models of budgetary processes at subnational levels, and incorporating elements of central-subnational relations into these models. Table 4 summarizes the conceptual notions of four of the models being developed. These models suggest a great variation in the extent to which local factors determine the nature of programs of basic public goods and services provided to citizens by subnational units. These variations in basic budgetary strategies may be of great importance in explaining interregional inequalities in citizen access to basic public services.

Finally, an important aspect of our work is the cataloging of methodological problems involved in comparative studies of public policy. Much work has been done in this area and a draft of a book-length monograph describing some of these problems has been completed. Ultimately, we hope to recommend approaches and techniques that researchers can use to compare public policy activities across societies with different forms of social, economic and political organizations.

Table 4. Conceptualization of four inductive budgetary/expenditure models.

The "Compensatory" Model

- Equilibrium-seeking
- Negative correlations between first-order differences in central expenditures and first-order differences in subnational expenditures
- Subnational units use marginal funds to compensate for fluctuations in central government expenditures and subsidies

The "Planometric" Model

- Norm-seeking
- Both central and subnational expenditures show consistently positive correlations with plan norms

The "Monitoring" Model

- Performance-seeking
- Changes in public expenditure levels in subnational units are best predicted from measures of policy performance
- Expenditure levels are determined primarily by perceptions of the adequacy or inadequacy of current levels of services

The "Initiative" Model

- Flexibility-seeking
- Little relationship between central expenditure changes and subnational expenditure changes; or, between subnational expenditures and national plans; or, between subnational expenditures and national performance indicators
- Expenditure levels respond substantially to locally-defined needs

Transportation, Automation and Urban Development

H. Strobel

This paper presents a brief overview of the objectives, activities, results and future plans of the transportation-oriented research developed with modest in-house resources at IIASA over the last two years [1,2].

Almost all countries of IIASA's National Member Organizations are faced with serious, sufficiently well-known urban traffic problems [3,4,5]:

- A large number of fatalities from traffic accidents--in 1970, for example, about 56,000 in the USA, 19,000 in the FRG, and 2,000 in the GDR;
- Congestion causing not only loss of time but also increased levels of fuel consumption and air pollution--for example, these losses, measured in economic terms for Tokyo's 268 main intersections, amount to about $200 million annually;
- Endangered urban environment: the severance of the city resulting from more and bigger streets, vibration of buildings, traffic noise and air pollution--for example, in US cities, automobiles cause about 50 percent of all man-made air pollution;
- Corruption of resources, i.e., energy and land--for example, in the USA, about 26 percent of all petroleum consumed is used for motor cars, and 28 percent of city areas is reserved for parking and driving (which is still insufficient in many cases).

In the USSR and in East European countries, such serious situations do not exist at present. However, the rapidly increasing number of motor cars in these countries may cause--with a certain delay--similar difficulties if future developments there are not analyzed and controlled carefully. Therefore, a systems analysis approach is needed to assist decision makers in urban and national governments in creating transportation and urban development policies that take into account the complex interrelationship (see Figure 1 and [6]) between the control of:

- *Transportation demand*, by changing its *spatial distribution*, decreasing its *volume* and changing its *time-distribution*; and

- *Transportation supply*, by changing the system's *structure*, increasing its physical *capacity*, and improving the *operation* of existing transportation systems.

	CONTROL OF *SUPPLY*	CONTROL OF *DEMAND*
LONG TERM	CHANGE THE *STRUCTURE* OF THE TRANSPORTATION SYSTEM (e.g., creation of new systems)	CHANGE THE *SPATIAL DISTRIBUTION* OF DEMAND
TIME SPAN (to accomplish results)	INCREASE THE PHYSICAL *CAPACITY* OF THE TRANSPORTATION SYSTEM (e.g., enlargement of traffic areas)	DECREASE THE *VOLUME* OF DEMAND (e.g., controlling automobile ownership and use)
SHORT TERM	IMPROVE THE *OPERATION* OF EXISTING TRANSPORTATION SYSTEMS	CHANGE THE *TIME DISTRIBUTION* OF DEMAND

Figure 1. Long- and short-term transportation supply and demand policies (cf. [6]).

This paper restricts itself to the role that new technologies and modern management techniques play in such a systems analysis approach. In the past, new technologies such as the steam engine created breakthroughs to entirely new modes of transportation, resulting in well-known changes in the structure of cities and the quality of urban living.

It seems reasonable to ask whether the fundamental new technology of our age--modern automation and computer techniques--could contribute to a new breakthrough in urban transportation. Past developments of transportation systems have been achieved by brute force--more and larger traffic areas using more concrete, stronger engines, more and more vehicles--at higher cost (see Figure 2 and [7]). The digital computer and the related automation technology provide, for the first time, a promising alternative. The extensive use of automation in urban transportation could lead to an entirely new and improved level of transportation services, to an increase in capacity and a decrease in operating costs, and to new safety standards.

This new systems technology could give an impulse to better urban transportation similar to that given by the magnetic compass to the extension of sea transport from the local to the global arena, and by the telegraph and telephone to the development of

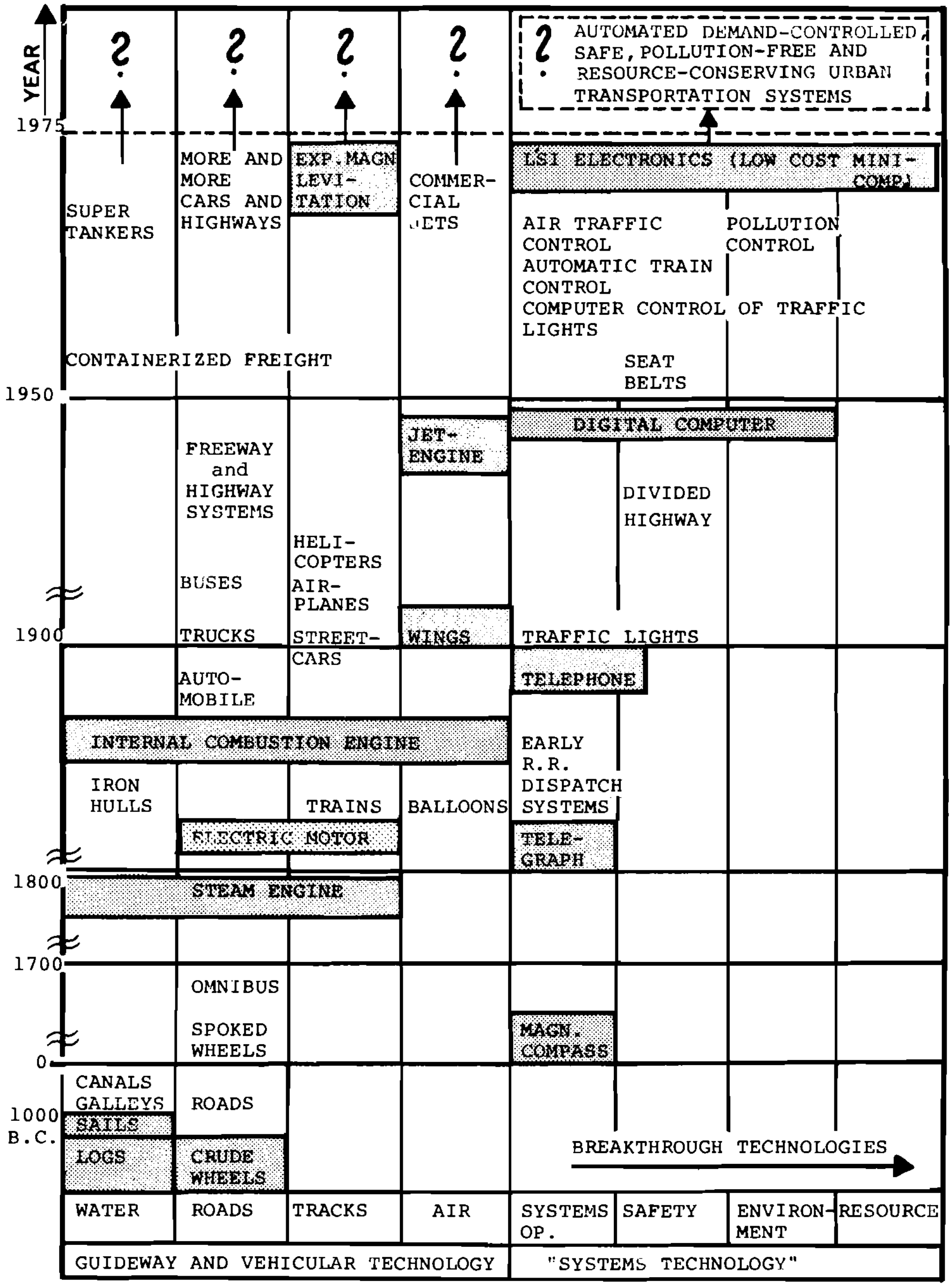


Figure 2. New technologies that have or probably will create breakthroughs to new modes of transportation resulting in essential changes in urban structure and the quality of urban living (cf. [7]).

nationwide railway dispatching systems. Therefore, the following two questions have been chosen as the subject of our research:

- What benefits can a city expect by implementing computerized control systems for existing modes of urban transportation?

- During the next ten years or so, will it be possible to create entirely new and highly automated urban transportation systems characterized by demand-oriented, safe, pollution-free and resource-conserving operation?

The first question concerns the extensive use of computers for urban street and freeway traffic control--for example, optimal route guidance systems for freeway corridors and large urban street networks; traffic flow control by traffic light coordination, ramp metering, and merging control; distance control in a string of moving vehicles so as to increase lane capacity and safety [1,2,3,8,9,10]. Moreover, the contribution of automation and computer control to an increase in the attractiveness of public transport and a decrease in its personnel and operating costs fall within this topic.

Concerning the creation of new modes of urban transportation, we must distinguish between *operational* and *total-systems innovations*. An example of an operational innovation is the DIAL-A-RIDE system that supposedly covers a wide variety of transport needs, and broadly fills the gap between the conventional scheduled and routed bus service, and the taxi or private car [11]. Here a powerful computing and communication system is needed for real-time routing and scheduling of the operation of a bus fleet (see Figure 3). The proposals for total-systems innovations concern mainly Automated Guideway Transit (AGT) systems characterized by driverless vehicles operated along fixed guideways [12,13]. The simplest version of the AGT systems is a Shuttle-Loop Transit (SLT) system that may be considered the horizontal equivalent of an automatic elevator. At the other end of the scale of the AGT systems is the Personal-Rapid Transit (PRT) system, characterized by a complex guideway network and small vehicles carrying one person or groups of up to six persons. The well-known AIRTRANS system at the Dallas/Fort Worth airport as well as the Morgantown system belong to the category of Group Rapid Transit (GRT) systems that use larger vehicles and headways and have less complex network structures than the PRT systems [13]. The efficiency of the GRT systems, and especially of PRT systems, is highly dependent on the efficiency of a multi-computer control system consisting of a network-, a guideway-, a station- and a vehicle-control level.

There are fairly large demonstration projects of the PRT systems in Japan, the FRG, and France, and advocates of these systems believe that they will create the breakthrough to better urban transportation needed for solving the urban traffic problems mentioned above [13]. The research work outlined here will be discussed in a volume on *Computerized Urban Traffic Control and Guidance Systems* in the IIASA State-of-the-Art Series.

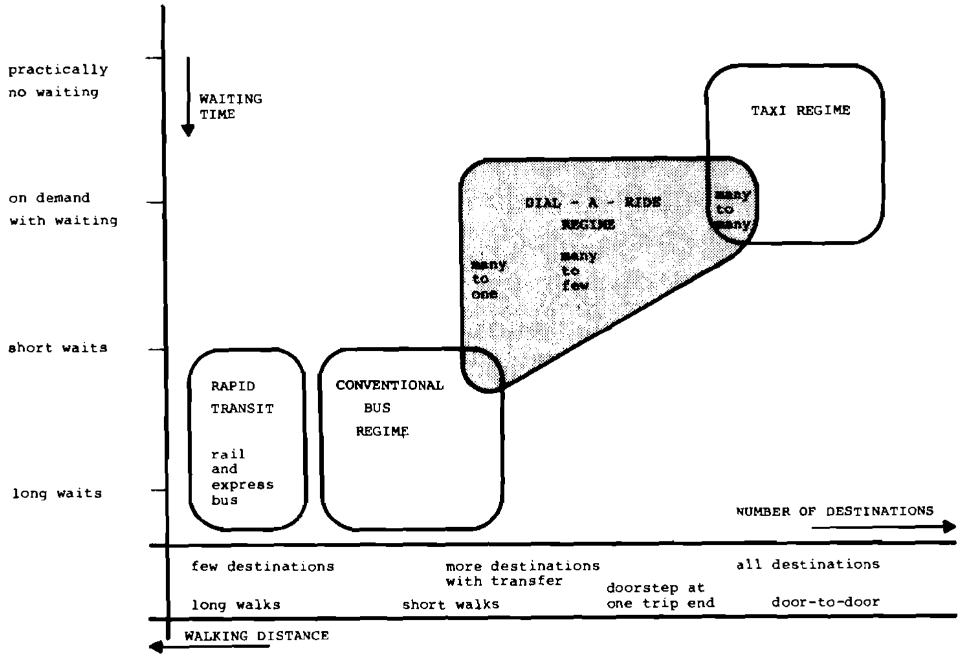


Figure 3. DIAL-A-RIDE in the public transportation spectrum (cf. [11]).

In addition to giving a comparative analysis of the *concepts, methods,* and *experiences* of these systems in use in Japan, North America, and East and West Europe, the volume will contain case descriptions prepared by experts from advanced systems in operation in these countries. Moreover, first steps in creating a network for external cooperation between IIASA and advanced transportation research centers have been made as a result of the IIASA Planning Workshop on Transportation Systems Analysis held in February of this year [14]. The Workshop made several proposals for future transportation research work. For example, it recommended that IIASA continue its work on computerized urban-traffic control systems within the broader context of *environment- and resource-conserving urban/regional transportation systems* that should deal with the complex interrelationship between urban development policies in general, and urban transportation management methods and techniques. The objectives should be to

- Identify the most advanced technologies for urban/ regional transport simulation, planning and control; and

- Analyze these technologies by means of comparative case studies done mainly on an external base.

It is expected that such activities will contribute to IIASA's clearinghouse function for solving the earlier mentioned urban traffic problems in both the East and the West, thus representing a truly universal IIASA problem.

References

[1] Strobel, H., *Transportation, Automation and the Quality of Urban Living*, RR-75-34, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[2] Strobel, H., Computerized Urban Traffic Control and Guidance Systems, in *IIASA Project on Urban and Regional Systems: A Status Report*, SR-75-1, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[3] Watkins, L.H., et al., *Effects of Traffic and Roads on the Environment in Urban Areas*, Organisation for Economic Cooperation and Development (OECD), Paris, 1973.

[4] The Wheel Extended, A Toyota Quality Review, *Transport in Tokyo*, IV, 1 (1974), 4-13.

[5] Council of Mutual Economic Assistance, *First Scientific Conference, Problems of Street Traffic Safety*, Alma-Ata, USSR, May 20-23, 1975, Moscow (in Russian).

[6] Japanese Ministry of International Trade and Industry, *Comprehensive Automobile Control Systems*, preliminary report, Tokyo, 1975.

[7] Cannon, R.H., Transportation, Automation, and Societal Structure, *Proc. IEEE*, 61, 5 (1973), 518-525.

[8] *Traffic Control and Transportation Systems, Proceedings of the Second IFAC/IFIP/IFORS World Symposium*, Monte Carlo, September 16-21, 1974, North Holland-American Elsevier, Amsterdam, 1974.

[9] Hillier, J.V., et al., *Area Traffic Control Systems*, Organisation for Economic Cooperation and Development (OECD), Paris, 1972.

[10] US Department of Transporation, Office of the Secretary and Urban Mass Transportation, *Demand-Responsive Transportation: State-of-the-Art Overview, August 1974*, US Government Printing Office, Washington, D.C., 1975.

[11] Slevin, R., *The First British Dial-a-Ride Symposium*, September 9-12, 1974, Centre for Transport Studies, Cranfield, Bedfordshire, 1974.

[12] Becker, K., and H.O. Hannover, Cabinentaxi: Ein neuer Weg für den Stadtverkehr, *Der Städtetag*, No. 8 (1974), 2-7.

[13] United States Congress, Office of Technology Assessment, *Automated Guideway Transit--An Assessment of PRT and Other New Systems*, US Government Printing Office, Washington, D.C., 1975.

[14] Strobel, H., ed., *Transportation Systems Analysis*, Report on the IIASA Planning Workshop, February 16 and 20, 1976, International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

Urban Emergency Services

E.H. Blum

In the last twenty years, local public services have grown rapidly in nearly all industrial nations. As so often happens, standards and demands for such services have kept pace, adding pressure for expansions and improvements while costs of providing even current levels have risen. Concurrently, interest has grown in treating relevant features of key services as integrated systems. These parallel trends have generated strong interest in many countries for systems-analytic approaches to service planning and management.

IIASA has chosen to focus on urban emergency services--especially emergency medical services (EMS), fire protection, and elements of police and disaster protection. The work has begun with an extensive, in-depth synthesis and review to be published (*Modern Service Management: Planning, Analysis and Management of Emergency Services*) in IIASA's State-of-the-Art Series. These services are a natural choice: important, even critical to many citizens' survival and security; amenable to relatively rapid changes that can almost immediately save lives; remarkably similar from country to country; and a domain of recent significant advances that have yet to be unified, integrated, or even documented in ways that would open them to widespread understanding and use.

Rough estimates indicate, for example, that improving emergency services in the 25 most advanced countries of the world could save as many as 350,000 lives per year overall and reduce losses from injuries and property damage by as much as $\$10^{11}$ per year. The gains achieved thus far from systematic improvement are obviously more modest, but significant and illustrative.

For example, in New York City, the research from which our IIASA project stems developed new management methods, deployment policies, and technologies for fire protection. These have been credited with enabling the city to maintain its high level of protection in spite of fire department budget reductions amounting cumulatively to nearly 15 percent, or $50 million per year. Seattle, a city of half a million people, has systematically developed an emergency medical system that includes extensive training of the public in cardio-pulmonary resuscitation. During the past six years, approximately 80,000 persons have been trained. Careful evaluation over this period shows that the new system has saved over 100 lives per year, of which 30 percent are attributed to public participation. Numerous other cities have begun to adopt similar approaches.

At the same time in the USSR, Moscow has increased its level of ambulance service threefold in less than ten years. This increase has been supported by numerous analyses--of call patterns, service requirements, dispatching priority assignment (telephone triage), computer-aided management control, etc. The fire services in Hamburg, Munich, and Frankfurt have installed or are installing computer-assisted dispatching systems. Fire and ambulance service in Great Britain is developing new sets of service standards based on detailed, sophisticated analyses; the Metropolitan Toronto (Canada) Emergency Medical Service has chosen the sites for nearly a 100 percent increase in stations, using models our group has developed; and so forth.

In the synthesis of this state of the art, the major steps are now complete. A ten-nation network of research institutes, government agencies, and corporations has been developed to advise and work with IIASA and provide hitherto unavailable information. Participants include contributors to planning, analytic, and management methods, leaders in the application of modern techniques, and service agencies with particularly notable practices. Important materials totalling over 1,300 items in six languages have been uncovered, collected and digested, including many usually available only in local or fugitive literature and some not otherwise likely to have become accessible.

This part of the work could have been accomplished only at a place such as IIASA, with access to officials and scholars in key nations of the East and West, and with both the credibility and the capability to undertake comparative synthesis and analysis. Table 1 shows the case studies we have thus compiled.

Table 1. Emergency services case studies.

Country	EMS	Fire	Police	Catastrophe
Australia				√
Austria	*	*		
Canada	√	*		
Denmark	√	√		
FRG	√	√		*
France	*	*		
Great Britain	√	√	√	*
Hungary	√			
Japan	*	*		
Netherlands		√	√	
USA	√	√	√	√
USSR	√			

√ Detailed case study or application example.

* Information about systems and applications.

Building on this base, the project has identified key weaknesses in the state of the art and rectified them. Analyses have been conducted to sharpen and clarify the complex planning and management methods and to reveal the common foundation shared by practices developed in different countries for different emergency services. The central policy questions treated are shown below.

Modern System Design and Management
- Criteria
- Principles
- International Comparative Experience.

System Improvements
- Needs
- Methods
- Tools
- Evaluation.

Policy Formulation
- Strategic (long-range)
- Tactical (short-range)
- Prevention and Response.

Implementation.

Such work, for example, has helped to unify different approaches to the basic problem of telephone triage and dispatch recently developed for several services in the USA and the USSR. Its results also help to structure and set priorities for data analysis and the design of computer-aided dispatch systems. Other work has criticized the vast facility-location and site-selection literature, based on both case studies and recent experience in applying advanced techniques. And work directed toward top management has synthesized a large number of analytically based principles of service management, distilling and generalizing them into applicable, almost intuitive "rules of thumb" that show how to improve most public services.

For example, in examining potential improvements, it is useful to classify urban services by their "production functions". We distinguish four component types of service that together constitute emergency services:

- Technological,
- Personal,
- Economic,
- Administrative and regulatory.

Of these, generally the most important and also the most difficult to improve is the personal component: emergency services require that skilled people be physically present at the service site for the time the service is being rendered.

Distilling the analytical results yields three basic ways of improving this personal component: reducing or reshaping the demands for the services; improving the services produced during each man-hour; and allocating men and equipment to best meet priorities and demands. Programs to realize these improvements include:

Strategic (long-range) programs
- Service levels (quality and quantity),
- Locations,
- Scheduling.

Tactical (short-range) programs
- Dispatching,
- Relocation,
- Manning,
- Computer-aided management and control.

These programs are analyzed for importance and potential implementation in terms of potential impact, time required to achieve the impact, and cost (TIC), as Figure 1 depicts.

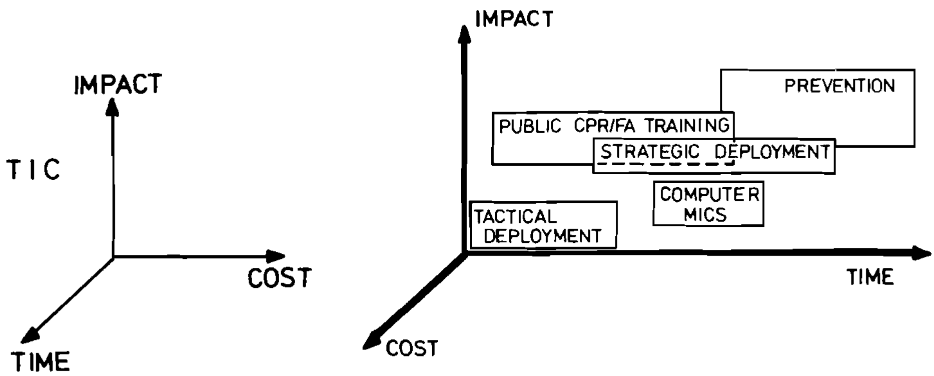


Figure 1. TIC analysis of emergency service strategies.

Figure 2 shows a representative sample of the comparative data we have obtained, illustrating the distributions of emergency medical response times in five cities and selected non-urban areas.

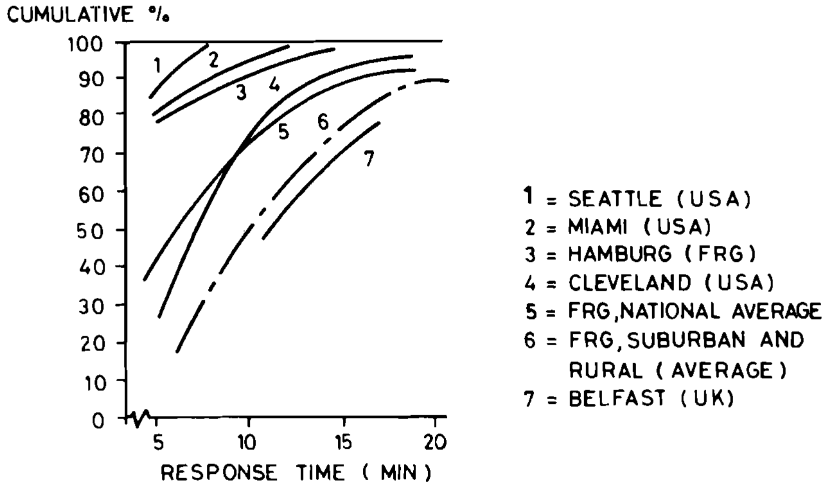


Figure 2. Comparison of EMS response time distribution.

Figures 3 and 4 display representative patterns for calls requesting emergency medical services, showing how they vary by time of day. The large differences in numbers of calls at different times, and concomitant variations in the probability that initially non-specific calls will prove serious, create the need for sophisticated scheduling and dispatching techniques.

We have also developed new approaches to basic questions of objectives and criteria, for example, risk, robustness and resilience, service productivity, and equity (distributional fairness).

Questions of risk are fundamental, even critical, to the emergency services as to the design of broader societal systems. This work, and that on resilience, thus has benefited from the cross-fertilization of concepts among research areas that an institution such as IIASA can provide.

Some more basic research has led to analyses of combustion type processes, applying the new topological methods of catastrophe theory to give insight into and to simplify otherwise

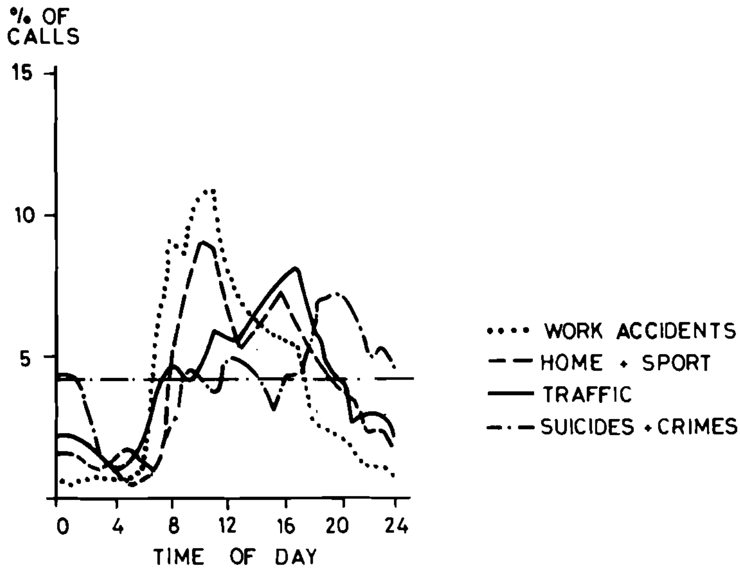


Figure 3. Time pattern of EMS calls (FRG).

After: [1]

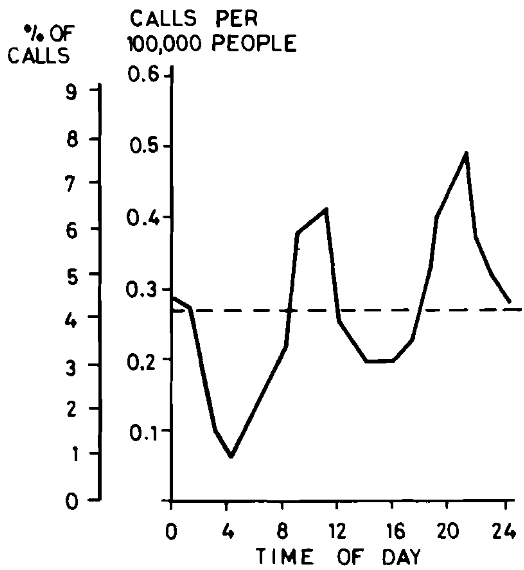


Figure 4. Time pattern of calls for cardiological EMS (Gorky, USSR).

Source: [2]

complex phenomena. This work illustrates a potentially important methodology, and provides a basis for results of value to fire protection policy and perhaps to energy process analysis and materials design as well.

In addition, new results have been obtained on broader issues including the value of safety and related attributes, distributional equity, determining desirable levels of protection, and the use of relatively new planning criteria such as robustness and resilience, and documentation is well advanced.

References

[1] Bonn, H.P., *Dokumentationsstudie: Rettungsdienst und Krankentransport*, Vols. 1 and 2, Institut für Rettungsdienst und Krankentransport, Bonn, 1975.

[2] Arbakov, A.I., *Sov. Zdravookhr.*, 32, 8 (1973).

Modeling of Health Care Systems

D.D. Venedictov

I would like to discuss the development of the former Biomedical project at IIASA, and to say some words about its present and future activities on the topic of modeling national health care systems.

The history of the project is short. During the three-year period in which it existed, the project held three conferences, organized several workshops, and published a book [1] as well as reports on various problems of medicine and health care.

Experts from various countries have worked with the project: A. Afifi, P. Fleissner, N. Glass, A. Kiselev, A. Klementiev, G. Majone, J. Miller, J. Page, M. Thompson, and others. At the end of 1974, I assumed the general leadership of the project.

The IIASA Executive Committee decided that biology and medicine were priority areas that should be included in the IIASA Research Plan. This decision was influenced by a number of factors outlined below.

The need for a comprehensive (systems) approach to analyzing complex processes was recognized initially by scientists working in the fields of biology and medicine. It was believed that the application of the systems approach would yield new and important information in all spheres of applied systems analysis, including the analysis and control of ecological, social, industrial and other systems.

In medicine, there are tightly interwoven biological and social processes that influence people's health--e.g., by increasing or decreasing their health status, by increasing or decreasing their access to health care facilities (Figure 1). To solve these problems requires more financial resources, more sophisticated measures, and more responsible decisions on the part of politicians and managers. These problems become urgent at the local, national, and international levels.

Recently, in many countries there has been increasing criticism of the unsatisfactory work methods of physicians, the insufficient provision of medical services, and the inefficient organization of health services, in spite of the constant increase in funds for health care, and the increase in the manufacture of drugs and in the number of physicians, nurses and hospital beds.

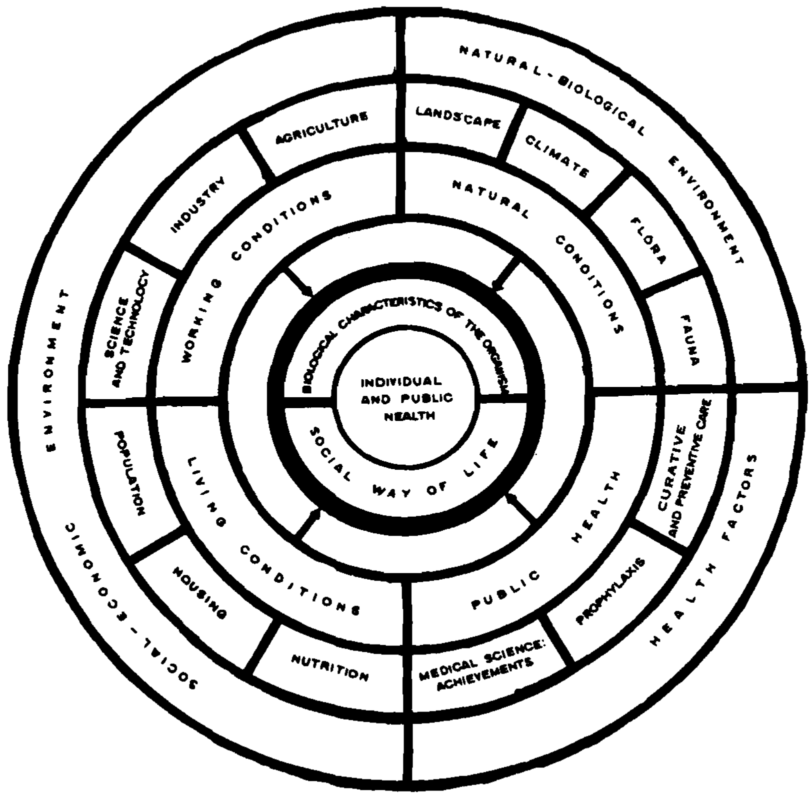


Figure 1. Factors influencing health of man.

Over the past 25 years, there has been rapid development of broad international cooperation in the field of medicine. Health care problems are being examined on the local, national, international, regional, universal and global levels. Thus, health care and medical science are important fields of social activity and international cooperation that require the application of systems analysis at the highest level.

The development of the Biomedical project began by questioning whether systems analysis should be applied to the whole medical and biological sciences or only to individual problems, e.g., cures for certain diseases, health care systems, or individual medical services. In August 1973, IIASA held its first conference on biological and medical systems. The participants suggested possible research directions, ranging from the problems of long-term health care planning to studies of various diseases. Such studies began in 1973 and continued until the middle of 1975. The subject of the research varied, and the work was done using mathematical techniques of systems analysis. The participants at the conference did not recommend activities other than those that are already being carried out by experienced health care organizers.

At the second IIASA biomedical conference, held at Baden in August 1974 [1], the majority of the participants believed that the efforts of the project should focus on the following major problems: systems analysis and modeling of health care; and systems analysis and coordination of medical and biological research. Research should be directed to modeling of health care and its services, based mainly on data from the World Health Organization (WHO) and national organizations.

In response to these suggestions, IIASA undertook the difficult task of defining a health care system, since future research would depend on this. The "health care system" is that set of measures taken by society to preserve and improve public health.

The complexity of medicine has long been recognized and documented: physicians and scientists have stressed the dependence of health on living and working conditions and proper nutrition, and also noted that medical science is closely connected with the prophylaxis and treatment of disease. Recently WHO has defined terms and established categories connected with the health care system and its place in society. These were clarified at the general and technical meetings of WHO, in the organizational research of its Executive Board, in reports by the Director General of WHO, in program papers of WHO, and especially in the *Sixth General Program of WHO for 1978-1983 Inclusive*, adopted by the 29th World Health Assembly on May 6, 1975 [2].

Defining the general concepts of the health care system is not sufficient. The functions of the health care system and their characteristics should be expressed mathematically. WHO has been active in this area. However, for a number of reasons including the scope of the programs, complex mathematical models, of health care systems have not yet been created. This task, in our opinion, should be part of IIASA's activities.

WHO's interest in the early activities of IIASA was not immediate. While it has vital organizational, social and medical data, it appears that WHO's experience in this area may be somewhat disappointing. It may be their belief that systemologists and mathematicians are not able to provide more than pure theoretical equations of simple and evident recommendations. I think that this reservation could be overcome.

Also, as a result of the second IIASA biomedical conference, it became evident that the project's work should represent the efforts of not only a small group of scientists working at IIASA, but also those of scientists in research institutes and departments of health care in IIASA's National Member Organizations

(NMOs) and in member States of WHO. It is in the interest of WHO, IIASA, and many national organizations to combine their efforts for systems analysis and modeling of health care systems. Currently, exchanges of information and collaboration on solving some important medical and social problems take place among ministries and departments of health in many countries with different political, social, and economic systems.

Early in 1975, with the view toward international collaboration, two groups of specialists in the fields of medicine, health care organization, international relations, engineering, mathematics and control theory were established in Moscow, with the goal of developing a methodology for modeling health care activities. Among the leading Soviet scientific research institutes that participated in this work were the Semashko Institute of Social Hygiene and Health Care Organization, the Institute for Clinical and Experimental Oncology, the Research Institute of the Medical Industry, and the Institute for Control Sciences of the Academy of Sciences of the USSR. The work was enthusiastically carried out and fully supported by the National Committee on Systems Analysis of the USSR.

Alexander Kiselev, who joined IIASA as deputy leader of the Biomedical project, has experience in modeling psychiatric care systems. He established valuable contacts with several national health care organizations that have helped in identifying specialists in health care modeling.

In December 1975, the third IIASA biomedical conference was held in Moscow and in Laxenburg. The conference was co-sponsored by IIASA, WHO, and the Academy of Medical Sciences of the USSR. More than 80 specialists from many countries participated. The participants' reports--in particular two papers by Soviet experts [3,4]--formed the basis of the discussion. The participants expressed their satisfaction with the two models presented, and acknowledged the need to continue, at the international level, the work on modeling health care systems and medical science.

I would like to comment further on [3]. The cancer research information exchange model was developed on the basis not of traditional (retrospective) information, but rather of future scientific developments, with emphasis on the most probable directions of the scientific research in this field. The proposed model of the international long-term cancer program provides for the elaboration of the research priority list, voluntary participation of all national organizations and scientists, unification of models for codification and information exchange, etc. Because of financial constraints, it was decided not to include this research program in IIASA's Research Plan for 1976. Under present circumstances, this is understandable; however, we believe that time and experience will prove the need for--and benefits of--the united efforts of WHO, the International Agency for Research on Cancer (IARC), IIASA, and large national organizations concerned with health care.

Now allow me to proceed to the health care simulation model. I am pleased to report on this model on behalf of the specialists who participated in its development, and primarily on behalf of Alexander Kiselev and Alexander Klementiev who, over the past months at IIASA, have improved the model. The model's characteristics are outlined below.

The model was defined as a set of measures for protecting and improving public health. It is oriented toward a population of a specific area, and takes into account the interconnections of the health care system and the natural and socio-economic environment (Figure 2). The model's development proceeds from an understanding of general criteria to the investigation of particular phenomena and processes. Thus, the universal model of a health care system could be used in the future to analyze the basic processes of health care management at various levels, from local to national and international.

There are still those who doubt that a universal model of a health care system can be established, because of major variations in morbidity and mortality of populations of different countries, differences in medical traditions, types of institutions and staff, etc. One may state that there are as many different health care systems as the number of existing States, and perhaps even more. However, in spite of all the variation among certain national systems and health care services, there are many common aspects that can serve as a basis for a universal model describing these phenomena and processes.

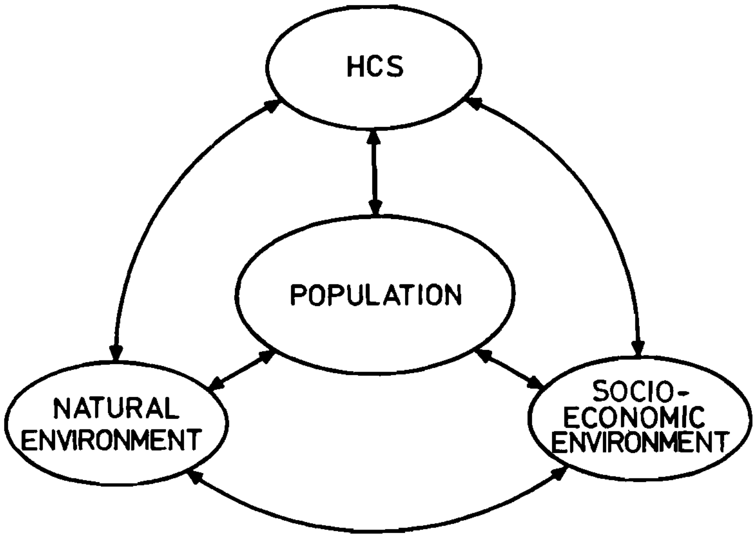


Figure 2. Health care system's interconnections.

The health care system simulation model takes into account the specific administrative territory, the major functions of the system, and the human, capital, and technological resources needed to carry out these functions. Such a system should optimally integrate the activities of central and local management (Figure 3).

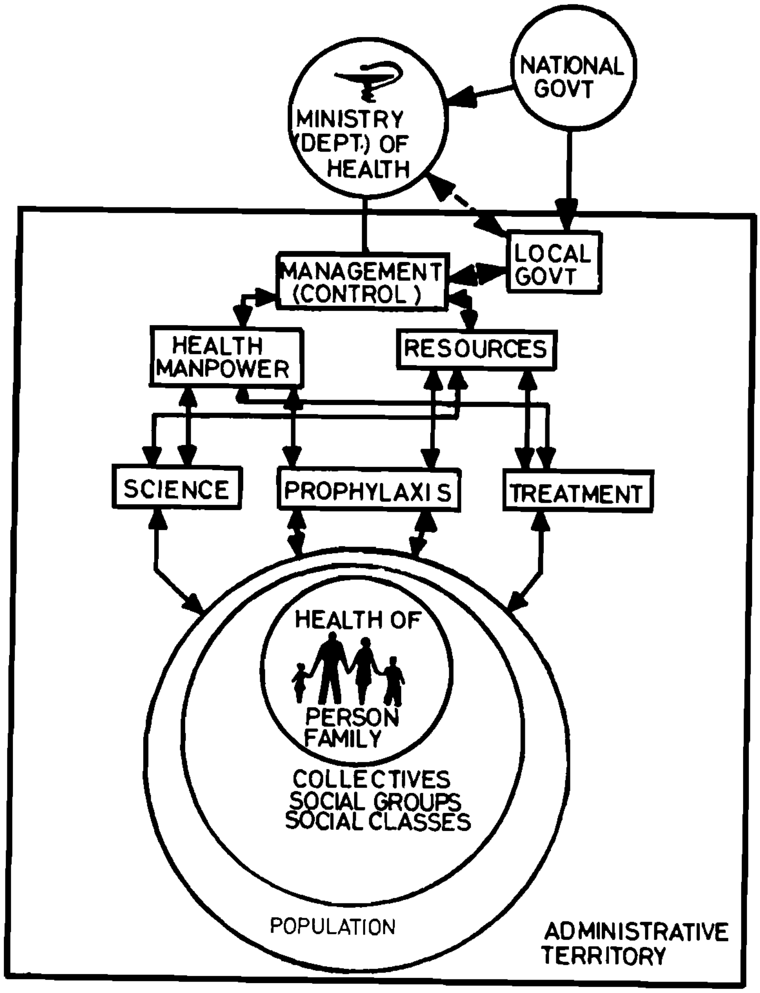


Figure 3. Health care system functions.

Even where local "non-systems" of health care services exist, as is the case in certain countries, we can observe the same processes and structural units, with one difference--their interconnections are not orderly and obvious (Figure 4). However, in practice, most territories have several types of medical and health care institutions that, while different in name, do

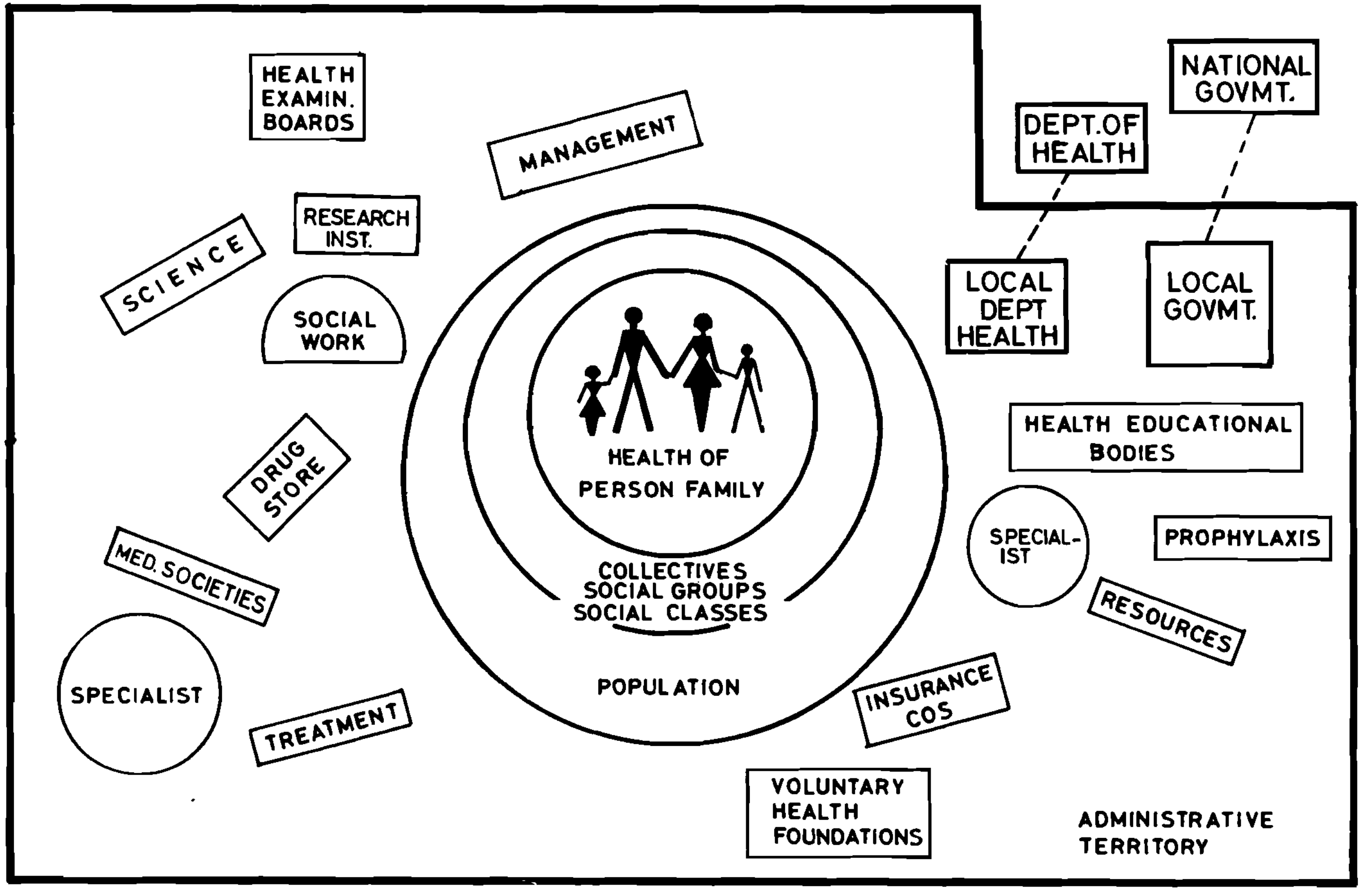


Figure 4. "Non-system" of public health.

implement common functions in different proportions and with different degrees of centralization, depending on the country's social, economic, and geographic conditions and its traditions. Experience shows that functions such as planning and coordinating scientific research, meeting the demands for trained medical personnel, setting up pharmaceutical standards, organizing sanitary and epidemiological services, determining the direction and the development of health care services are best conducted at the *national* level. Activities that are best carried out at the *local* level include the direct practical management of medical establishments, administration of medical staff, flexible and rational use of local resources, and provision of accessible medical services.

In the process of developing the health care system simulation model, we have drawn up a table that provides details about the major elements of the public health system mentioned earlier.

Elements of a public health system.

SCIENCE	PROPHYLAXIS	TREATMENT	MANPOWER	RESOURCES	MANAGEMENT
Evaluating problems & needs in theoretical practical medicine	Analyzing factors unfavorable to human health	Analyzing health status of population	Evaluating personnel needs	Analyzing needs for facilities, equipment, drugs	Analyzing health status of population & available resources
Planning biomedical research	Providing preventive health measurss/epidemologival surveillance	Ensuring population access to primary curative/preventive care	Training all health personnel	Allocating financial resources	Interrelating public health with other socio-economic systems
Conducting biomedical research	Undertaking current health/ epidemiological surveillance	Undertaking preventive screening and early care	Organizing public health teams	Producing/supplying medical instruments/equipment	Allocating personnel & resources within health systems
Evaluating research results: new recommendations	Providing health protection of vulnerable population groups	Providing specialized medical & rehabilitative out-patient/in-patient care	Providing advanced training/upgrading for all staff	Producing/supplying drugs & biopreparations to medical establishments & populations	Controlling public health establishments and evaluating efficacy
Management recommendations	Providing health education	Preventing disease relapses: special follow-up of chronically ill			Adopting and executing management decisions

We have mapped these functions in the master flow-chart (Figure 5) that shows in detail the above-mentioned scheme. Then we have studied both ther interconnections of the main blocks within the model (Figure 6) and the main directions of the information flows.

A preliminary approach has been made to mathematically describe these processes, and when this is finalized, we will check it against the available data on health care in different countries. The model could become workable if national organizations would collaborate actively, and if the model could be linked with global or regional models.

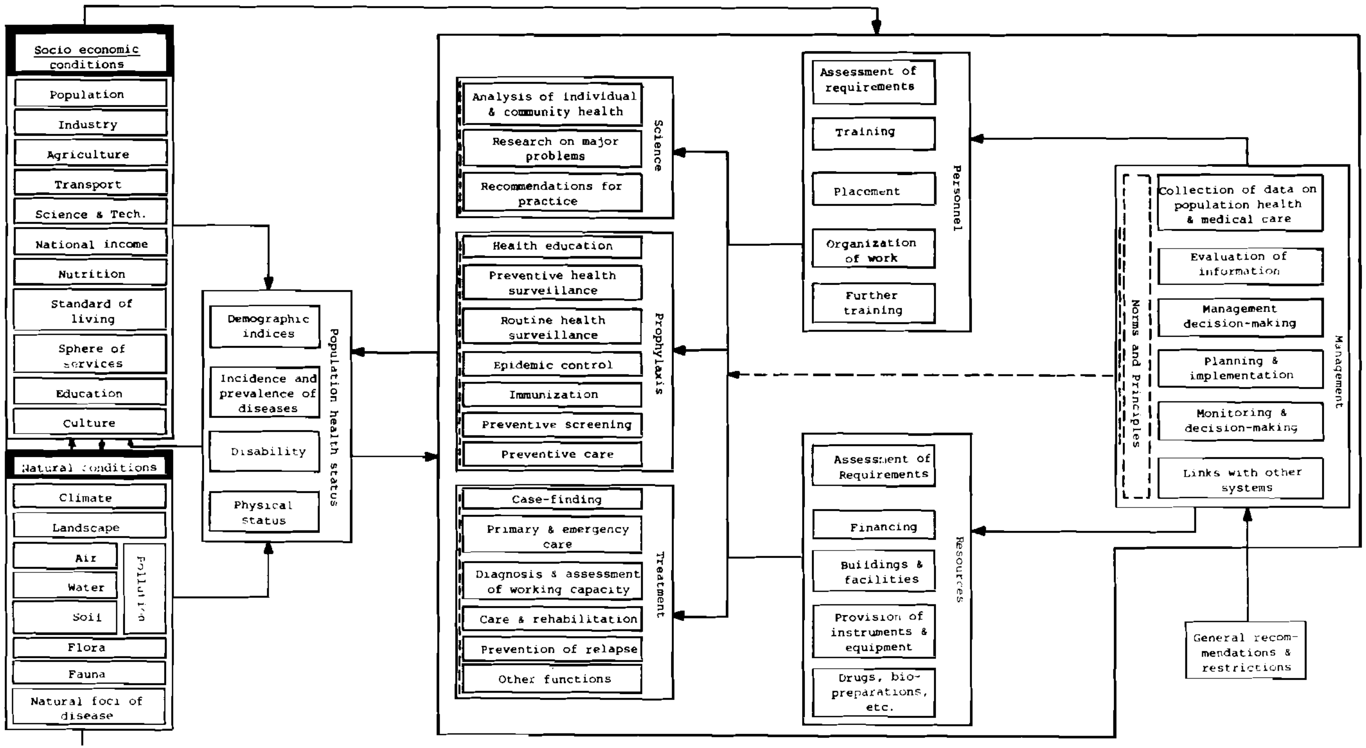


Figure 5. Functional chart of a public health system.

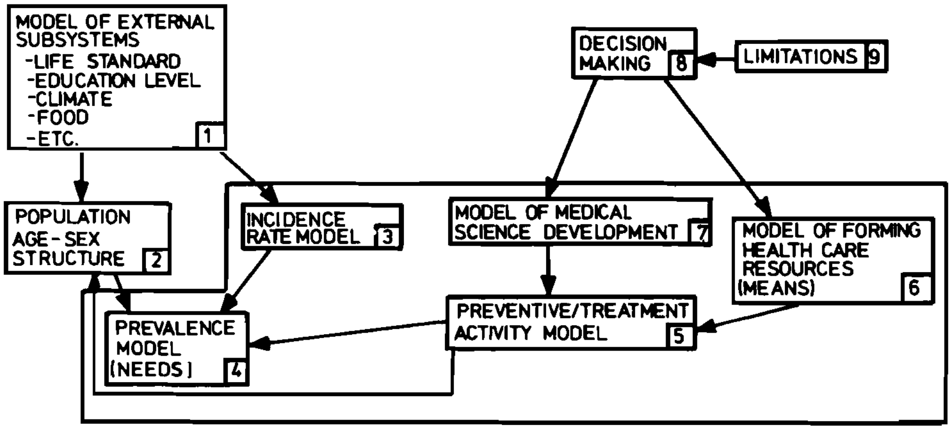


Figure 6. General structure of interconnections in health care system model.

The most urgent task is to review and classify the various health care system models, and to describe (in similar terms) the health care structures of different countries, with a view to finding common features in their development. The work on modeling health care systems being carried out in some countries and by international organizations (especially by WHO) makes the fulfillment of this task easier. It would be desirable if in late 1976 or in the beginning of 1977, IIASA and WHO could jointly hold a workshop. Its tasks would be to review the work already completed, introduce some possible changes into the main blocks of the model that reflect the main ideas of WHO concerning health care system management, and mutually develop the model by making it more adaptable to conditions in different countries and to the task of solving health care problems.

While working on the model, we kept in mind the model user and, in particular, the decision makers concerned with developing health care systems--i.e., politicians, economists, health care organizers and other specialists (Figure 7). The broad use of health care system models is needed at this stage as well as at future stages of health care development at the national and international levels. Health care organizers, physicians, engineers and mathematicians of various countries should work together to identify problems and seek solutions.

Among the major uses of models of health care systems are the following: specifying and measuring the individual and public health status; analyzing health care links with socioeconomic factors; analyzing the role of health care factors in determining the health status of the individual and the community; establishing criteria for measuring the effectiveness of health care systems; setting up a health care systems information support; forecasting and planning for the development of health care

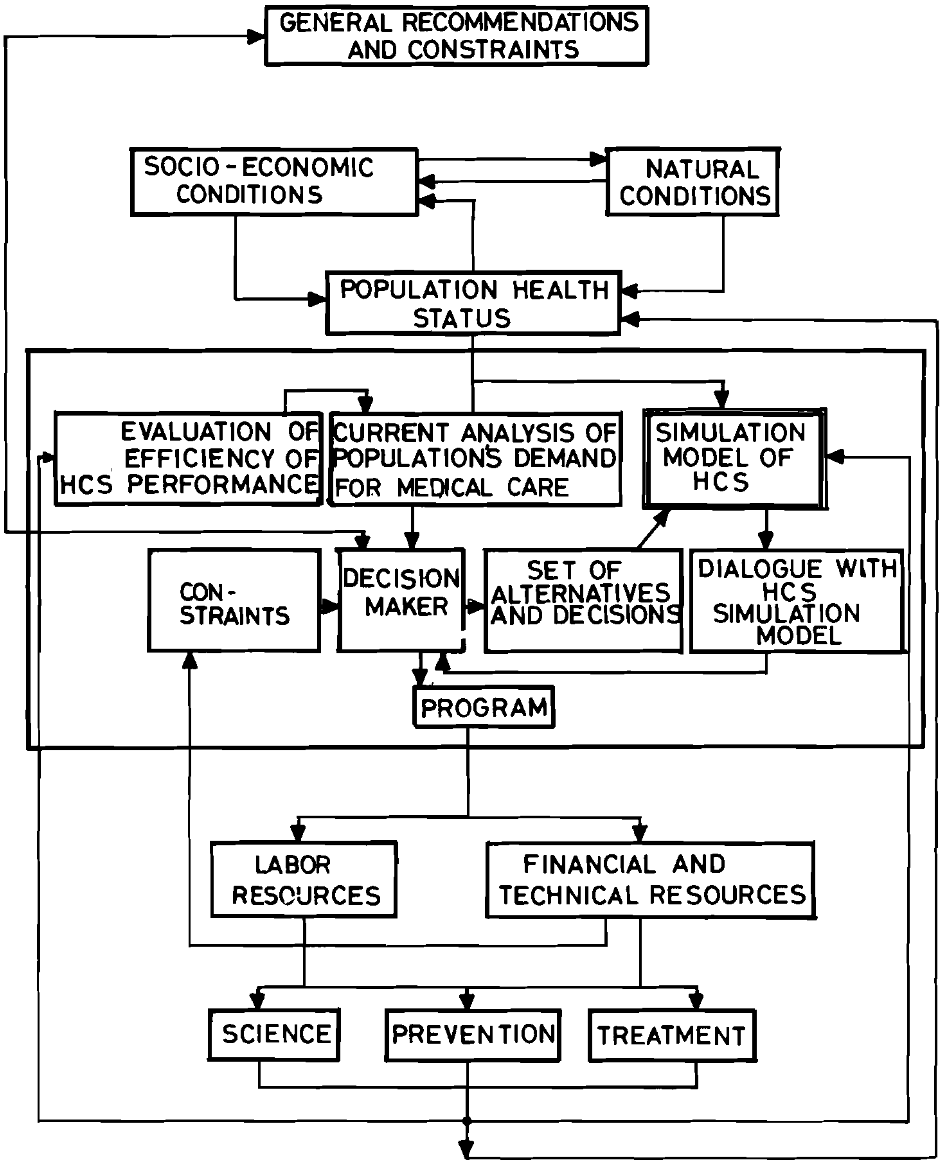


Figure 7. Simulation model of a public health care system.

services; fitting together the micro-models of a health care system; and expanding international cooperation in the health care field for the purpose of solving health care problems.

While I am not an expert in the techniques of applied systems analysis and mathematics, I am ultimately a user of the health care system model, i.e., a decision maker. My interest in the dynamic model of the health care system stems from my belief that present health care problems cannot be solved at the national and international levels without the use of systems analysis and simulation modeling.

At a national level, for example in the USSR, we have a health care system that employs 5.5 million workers, including more than 830,000 physicians and 2.5 million trained medical assistants. There are more than 30,000 various medical institutions, almost 90 higher medical schools, and more than 400 research institutes and laboratories. The programs and activities of the health care system are effective. However, we are now faced with the problem of full-scale management optimization of the health care system, as a result of the socio-economic aspects of the worldwide developments in medicine and technology.

Thus, we are directly interested in developing health care models, elaborating various alternatives of managerial decisions, and analyzing various socio-medical problems. We wish to understand and learn from the experiences of other countries in this field, and to adapt their positive elements to our system. We hope that other countries share our desire for this mutual learning experience, and will adapt from our system those elements that can be useful within the framework of their economic and social systems.

In addition to national and universal health care problems, there are similar problems of a regional and global nature, for example, problems of environmental protection and sanitation that exist in both industrialized countries and those emerging countries that are developing irrigation and energy systems; and epidemics of such diseases as onchocerciasis, and schistosmiasis. Moreover, there are global problems whose solutions require worldwide coordinated efforts, as for example, international coordination of biomedical research; global epidemiological surveillance and control of epidemics; study, prevention and control of cardiovascular, oncological and other widespread diseases; protection and improvement of the biosphere; monitoring and control of quality, efficacy, side effects and use of drugs; assistance to developing countries in training medical personnel, developing national health care systems etc; and population dynamics and nutrition.

References

[1] Bailey, Norman T.J., and Mark Thompson, eds., *Systems Aspects of Health Planning*, North Holland, Amsterdam, 1975.

[2] World Health Organization, *Sixth General Programme of Work Covering A Specific Period 1978-1983 Inclusive*, A29/6, WHO, Geneva, 1976.

[3] Venedictov, D.D., et al., *On Development of a Long-Term Program for International Cooperation in Cancer Research*, paper presented at the Third IIASA Biomedical Conference, Moscow and Laxenburg, December 8-12, 1975.

[4] Venedictov, D.D. ed., *Systems Approach to Health Care*, paper presented at the Third IIASA Biomedical Conference, Moscow and Laxenburg, December 8-12, 1975.

Discussion

(J.R. Miron and A.A. Klementiev, Rapporteurs)

Discussion centered on three research topics: inter-urban systems, intra-urban systems, and health care systems.

A number of discussants reacted to the emphasis on demographic models in the presentation on inter-urban systems research. They questioned the need for constructing more comprehensive, multidisciplinary models of urban growth. One discussant commented that an example based on the future rural-urban population split in India was too simplistic, because it ignored the different kinds of urban areas to which rural migrants might move. Another discussant stressed the need for more investigation of the theoretical principles (or laws of motion) in urban and regional development.

One discussant presented several ideas on the concept of a unified settlement system that should underlie inter-urban systems research. A number of public policy goals in settlement system design were mentioned including an adequate provision for growth capacity, a resilience under changing economic conditions, and an efficient spatial structure for economic production and social development. Further, issues related to the manageability of an inter-urban system--its efficiency and unity--were discussed.

Several comments were made about the need for IIASA to work more closely with national research institutes. Specific research already undertaken in the USSR on world population growth and distribution was given as an example of the type of information that could be provided to IIASA.

On health care systems research, a comment was made that IIASA should promote comparative studies of national health care systems. Also, an emphasis should be placed at IIASA on the detailed application of systems analysis to health care problems. Finally, it was felt that there should be more coordination between IIASA and the World Health Organization.

MANAGEMENT AND TECHNOLOGY

Introduction

H. Knop

This volume contains three presentations by members of the IIASA Management and Technology area that deal with the managerial aspects touched upon in my first presentation.* The first, *An Organizational Approach to Integrated Regional Development* by C. Davies, is based on the research done over the past eight months by a small working group of full-time staff members of the Management and Technology area: C. Davies, A. Demb, R. Espejo, and R. Ostrowski. In addition, several visiting scientists contributed to the case studies of the Tennessee Valley Authority (TVA) in the USA and the Bratsk-Ilimsk Territorial Production Complex (BITPC) in the USSR: A. Agani, J.L. Evenko, B. Milner, J. Tomb, and R. Tomlinson.

By way of introduction, I will use a simplified scheme of managerial activities and their interaction (Figure 1): analysis, forecasting and planning, modeling, and implementation. Davies' presentation concentrates mainly on the organizational problems (Figure 2) related to those managerial activities shown in Figure 1. Besides the TVA and the BITPC cases mentioned earlier, this working group studied the organizational approach and experience of three other regional development programs, namely, the Regional Development Program of Guyana and the Scottish development program.

The second presentation, *Models and Decision-Making in Integrated Regional Development*, was authored by J. Owsinski and D. v. Winterfeldt, both members of the Management and Technology area. While at IIASA, A. Straszak and V. Takhadze also took part in analyzing the TVA and the BITPC case studies. This presentation is concerned mainly with the present stage of our research on these two case studies. In terms of the interaction of managerial activity, it deals with the planning and decision processes, based on an analysis of the state and trends of development (see Figure 3).

The third presentation, *The Steel Case: Conceptual Framework and Hierarchical Control Approach*, is by I. Lefkowitz who, together with the late Professor Cheliustkin, was co-project leader of the former Integrated Industrial Systems project. Professor Cheliustkin left IIASA in January of this year, having

*Volume 1.

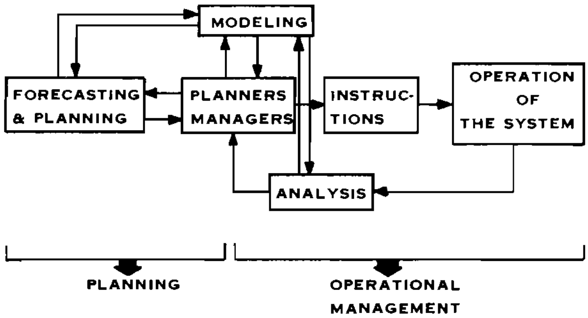


Figure 1. Managerial activities.

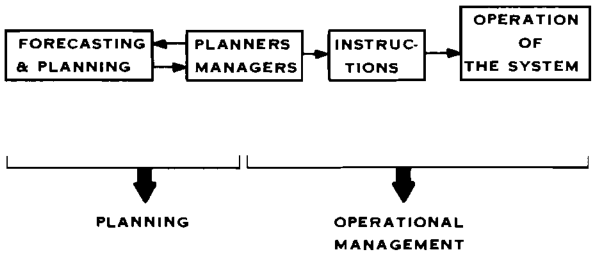


Figure 2. Organizational problems.

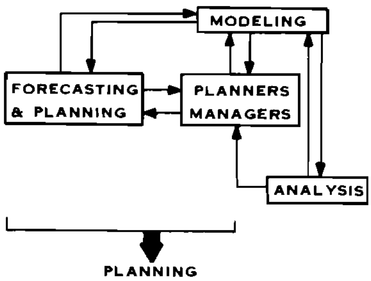


Figure 3. Role of decision makers in model calculations and the planning and decision processes.

been at the Institute for two years. He was a person of high scientific repute, with tremendous practical experience and a high degree of dedication to his work. Other members who contributed to this study were D. Kelley, B. Mazel and G. Surguchev. Lefkowitz's presentation outlines some of the major results achieved by the project during the last two years. This activity is being continued as part of the work of the Management and Technology area, under the research task entitled Computer Based Management Systems. The main emphasis of this study is on the interaction of model calculations and managerial decisions, mainly in the light of operational management, with strong emphasis on data-base mangement (Figure 4).

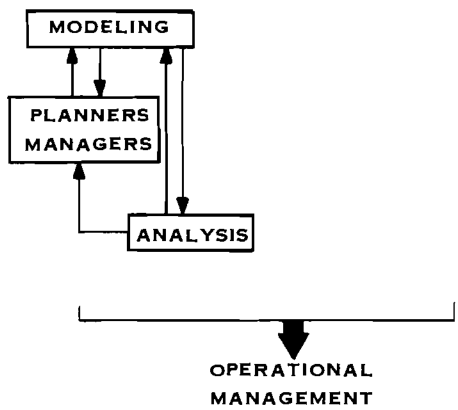


Figure 4. Interaction of model calculations and managerial decisions.

An Organizational Approach to Integrated Regional Development

C. Davies, A. Demb, R. Espejo, and R. Ostrowski

INTRODUCTION

This paper presents a broad overview of a research program directed at the organizational aspects of integrated regional development. The program of research includes five cases of regional development. Two of the cases--the Tennessee Valley in the USA and the Bratsk-Ilimsk Territorial Production Complex (BITPC) in the USSR--formed the basis of the comprehensive management and technology studies described by Hans Knop in his presentation.*

The other three case studies are more limited in scope. The Polish case is concerned with the development of coal reserves in the Lublin region of Poland (Figure 1). The reserves, which are a major national resource, are situated in an area that currently supports only agricultural activity. The development scheme is at a very early stage.

The second case concerns development related to the exploration and exploitation of oil fields off the northeast coast of Scotland. Exploration started about six years ago, and oil is now beginning to flow to the mainland. The major impact of the development is concentrated in three areas of Scotland and is reflected in particular in the demands on infrastructure (Figure 2).

The third case is the Guyana region of Venezuela (Figure 3). Here development, which began about 20 years ago, took place in an almost virgin region. It features hydropower generation, urban development and somewhat diversified industrial development.

Later in this paper we shall present some early observations on the organization in each of the cases, but first let us examine the main purpose of the research program.

The research program aims at providing support for policy decisions made about the organization of regional development programs. In none of the five cases does it seem possible to effectively manage mature development through the organizational mechanisms that ordinarily exist in the setting. Thus in all cases there is need for such decisions about organizational change. We should like to mention some issues that need to be resolved.

---

*See Volume 1.

Figure 1. Lublin coal region in Poland.

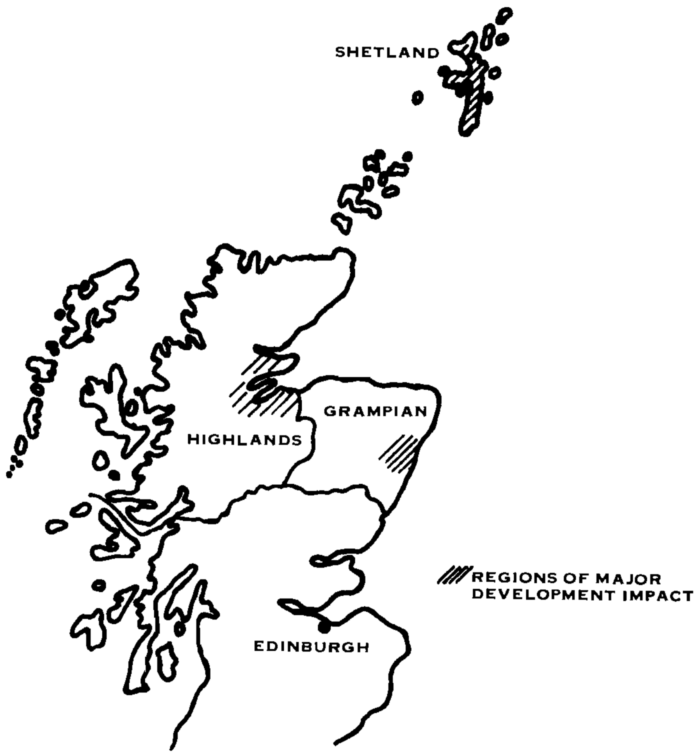


Figure 2. Scottish regions being developed.

Figure 3. Guyana region, Venezuela.

In the Polish case, the development program is at a very early stage. At present, the main activities are concerned with construction of pilot mines and surface structures. At this stage, it is proving possible to manage the activities through the Ministry of Mining. However, in addition to mining, the final stage calls for the construction of a town for 125,000 people, with provisions for their recreational and other needs, and environmental management. It is questionable whether at this final stage, the Ministry of Mining will be an adequate integrating body for all these activities. The question how to manage the whole program most effectively is currently being discussed in Poland.

Moreover, we cannot assume that decisions made about organization will remain effective indefinitely. For example, the development program of the BITPC has been successfully ongoing for many years; however, the activities have become so complex that policy makers in the Soviet Union are now considering whether a new comprehensive management body is required.

In the case of Scotland, rapid physical development prompted by national energy needs has sometimes moved ahead of the organizational responses to this development. To the extent that this has happened, it is possible to detect development problems, for example, the imbalance between the supply of infrastructure and the new demands for it.

In all the above illustrations, there are common features that arise from the special characteristics of regional development.

All the problems involve more than a single organizational unit--they are problems of *multi-organization*. All involve an examination of the *linkages between the units of the regional system*, and *linkages between the regional organizations and the national system*. Furthermore, they all are concerned with *managing* a process of *organizational change*, sometimes in the face of rapid change in the activities of the region.

RESEARCH DESIGN

We believe that organizational sciences can support policy makers in facing these problems, and can support the transfer of experience gained in one setting to the benefit of different settings. However, while theory and application experience exist in organizational sciences, theory has not been applied to the regional development context. Moving from existing theory and application to support for policy-making in regional development is a multi-stage process.

The first stage involves translating existing theory into a form applicable to regional development--that is, establishing a new framework. This framework has to be applicable to cases drawn from different settings. Much of our recent work has been devoted to constructing such a framework, the main features of which will be discussed below.

The second stage--at which we are at present--is the application of this framework to the five cases. The result of this stage is the production of a consistent set of regional development case descriptions from the organizational viewpoint. These descriptions should provide a valuable addition to the case literature of regional development. While many case descriptions exist, we have found few that focus on organization and management features. The case descriptions will also provide the data for the third stage of our research program.

In the third stage, we will apply three different models of organization and change processes to each of the five cases [1,2, 3,4]. This will involve the advanced and novel application of these approaches, and will provide an assessment of the value of studying regional development from the organizational perspective. To the extent that the approach is valuable, support for policy decisions will result.

Let us now go back to the first stage, and discuss the approach we have developed.

We are conscious that the scientific benefit from a multi-case approach depends upon the application of a consistent framework across cases. This framework must meet two primary requirements.

First, the language used to describe the cases must be universal--it must not contain elements or concepts that depend on a particular case. Language that is based on organizational forms does not satisfy this requirement--any one of the cases may contain forms that have no apparent parallel in the other cases.

We must go beyond form and examine function to find our universal language. We are using models that postulate that all organizational forms and mechanisms are concerned with one or more of the five following functions only. These are policy-making, planning and information gathering, control of system activities, coordination of the activities, and operational implementation of the activities.

Since these functions are universal, they can be used consistently to describe each of the cases. They provide our language.

The second requirement is that the case be placed conceptually within a larger system. Our systemic approach recognizes three system levels: the *national system* in which the regional system is embedded, the *regional system*, and the *subsystems* that are embedded in the regional system. The focus of our attention is the regional system. To define and under this system, we need to look outward at the national system and inward at the subsystems.

The concept of system embedding is illustrated in Figure 4. It is more accurately conveyed as shown on the left of the figure; however, to present observations on particular cases, we will use the diagram on the right. In particular cases, the relative sizes of the circles representing the regional and the national systems suggest the influence each has on the subsystems.

Our definition of system is not a simple one based on the geographic location of an organization unit within the regional boundaries. Rather, it is based on the nature of the decisions or the tradeoffs made by the unit.

Organizations in the national system make tradeoffs involving regional interests with interests outside the region. In the regional system, the organizations make tradeoffs only between the regional interests. The regional system embeds the subsystems that make tradeoffs only within one area of the regional activities. Whereas subsystems are always located in geographic regions, any part of the regional system may or may not be located in these regions.

CASE OBSERVATIONS

Using the concepts of system embedding and viewing regional development as a change process, we shall discuss some of the early observations on each of the five cases. Naturally, these observations may be subject to revision as our information on the cases increases.

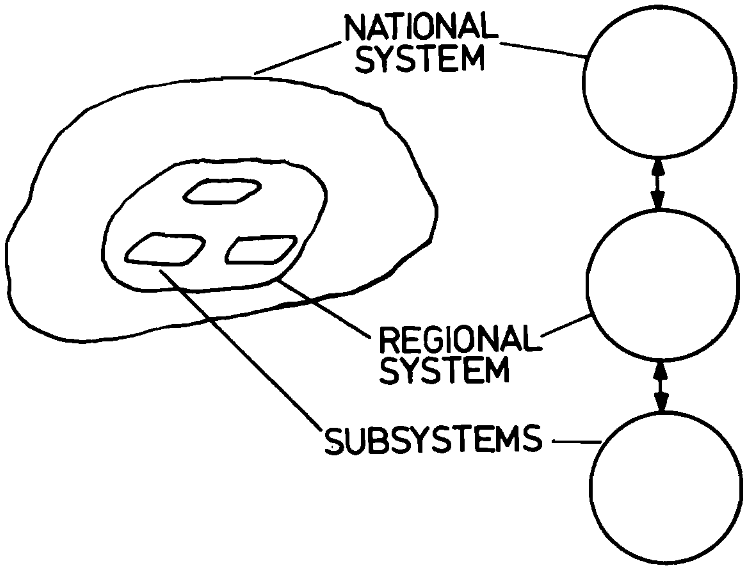


Figure 4. Embedding of systems.

Let us look first at the BITPC case. According to our information, there are several different development phases (Figure 5). The first phase involved the rapid construction of productive potential--i.e., the creation of hydropower dams and energy-intensive industries. Initially, the activities were not complex, and could be managed through the use of the highly developed national system of sectorial management. Therefore, the production complex moved toward diversifying its activities. The increased complexity of the activities led to a broadening of the linkages between the national system and the subsystems, and also led to the creation of new mechanisms at the regional level. We have read of the increased powers of the territorial bodies vis-à-vis the sectoral ones in the USSR, and in the case of the BITPC, a Board of Directors has been created.

The BITPC has continued to grow in complexity; at present, it is a highly developed social and production system. Currently, there are discussions of possible new organizational solutions, as for example, creating a new body for managing the complex. The BITPC's diversity may be becoming too great to manage even for the highly developed national system. If a new body is created at the regional level, then there is an accompanying need to modify the influence of the national system.

In the Tennessee Valley case we find a contrasting situation (Figure 6). In the USA there was no readily existing capacity at the national level to manage the development of the region. We

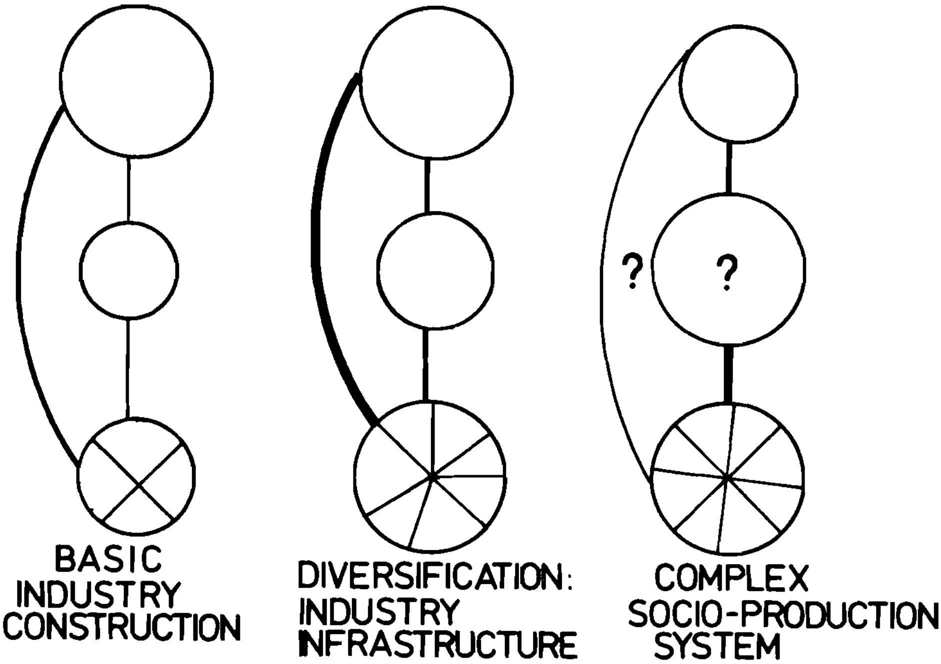


Figure 5. BITPC regional development.

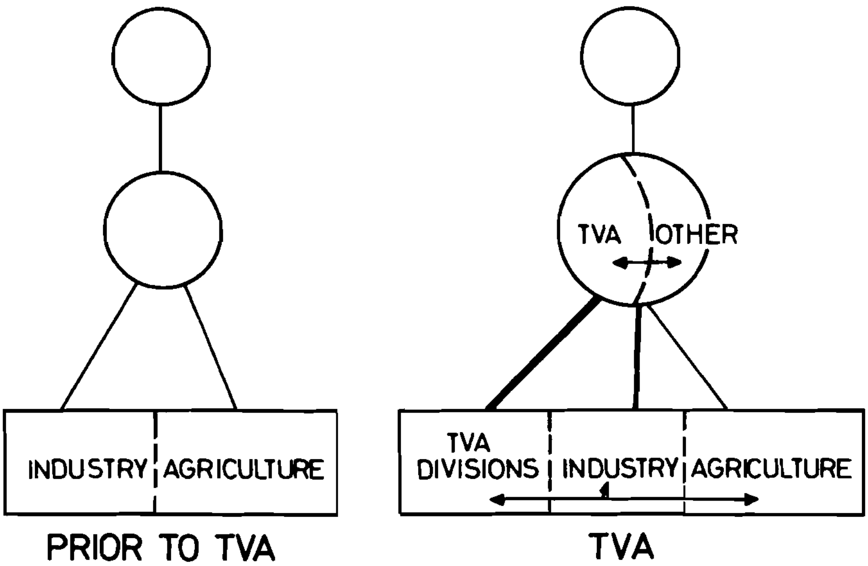


Figure 6. Tennessee Valley case.

know that there were some federal agencies for development activities (e.g., agriculture), but our information at present is limited.

The essence of the development plan was to harness underutilized and, indeed, destructive water resources for navigation and power generation. Agriculture would benefit from the improved flood control, and industry would be attracted through cheap electric power. The Tennessee Valley Authority (TVA) was created to implement this.

The legal act creating the TVA did not, however, give details on the scope of its activities or the nature of the relationships with other units (private, state or federal) operating in the region. How these relationships and boundaries were established is an interesting feature of this case. The early period was far from conflict-free. The TVA had to find some accommodation with these other units, which involved reducing the scope of its initial activities. At times the heat of the issues was such that the survival of the TVA was in doubt. While this episode now belongs to history, it does illustrate the importance of the issues we are discussing.

The Scottish case represents development in a setting that was already sophisticated, both industrially and organizationally (Figure 7). The existing regional system consisted of many separate units concerned primarily with infrastructure development as well as with general industrial development. Established patterns of authority and influence existed to deal with the integration and coordination of these activities.

Oil, the major driving force of the development being considered, is, however, controlled at the national level. Thus, the region was forced to respond to something it could not control. While some adjustments have taken place within the regional system, the main obstacles to overall integration arise because of the different centers of control.

The Venezuela case represents, by contrast, development in almost virgin territory (Figure 8). Of the five cases, it is the one clear case where development did not proceed along the lines envisaged, and organizational solutions had to be changed as a result.

It was originally intended that many of the development activities would be carried out with private capital. A new organization, Corporación Venezolana de Guayana (CVG), was set up to promote the region to private developers and to coordinate their activities, having implementing powers only for hydropower development.

However, no means existed in the setting for effectively pushing private capital in the desired direction. The result is that public corporations now represent the bulk of the investment in the region. CVG plays a more powerful role vis-à-vis the region to set up these corporations and manage their activities.

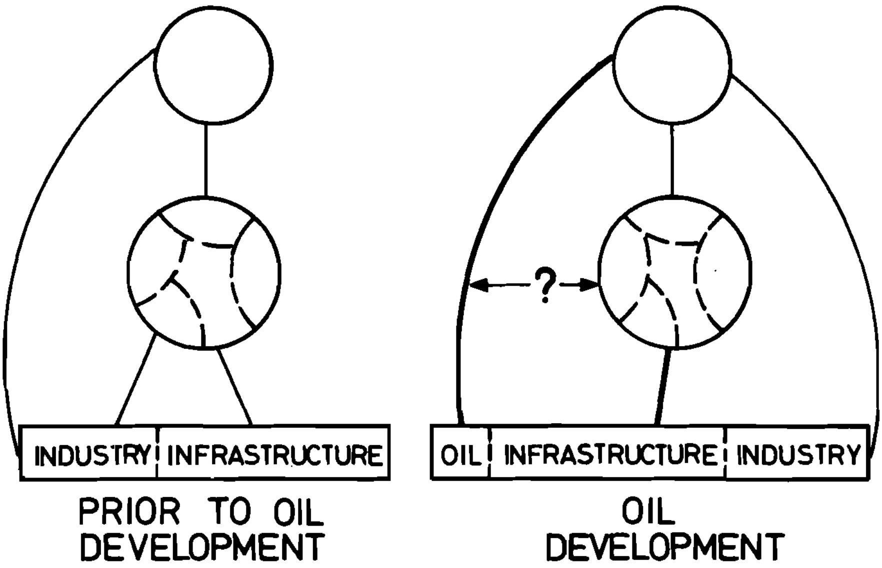


Figure 7. Scotland.

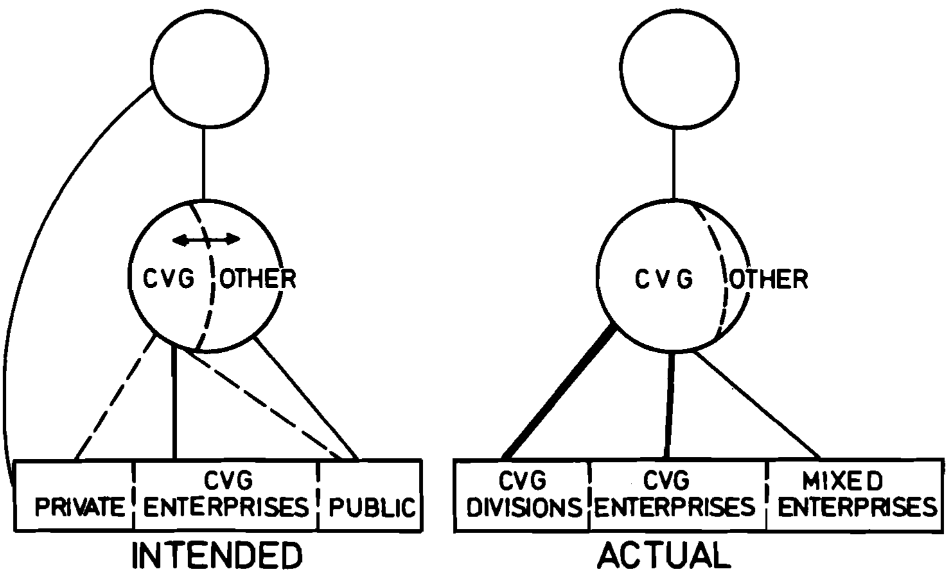


Figure 8. Guyana (Venezuela) case study.

We move finally to the Polish case, which brings us back to our starting point (Figure 9). Activities in the region are at a low level--they are primarily related to coal mining. Here management of the activities through the Ministry of Mining is an obvious solution.

But we are only at the beginning of the story. The type of regional organizations and their linkages that are effective for managing the complex activities that do not follow sectoral boundaries, and that are appropriate to Polish conditions, still have to be defined.

Scientific research can never be a substitute for policy decisions in the field of complex organizations, but it can support policy makers. Poland today, or in the near future, must make such policy decisions. The time scale here may indeed preclude our contribution. However, we are certain that the final judgment on research such as we have outlined here must rest on the ability of the research to provide the necessary support.

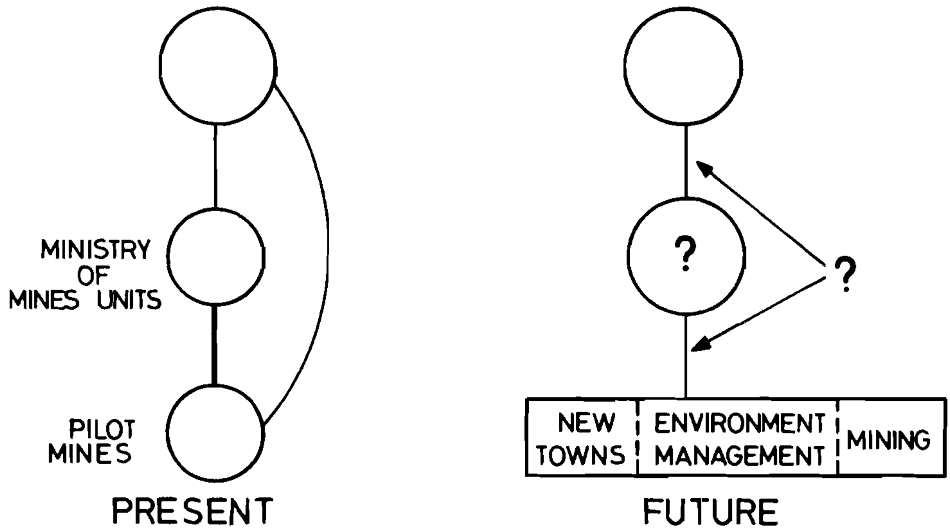


Figure 9. Polish case.

References

[1] Davies, C., A. Demb, and R. Espejo, *An Overview of Organizational Research in Regional Development*, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[2] Davies, C., *A Force Field Approach to Assessing Organization for IRD*, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[3] Demb, A., *Application of a Model of Planned Change to the Analysis of Organization of Regional Programs*, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[4] Espejo, R., *A Method to Study the Organizational Dimesion of Regional Programs*, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Models and Decision-Making in Integrated Regional Development

J. Owsinski and D. v. Winterfeldt

RESEARCH GOALS AND CONCEPTS

One of our research interests in the Management and Technology area is the use of models in planning and decision-making of large organizations. Within IIASA's research program of Integrated Regional Development, we focused our research on the use of models in integrated regional development programs based on an accumulation of experiences from the retrospective case studies of the Tennessee Valley Authority (TVA) in the USA, and the Bratsk-Ilimsk Territorial Production Complex (BITPC) in the USSR. Our objectives were to describe the role that models have played in planning and decision-making for these two important development programs, and to assess the possibilities and needs for further integration of modeling and decision-making.

Our research was motivated by two problems: first, the need for models to overcome the difficulties of intuitive decision-making in large organizations, and second, the often inefficient use of existing models in decision-making. Many studies of behavioral decision theory have demonstrated that man has difficulties in handling even relatively simple information-processing, evaluation, and decision-making problems when left to his own intuition (e.g., [1,2]). Thus, it is understandable that decision-making tasks as complex as regional strategy selection or regional planning need support from models to ensure rational decision-making.

Such models exist, of course, ranging from direct formalizations of the information processing and decision-making (e.g., decision analysis, probabilistic information-processing systems) to models of the decision object (e.g., simulation and forecasting models). Those models that are based on simple and well-known techniques or model systems [3,4] are used frequently and effectively in the decision-making process. Other, more refined and comprehensive models of, say, urban and regional systems (e.g., [5,6,7]) are not efficiently used--if at all--in planning and decision-making. Different types of models are usually badly linked, often ill understood, and seldom well adapted to actual decision-making.

The main problem is therefore one of *integration:* integrating various types of models that support decision-making, and integrating models into the decision process. This problem of integration has been widely recognized, and research institutes in many countries are making extensive efforts to solve it. Our research focused not so much on the various attempts to formalize the process as such and to draw mathematical modeling conclusions [8] or to design man-computer interfaces [9]. Rather, our goal was to contribute to integrative methodologies by analyzing the actual use of models in real-world decision-making cases.

To describe our approaches to analyzing the use of models in decision-making, we needed to clarify some concepts. What do we mean by models, decision-making, and the need for integration?

The two basic elements of any decision process are the *decision unit* (decision maker), and the *decision object* (region, regional subsystem) (see Figure 1). The purpose of decision-making is to select alternative courses of action that produce a desired behavior on the part of the decision object. Models to support decision-making are, on the one hand, models of the decision object. When we talk about such models, we do not mean mere concepts, but rather precise and operational abstract (physical or mathematical) representations of the decision object and its possible action-dependent futures. Examples of this type of model are econometric forecasting models, regional simulation models, and balance or optimization models [10]. On the other hand, models to support decision-making are decision theoretic models of the decision maker's tradeoffs, time preferences, and risk preferences, that is, formal representations of the decision maker's opinions and values. Examples of such models are multiattribute utility models, discounting models, and expected utility models [11,12].

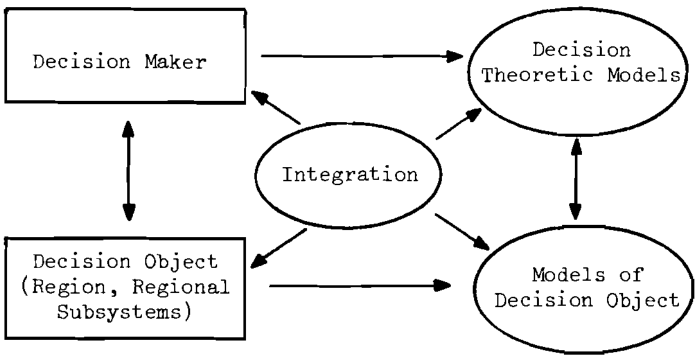


Figure 1. Basic elements of a decision process.

The need for integration arises at several points:

- Integration of the various models of the decision object *and its behavior;*

- Integration of models of the decision object *with decision-making;*

- Integration of models of the decision object *with models of the decision maker's values and opinions.*

Reflecting our different research interests, we analyzed, along two different lines, the use of models in regional decision-making and the possible need for integration in the TVA and the BITPC cases. The first line of research made the decision process in regional development an object of study itself. It focused on the elements *decision maker, decision theoretic models*, and *decision object* (Figure 1). Using elements of decision analysis, we studied the actual decision processes in the TVA and the BITPC to learn how models of the process itself could be used in decision-making to determine the appropriate application of models describing or optimizing the system. The second line of research was a study of such existing descriptive or optimization models, their interconnections and embedding in regional decision-making in the TVA and the BITPC. This analysis focused on the elements *decision maker, decision object*, and *models of the decision object.* Thus we were able to describe the kinds of models used in both cases, to assess different attempts at integration, and to identify the gaps between models and those between models and decision-making.

DECISION ANALYSIS OF REGIONAL DECISION-MAKING

Decision Analytic Approach

Decision analysis is a formal method for improving decision-making in complex situations that are characterized by multiple objectives, uncertainty, time variability, and group conflicts [11,12]. Decision analysis is a rational approach for structuring decision problems, assessing the consequences of alternative actions, and evaluating them with a mathematical model of the decision maker's preferences. To perform these tasks, decision analysis poses four classes of questions to the decision maker (Figure 2). What are the problems and opportunities? What are the goals and objectives? What are the alternative courses of action, possible events and consequences? What are the tradeoffs that characterize the decision maker's priorities among multiple objectives, his risk attitudes, his time preferences, etc.?

The formalized answers to the first three questions are given in the form of trees:

- A *problem* (or opportunity) tree that establishes the hierarchical relationships among major problems (or opportunities), subproblems (or subopportunities), and specific causes;

- A *goal* tree that shows the logical relationships among general supergoals, subgoals, main objectives, and lowest-level targets and indicators;

- A *decision* tree that maps out alternative initial actions, possible subsequent events, follow-up actions, and final consequences.

Question	Formalized Answers from Case Material
Problems and Opportunities?	Problem or Opportunity Tree
Goals and Objectives?	Goal Tree
Decision Alternatives and Events?	Decision Tree
Preference Characteristics of Decision-Making Bodies?	- Importance Weights - Utility Functions - Risk Measures - Discount Rates

Figure 2. Decision analytic approach.

The formal answers to the fourth question are numerical parameters that are to be incorporated in the decision theoretic model of the decision maker's preferences. Such parameters are utility functions, importance weights, risk measures, and discount rates. With these elements, the decision analysis constructs a mathematical model of the decision maker's preferences (e.g., a multiattribute expected utility model) with which alternative courses of action in the decision tree can be evaluated against the decision maker's objectives in accordance with his tradeoffs.

In our retrospective analyses of the decision processes in the TVA and the BITPC, we split up the processes along these decision analytic steps. We analyzed strategic decision-making and power production planning in the TVA, and began to look into strategic decision-making in the BITPC. Through this analysis, we could identify where, in such a formalized process, explicit or implicit models of decision-making and models of the decision object were used, where they could be used, and the possibilities and problems of integration.

Problems and Opportunities

Our analyses could usually identify a clear picture of problems and opportunities that the decision makers and experts had in mind. Several devices for identifying problems and opportunities were used in the case of the TVA. In the TVA's power production, for example, future problems were mainly identified through an assessment of demands and supplies. Capacity and demand forecasting models play a very important part in this process. On the strategic decision-making level, the task of structuring problems and opportunities is more conceptual, and models are used more to make problem definitions precise than to actually generate them. For more general problem definition tasks of this type, the TVA has implemented a reporting system called "situation assessment" that guides the top management in its problem identification task.

Goals and Objectives

Our attempts to structure goal trees retrospectively were not as successful as we had hoped, reflecting a possible need for further elaboration and specification of goals and objectives in regional decision-making. In the TVA's power production planning, we found at various places the following sets of objectives (Figure 3): power system improvement; engineering quality; economics (cost minimization); environmental impact minimization; and social objectives.

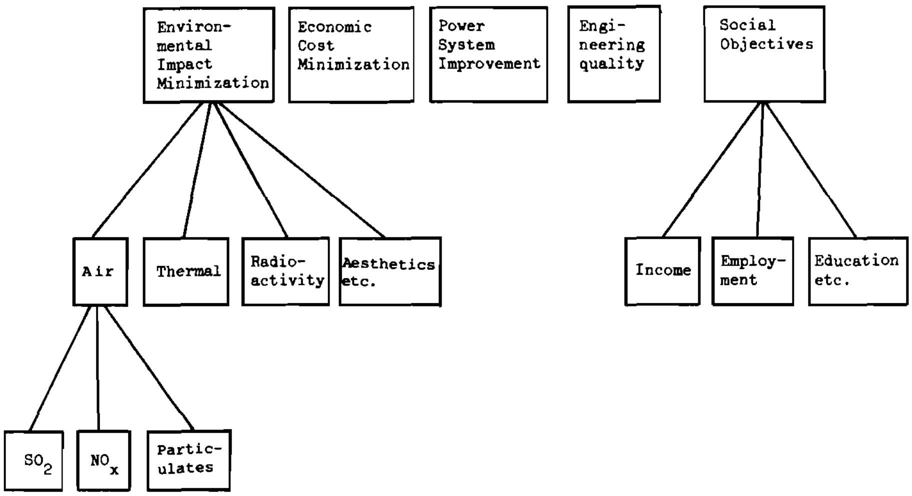


Figure 3. Segment of goal tree for power production planning, TVA.

The integration of these goals into the general supergoal structure for the regional development remained somewhat unclear. At the other end, several subgoals and subobjectives remained ill defined and lacking in operational definition. This was particularly true of the environmental and social objectives, such as aesthetics, and quality of health and education. As far as strategic decision-making was concerned, we could identify in both the BITPC and the TVA cases a well-structured set of goals based on the supergoals of "improving the national economy" (BITPC), and "improving the regional economy" (TVA). But we failed to uncover any specific translations of these supergoals and their subobjectives into targets against which specific alternative actions could be measured. Thus, it appears that specification, logical relation, and integration of goals and objectives in regional decision-making could be improved. Important also is the operational definition and the quantification of objectives that are more complex and subjective in nature.

Alternatives and Decision Trees

In our attempts to map out alternative courses of action (strategies, sites) in the form of decision trees, we usually found a reduced set of explicitly considered alternatives, often highly prescreened on the basis of a few initial criteria. The TVA's power production planning seemed at first glance to be an exception. The decision tree that the planners had in mind (Figure 4) represents a complete picture of the TVA's energy alternatives in 1970. However, only the coal and nuclear options were considered at any level of detail, and their respective

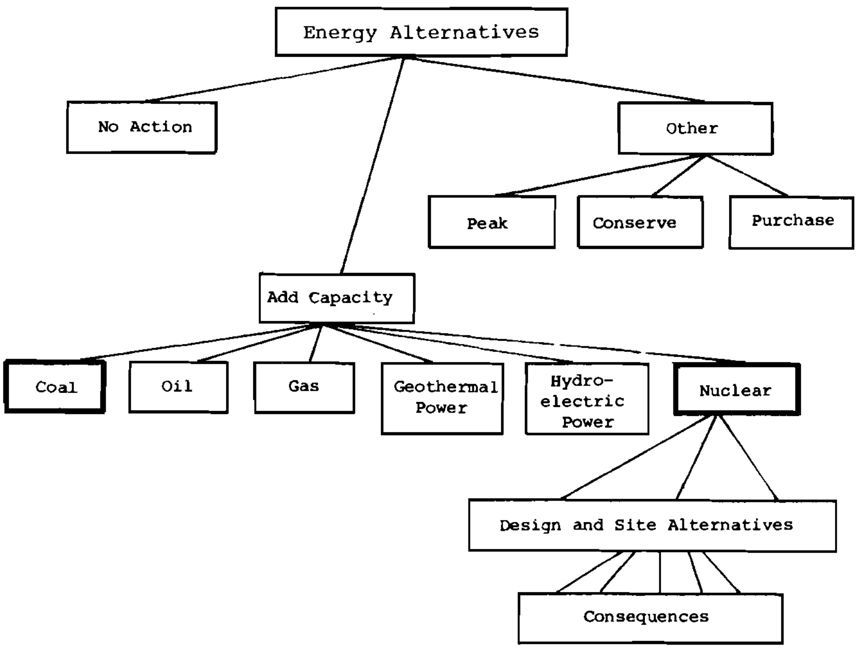


Figure 4. Power strategies, TVA.

evaluation was done almost purely on economic grounds. The remaining alternatives--sites and design alternatives (for nuclear plants)--were studied more thoroughly. Models were used in this process to assess some of the consequences of certain alternatives, e.g., economic models and environmental assessment models. It is possible that use of models could substantially improve the decision process here, by enabling the decision makers and planners to search more thoroughly through alternatives and their consequences than had been done in the case of the TVA.

A step in this direction is the way models are used in the BITPC strategic making. Many of the strategic aspects of the BITPC decision-making have to do with the alternatives to the chosen complexity strategy of territorial production complexes, e.g., an export strategy. In the BITPC case, an integrated model system was applied to analyze and assess such strategic variants (Figure 5).

Tradeoffs and Evaluation

To evaluate alternatives in the decision tree against the decision maker's goals and objectives, the decision maker has to lay open his tradeoffs. In our analysis we found little, if any, explicit consideration of such tradeoffs. In the TVA's power production planning, the more formal analysis was restricted to economic considerations (e.g., cost-benefit analysis), but when it came to tradeoffs between environmental and cost considerations, no attempt was made to assess any priorities. In the more complex strategic decision-making problems, tradeoffs were at best spelled out verbally. In some cases, uncertainties were discussed in terms of extremely small probabilities (e.g., a nuclear plant disaster), but there was no attempt to weigh these uncertainties against their consequences. For an effective evaluation, one would need not only impact models that predict the consequences of the actions, but also models that evaluate these consequences taking into account the decision maker's tradeoffs.

USE OF MODELS IN THE MANAGEMENT OF INTEGRATED REGIONAL DEVELOPMENT

Our second approach was meant to provide answers to the questions: how, in the two cases studied, did models help in practice in choosing the development strategies, and what was their role in the analysis of alternative decisions at different levels of the planning process? The existing or projected models studied can be characterized as mainly *descriptive* and *optimizing* process models.

Of course, the role of models in decision-making depends not only on model availability and model-building capacity, but also on the general policy toward model development and use.

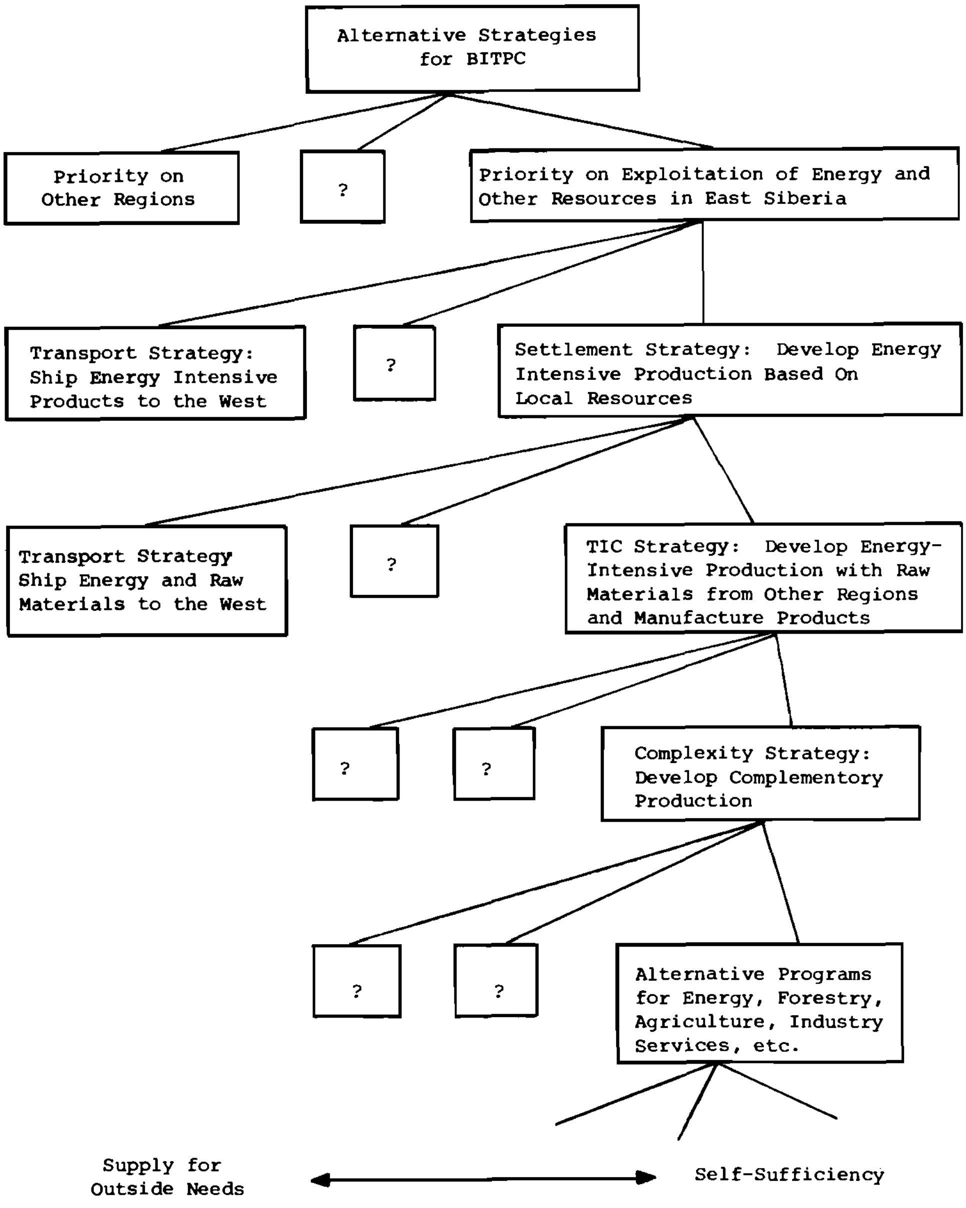


Figure 5. Elements of a decision tree, BITPC.

Therefore, we analyzed the general attitude toward the creation of models assisting decision makers, and the general characteristics of model use, rather than analyzing the individual models in depth [13]. Our approach consisted of three stages that can also be regarded as levels of analysis. The analysis started at the level of elements, i.e., individual models and their homogeneous groupings, then considered the model system as a whole, and finally mapped this system into the decision process.

Elaboration of the Table of Models

Figure 6 gives rough characteristics of individual models. For each model, we identified purpose, methods used, dimensions of tasks solved, use (e.g., analytic, forecasting, planning, operational or engineering), stage of development, and connections with other models. The sample of models considered consisted of those models that are significant in the planning and management of the regional program. In the TVA case, the sample comprised 65 models out of several hundred that exist in the organization; in the case of the BITPC, the sample contained descriptions of 37 preliminary models, a number that is very likely

	TVA		BITPC	
Table of Models	65 Models (out of several hundred)		37 Models (preliminary)	
Model System: Development	Isolated Operational Models ↓ Integration and Long-Range Considerations		Comprehensive Regional System Concept ↓ Successive Implementation	
Main Subsystems	Regional 10 Models	Power 18 Models	Regional ∿ 20 Models	Power ∿ 15 Models
Role in Management	Fore-casting ↔	Planning / Operative Manage-ment	Planning Pre-Plan Studies for Long Ranges	Sectoral Planning and Operative Manage-ment

Figure 6. Characteristics of individual models.

to increase in further studies. Our research on the use of models in the BITPC has merely begun, and we shall have to learn more about this case to be able to draw final conclusions.

Analysis of the System of Models

On the second level of analysis, the set of models shown in Figure 6, along with their interconnections, was considered as a system. The structure of this system and its dynamics were analyzed. Our aim was to assess the directions of the development of the system of models and its systemic properties such as connectivity and organization. This gave us an important insight into the philosophy of the treatment of models in a given setting and on an aggregate level.

In the case of the TVA, we were dealing with a number of relatively isolated subsystems, or even separate applications (Figure 6). The connectivity ratio was low, and the direction of development ranged from isolated models and computer applications to subsystems; we are currently witnessing efforts to interconnect several subsystems. The main subsystems of interest here were the regional socio-economic and the power/water subsystems. During the IIASA Conference on the BITPC experience [14], we were presented with the idea, already to a large extent implemented, of creating a consistent model system in the domain of general socio-economic regional planning. Other models relevant to the regional program, though not yet interconnected, were all related to the problem of power production and river control, just as in the case of the TVA.

Embedding in the Decision Process

We began this stage of analysis by mapping the general structure of the model system against the real structure of the planning procedure and the reality of the decision object. It is at this stage that we obtained the simple diagrams that reflect to some extent the planning rationale behind the system's creation (Figures 7 and 8). These diagrams show the main modules of the system of models and their connection with national-scale considerations, and the most important regional problems and subsystems. These modules are more or less coherent groups of models. Interconnections between modules show the main existing or potential information flows, and at the same time the points where the major decisions are made.

Although the set of modules and the outlook of the systems' structures in both cases are similar and reflect the objective reality of any regional socio-economic system, the role and functions of models in the TVA and the BITPC differ.

In the case of the TVA, the region-oriented model subsystem had predictive purposes for processes about which the model sponsors had little or no governing power; in the case of the BITPC,

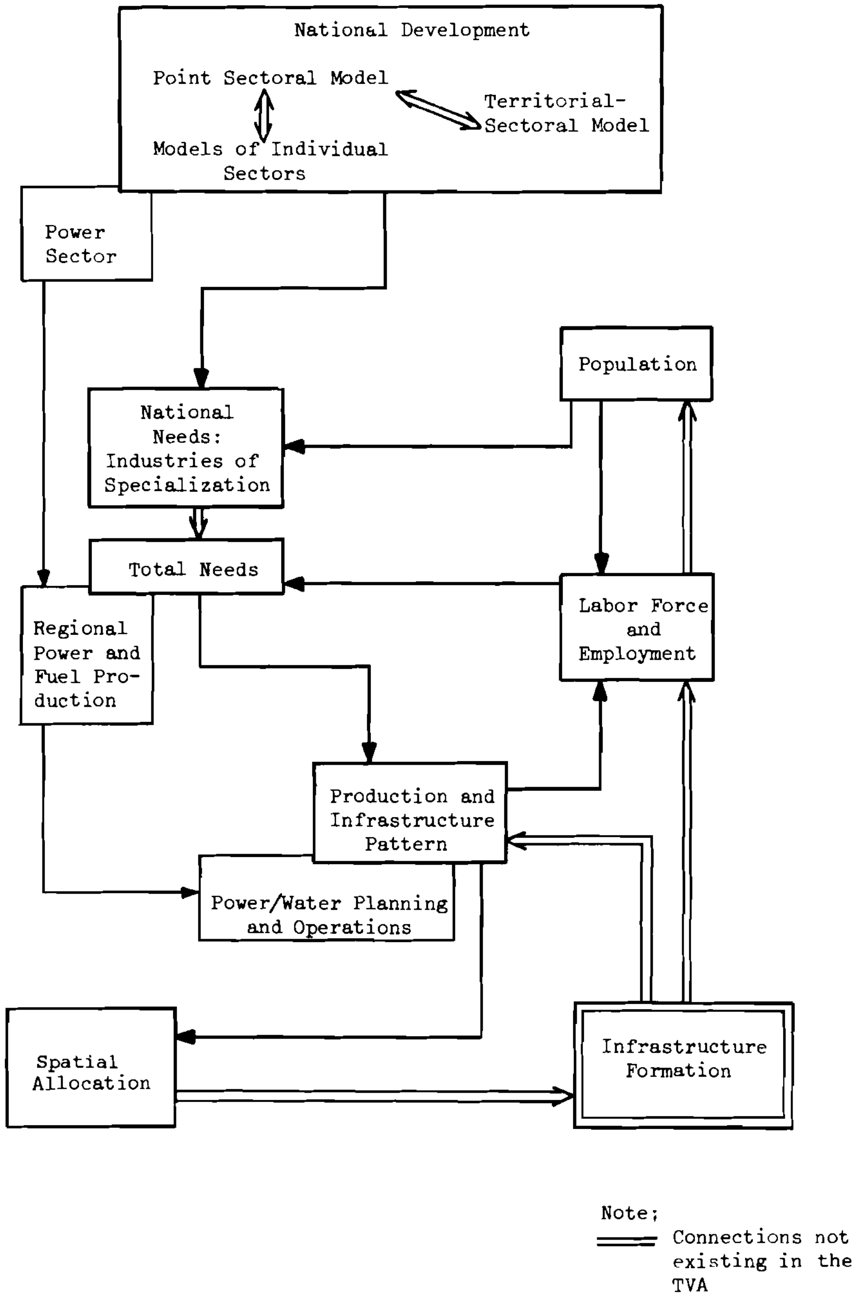


Figure 7. Regional model system, BITPC.

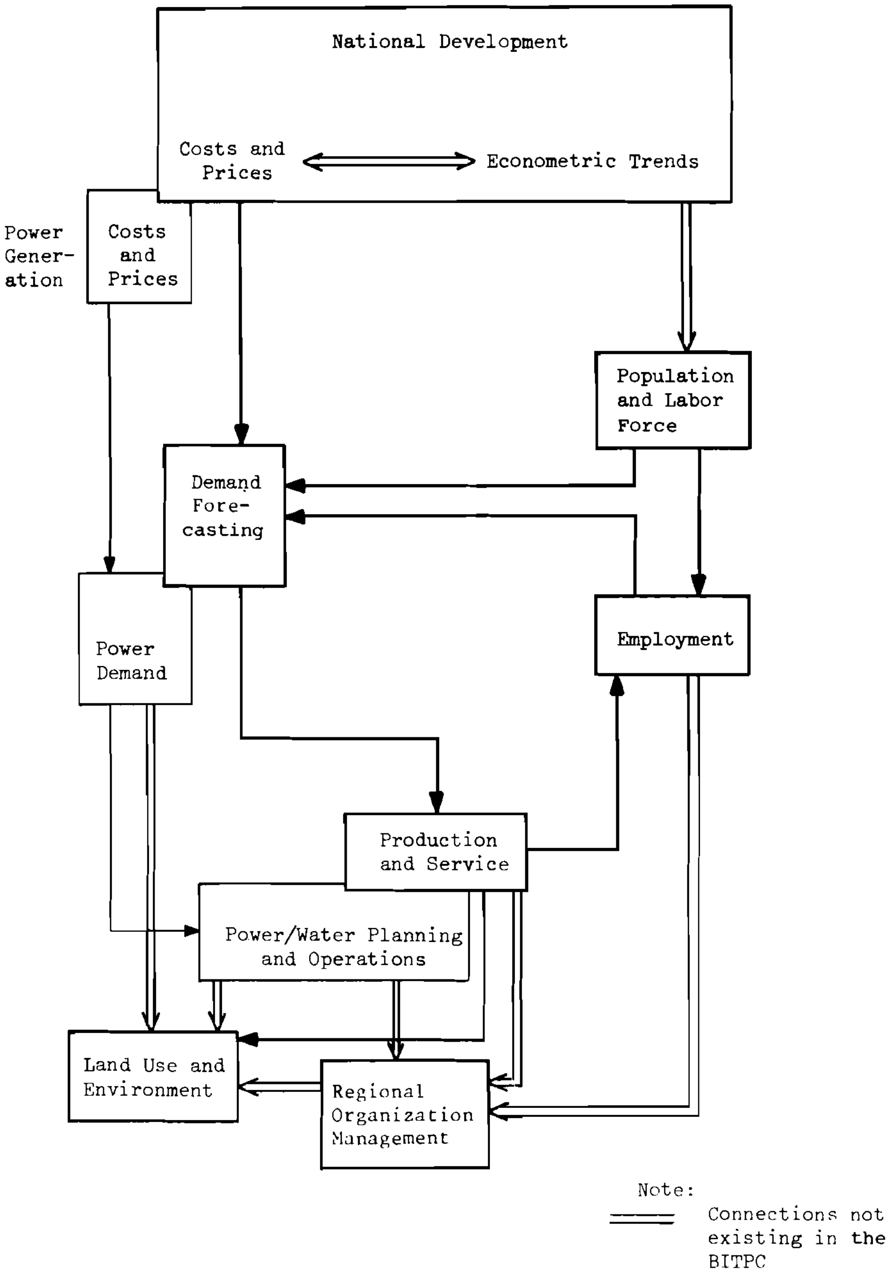


Figure 8. Regional model system, TVA.

the analogous system was much bigger in scope, and was meant to provide optimal planning alternatives to be implemented through the use of adequate measures. On the other hand, the TVA model system extended down to the operational level as a result of the operational nature of the TVA's activities; this was not the case with the BITPC, which was exclusively the object of planning.

Differences between the contents of seemingly similar structures of model systems can be illustrated by the example of a "Needs-Demands" module. In the case of the TVA, the demand for various commodities is projected on the basis of costs and prices forecasted by national econometric models, and on the basis of social-regional forecasts. In the BITPC system, the module is broken down into two parts. In the first part, the pattern of so-called industries or regional specialization is determined, i.e., the quota of production in branches selected on the basis of national importance. In the second part, the previous requirements are summed up with those resulting from social infrastructure formation needs and from other industries in the region. The information flow in the BITPC case has, then, a fully normative character.

The next step in embedding the model system in the decision process consisted in identifying the managerial inputs to the models and the use of their results. Assumptions made prior to activating any model, and the decisions based on its results, are not yet formalized (or may not be formalizable) human actions. By interconnecting these actions (decisions) of management with model calculations, we formed the "system of decisions and calculations"--i.e., the tool for assessing management/model interrelations.

The Role of Model Systems in the TVA and the BITPC

The use of models should be related to the requirements of the planning process. In our decision-analytic studies of the TVA and the BITPC, we identified the hierarchies of goals and the opportunities and decisions in the development of both regions; Figure 5 is one example. In the Bratsk-Ilimsk case, a consistent system of models was created that enabled us to analyze regional strategy alternatives and identify optimal plans at various levels of aggregation. This regional planning system is, in fact, a part of a greater concept of a national model system for planning at all levels and for all time horizons (Figure 7). At present, the regional system is operated in relative separation from the national-level modules. It is used for pre-plan studies of long-range planning of territorial entities of the territorial production complex type. The model runs are requested by the planning bodies at various levels, and serve mainly for elaborating so-called "general schemes of allocation of productive forces"--i.e., the main guideline for planning the spatial dimension of economic development. The system's operation is divided into stages that elaborate the plans with increasing detail. The stages correspond to iterations of procedure that are formed by closed loops of modules in the model system structure (Figure 7).

This system is not regarded as a main tool for long-range planning, but is capable of giving clear-cut recommendations for siting and determining the amount of different production and infrastructure activities. It has been run for data on various territorial units within and in the vicinity of the BITPC, and in several cases the proposed planning alternatives differed from those obtained by using traditional methods.

In the BITPC, the regional planning system has been implemented and thoroughly tested. However, in the TVA, the need for an analogous system has appeared only recently, and the system, having only forecasting and not planning purposes, is now being created.

In both regional cases, the leading sector of the regional economy is the power production. Thus, it is of paramount importance to be able to choose properly the direction of the development for this sector; and, in fact, in recent years the TVA management was bound to make substantial decisions concerning the development of its power capacity. This problem has been discussed earlier in this report (Figure 4). In this particular process of power generation strategy choice, some individual models were used--for forecasting of power demand, assessing future generating capacity, siting, etc.--in order to assess the consequences of alternative courses of action. But the need to create the consistent, comprehensive system of models for power planning purposes was realized only after the decision had been made. This system will be closely connected in its "upper-level" part with the regional forecasting system mentioned earlier. "Below" the planning system for power there is an operational system that has existed for several years, for power generation and water control scheduling and operations for time horizons ranging from one year to one half-hour or less. This system has never been designed as a whole; moreover, its elements operate by two different organizational units within the TVA: the Office of Power, and the Division of Water Management. However, well-defined embedding of individual models that constitute the system in the planning process allows one to view this system as a coherent whole within the decisions and computations framework. The question of the future is, how will this consistent operational system be linked up with longer-term power planning systems?

CONCLUSION

We began by stating our research goals: to describe the role of models in planning and decision-making in the TVA and the BITPC, and to assess possibilities and needs for further integrating modeling and decision-making. To summarize, our main conclusions are as follows:

The role of models in the TVA and the BITPC. In spite of the apparent similarities of the TVA and the BITPC model systems, as for example, the general structure and the existence of two major subsystems (such as the region as a whole and the leading power sector), the role of models and hence of the methodologies used for their development differ substantially, mainly due to differences in the socio-economic and organizational setting (Figure 6). In the TVA, the regional socio-economic subsystem has only forecasting purposes, while in the BITPC, it has definite planning and optimization aims. In the BITPC, there is a consistent, comprehensive system for detailed, pre-planned studies of long-range planning without, however, evident linkages with shorter-term models in, say, the power sector. In the case of the TVA, such linkages were created mainly as a result of the operational nature of the system.

Opportunities for integration. Some of the opportunities for integration have already been realized in the BITPC and the TVA. The BITPC system appears to be well fitted into the structure of long-range planning in the USSR, although the system was created to operate outside the planning procedure. In the TVA, the integration is best realized at the lower level of management, where the models were operational for some time.

Need for further integration. It would be advantageous if the BITPC system could be linked with, or extended to include, the shorter-term and operational considerations, and indeed such efforts are being made on a somewhat limited scale. In the TVA, the trend is to build bigger interlinked systems for managerial purposes, but integrating these systems into the managerial decision-making process requires much work.

It is our general point of view that in both cases--as in many others--there exists a substantial need for linking descriptive or optimizing models and model systems more strongly to the decision process. Such integration could possibly be achieved by modeling the decision process through decision theoretic models of the decision maker's values and opinions, along the lines of decision analysis. The formal representation of the decision process would then allow one to fit models of the decision object more tightly into decision-making, either as impact models (that describe or forecast the behavior of the decision object in terms relevant to the decision maker), or as optimizing models (that use the inputs of decision analysis for structuring and parameterization purposes).

References

[1] Edwards, W., Conservatism in Human Information Processing, in B. Kleinmutz ed., *Formal Representations of Human Judgement*. Wiley, New York, 1968.

[2] Slovic, P., *From Shakespeare to Simon: Speculations and Some Evidence About Man's Ability to Process Information*, Research Monograph 12, Oregon Research Institute, Eugene, Oregon, 1972.

[3] Granberg, A.G., and M.K. Bandman, Simulation of the Territorial Industrial Systems: Case Study of the Angara-Yenisei Region, in Hans Knop, ed., *The BITPC Experience: Proceedings of the Second Conference on Retrospective Case Studies of Large-Scale Planning Projects, March 22-26, 1976*, International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

[4] Courbis, R., and J.C. Prager, Analyse regionale et planification nationale: le projet de modele Regina, *Les Collections de l'INSEE*, Series R, 12, (1973).

[5] Wilson, A.G., *Urban and Regional Models in Geography and Planning*, Wiley, New York, 1974.

[6] Tou, J.T., Learning, Prediction, and Decision Making in Urban Systems Analysis, *Man and Cybernetics* (1974).

[7] Kulikowski, R., Optimization of Decentralized Regional Supply and Delivery Models, *Bull. Pol. Acad. Sci.*, 31 (1973).

[8] Kornai, J., Models and Policy: Dialogue Between Model Builder and Planner, in C.R. Butzev et al., eds., *Economy-Wide Models and Development Planning*, Oxford University Press, London, 1975.

[9] Sokolov, V., M. Valasek, and I. Zimin, *An Interactive System for Experimenting with Development Planning*, RM-75-69, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[10] Peschel, M., and C. Riedel, *Polyoptimierung: Eine Entscheidungshilfe für ingenieurtechnische Kompromisslosungen*, VEB Verlag Technik, Berlin, 1976.

[11] Raiffa, H., *Decision Analysis*, Addison Wesley, Reading, Mass., 1968.

[12] Keeney, R. and H. Raiffa, *Decision Analysis with Multiple Conflicting Values*, Wiley, New York (forthcoming).

[13] Straszak, A. and J.W. Owsinski, The Instrumental and Informational Basis of the Planning and Decision Making Process, in Hans Knop, ed., *TVA Field Study Report* International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

[14] Knop, Hans, ed., *The BITPC Experience: Proceedings of the Second Conference on Retrospective Case Studies of Large-Scale Planning Projects, March 22-26, 1976*, International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

Discussion

(R. Ostrowski, Rapporteur)

The discussion centered on integrated regional development (IRD), organizational analysis, and model application in the decision-making process. The presentation on the study of organizational aspects of regional development programs gave preliminary findings from five cases. The study was evaluated as an important attempt to apply organizational theory to regional projects. Further research on this subject could provide valuable results for policy makers.

The question arose whether the five cases were representative of actual and future regional development programs, especially those implemented in highly developed countries. The suggestion was made that future studies consider more explicitly the role of different socio-economic systems in the organization process of IRD programs. This is important especially for the transfer of experience from case to case where there are differences in the degree of participation of local and regional groups in the planning and decision-making processes, and in the capability of existing organizational units to use the experience.

One important point was made about the framework of organizational studies. The type of organizations needed for implementing an IRD program should relate to the content of the planning process. The analysis of organizational structures should take into account the goals, policies, strategies, and instruments of the various regional projects.

Two suggestions were made for further studies of the organizational structure of IRD programs. The effectiveness of organizational forms of IRD programs in terms of goal achievement should be evaluated. It is essential to be able to predict the next stage of program development, as defined by goal evaluation on the basis of the previous stage. The second suggestion concerned investigating time lags between changes in the planning process and changes in organizational structure, taking into account the legal and institutional systems and other characteristics of the national setting.

Another issue discussed was the role of program designers, management interpreters and researchers who create ideas within the management development process. Understanding the behavior and motivations of these "social engineers" is important for investigating the organizational dimension. The relationship of these social engineers and the organizational controllers who provide guidelines for their work should be studied. The research should determine the positive factors in these relationships.

Several comments were made about the role of mathematical models and computer applications in the decision-making process of IRD programs. The two regional programs discussed in the foregoing presentations have achieved valuable results, due in part to the application of formal methods and computational techniques. This occurred even though the development of the models started later than the development of the programs, and the application of the models in the two cases differed greatly.

Support was expressed for the IIASA clearinghouse function with respect to models and systems in planning and management. These activities might ultimately lead to the elaboration of appropriately generalized planning tools for IRD purposes.

The discussion then focused on the role of people in the planning and managerial processes. The first point raised concerned incorporating various social interests in the modeling of the decision object. The interaction between the formal and informal, technical and human aspects of the decision-making process was considered, along with the problem of including in the process those individuals and groups affected by it. The second point dealt with the interlinking of models within the system, and the need for considering possible human interactions with the models. Interlinkages within model systems and ways of integrating submodels differ from case to case. Nevertheless, there should always be provisions for possible human intervention and end-user interpretation of variables and results of various subunits, i.e., creating man-based rather than automatic linkages.

Another question concerned the appropriate choice of research objects, based on joint considerations of model systems and decision theoretic approaches. The proposal was made to consider large industrial undertakings as better structured and more readily quantifiable than IRD programs. This problem was thoroughly discussed during the second part of the session on the steel case.

The discussants then turned their attention to the third issue--approaches to the study of integrated regional development. IRD programs deal with highly complex socio-economic systems, and include various problems concerning the development of industry, agriculture, technical and social infrastructure, human resources, and other economic and social factors.

An interdisciplinary approach is needed for studying management problems connected with IRD programs. This can provide valuable results for many countries. The selection of the large-scale planning projects for investigation at IIASA was generally supported during the discussion. Suggestions were made concerning the content of these studies and the possibilities for transferring the experience gained.

IRD programs differ from programs for the physical development of subareas within countries. Criteria for evaluating these programs after they have been designed and implemented should be established. These criteria should cover such factors as regional articulation of national (or international) exogenous factors, intersectoral relations, development of coordinating mechanisms, and relations between the program's boundaries and the existing administrative structure.

The major emphasis of the cases in the foregoing presentations was on developing natural resources. This is typical for rather underdeveloped regions. The question arose whether the approach used in these cases and the experience obtained could be transferred to regional programs in highly developed areas. Projects in the latter areas are characterized by changes in the structure of already developed or settled regions, expressed by the transfer from the primary to the secondary structure, or by the shift from industry to service activities--all of which is greatly influenced by the existing population.

The selection of the two main cases--the Tennessee Valley Authority (TVA), and the Bratsk-Ilimsk Territorial Production Complex (BITPC) was in part restricted by IIASA commitments. However, taking into account the comprehensive approach used in both cases and the results obtained, this experience is highly relevant to other projects.

Another point was raised in connection with the approach for studying the various cases. A comprehensive approach involves mainly organizing field studies and analyzing both formal and informal records set up on the basis of broad communication with various managerial bodies, units involved in the program, organizations and agencies outside the program, and the public.

The Steel Case: Conceptual Framework and Hierarchical Control Approach

I. Lefkowitz

I would like to summarize some of the salient features of the Integrated Industrial Systems (IIS) project--its goals, orientation, conceptual approach and accomplishments.

First, I want to pay my respects to the late Professor Cheliustkin, who shared with me the leadership of the project and who passed away a few months ago. Cheliustkin brought to the project many years of experience in the area of systems control, with specific expertise in its application to the steel industry. He was enthusiastically committed to the goals of the research program, and devoted considerable energy and effort to their fulfillment. He exemplified that spirit of international scientific cooperation--particularly East-West--that Howard Raiffa referred to in his remarks.* As a result, we developed a good working relationship as project co-leaders, and a warm personal relationship nourished by mutual respect for our commonalities as well as our differences.

As Hans Knop mentioned in his introduction, I will restrict my discussion to the main activity of the IIS project in the period 1974-1975, during which I was directly involved in the project.

The project began to be formalized as a result of a planning conference held in October 1973. The participants generally agreed that research on integrated control of industrial systems was an important activity area for IIASA: they also felt that the project should focus on a specific industry in its initial effort so that the applied aspects of the systems analysis would be both appropriate and realistic. Specifically, the steel industry was proposed as a first candidate for study by the IIASA group.

The IIS project perceived as its overall goal the application of the systems approach to the integration of information processing, decision-making and control functions of industrial systems, in order to achieve an optimal overall performance. Among the motivating factors for the integrated systems approach were the increase in productivity and operating efficiency; the improvement of product quality (and quality control); the effective utilization of resources (e.g., raw materials, energy, labor); the assurance of compliance with technological and environmental constraints; the ability of the plant or the external environment to adapt to time varying conditions; and the maintenance

---

*See Volume 1, *Creating an International Research Institution*.

of system integrity, i.e., the assurance that the production facilities remain viable in the face of unusual or catastrophic events. (This is similar to the concept of resilience discussed by W. Häfele* and by C.S. Holling** in their presentations.)

The project was formally instituted around the middle of 1974; its immediate objectives were to develop some general concepts of integrated systems control, e.g., multilevel and multilayer hierarchical control concepts; to study and evaluate international experiences in integrated systems control; and to develop the case study of the steel industry.

Among the results of the first year's effort are the following:

- Preparation of a state-of-the-art review of integrated systems control, as applied to the steel industry, based on visits to steel works and research institutes in many different countries, discussions with leading practitioners and theorists in the field, literature reviews, etc.

- Formulation of new results concerned with the temporal multilayer control hierarchy; these results were strongly motivated by the steel study.

- An international conference on the state-of-the-art review of integrated systems control in the steel industry, held at IIASA on 30 June to 2 July 1975.

There were several reasons for selecting the steel industry as the first system for studying the integrated systems approach. First, steel is a basic industry that is of direct interest to most of the countries supporting IIASA. Second, it is a very complex industry with a wide variety of different types of processing and manufacturing facilities, hence it is rich in the broad spectrum of systems problems likely to be encountered in industrial applications. Third, and most important, the steel industry at present represents perhaps the most advanced area of technology with respect to applying computers for real-time information processing and decision-making. Thus, it was felt that the steel industry provided a good base for our investigation.

Having settled on the subject of steelmaking, the next step was to carry out a state-of-the-art survey based on information in literature, plant visits and discussions with various

---

*See Volume 1.

**See Volume 1.

experts in the field. Our major objectives were to determine the leading edge of current planning, scheduling, and production control functions and their integration as practiced in advanced steel works worldwide to identify the problem areas and limitations inherent in current practices; and to identify people and information sources (e.g., simulation models) that could be useful in further developing the project.

As stated earlier, the primary purpose of the survey was to identify *what are* the most advanced practices in planning, scheduling, and production control, and *how these are implemented and coordinated* to achieve systems integration.

In general terms, the steelmaking process is simple. Iron is extracted from iron ore by heating the ore together with coke in a blast furnace. The resulting molten iron contains many impurities that are removed by reacting with oxygen in a basic oxygen furnace (BOG). The produce is called steel; it is formed into slabs that go through a variety of processes, involving all kinds of rolling, shaping, and heating and cooling operations to produce the various kinds of products typical of the industry.

In actuality, the system is enormously complex. There are many operations in series, one dependent on the other. There are also multiple paths of great variety leading to a tremendous degree of freedom, i.e., decision variables to be determined by the controller or the decision maker.

This induces many problems with regard to system structure and organization, the tracking of materials in process, transmission and handling of huge quantities of information, data bases, and so forth. In my discussion, I will relate only to the decision-making and control aspects of the problem.

There is considerable interaction among the processing units. For example, in Figure 1 we see the block diagram of a small part of the steelmaking process consisting of the basic oxygen furnace, where iron is converted to steel; the continuous casting machine (CCM), where the molten steel is cast into slabs of specified width and thickness; the slab yard, where the slabs are stored until scheduled for rolling; the hot strip mill (HSM), where the slabs are rolled into thin strip according to customer specifications; and the coil storage yard, where coils of steel strip are stored until ready for the next operation or shipment.

Each processing unit has associated with it a control unit responsible for the proper operation of the process, in relation to locally defined objectives and constraints.

There exist various conflicts among the control objectives of the processes identified in Figure 1. For example, the HSM scheduler wants to maximize the throughput of a steel strip. However, this throughput is greatly affected by constraints imposed on the sequence of slabs rolled, and these constraints are

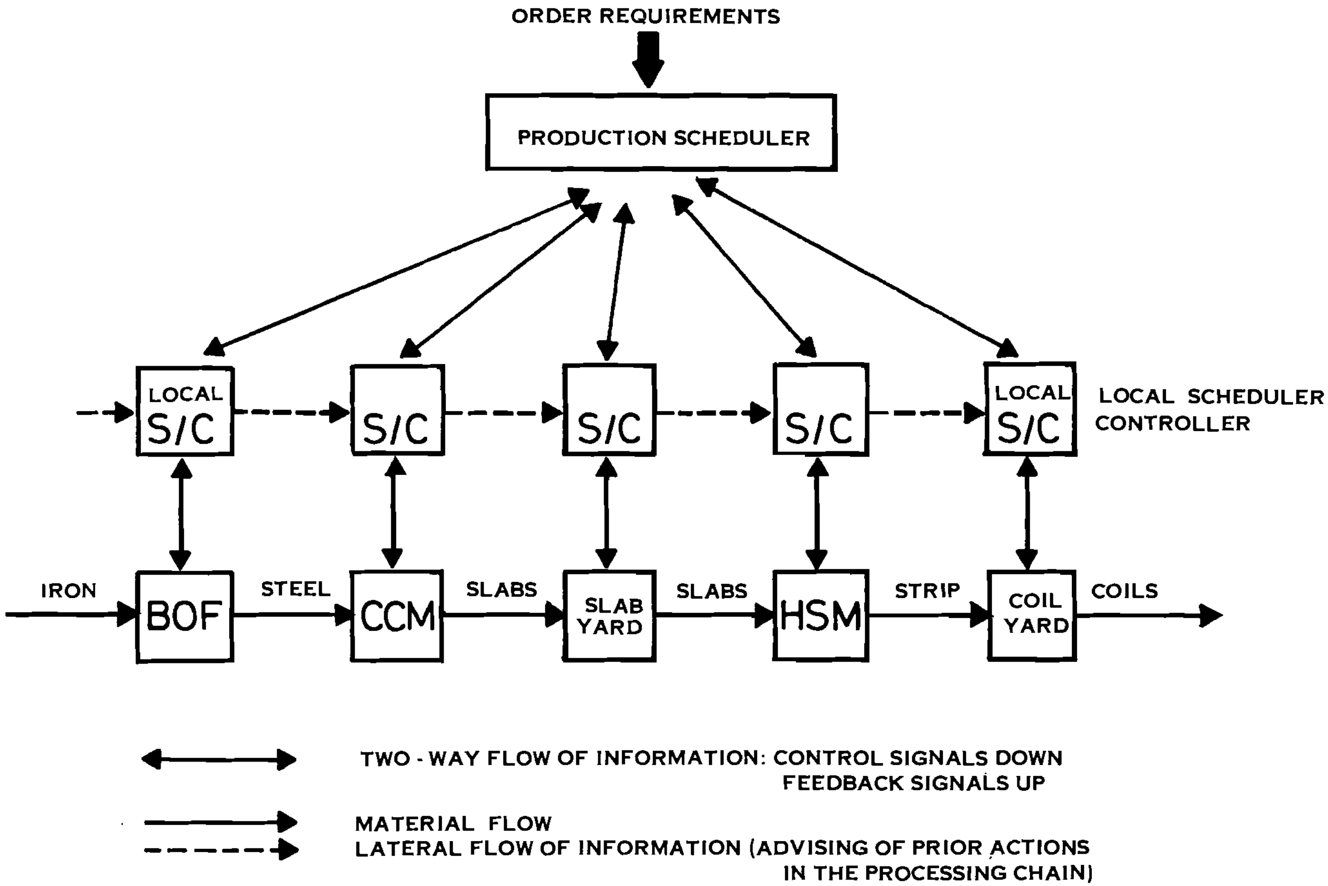


Figure 1. Part of steelmaking system.

related to the period of roll changes in the mill--six to eight hours for working rolls, eight to ten days for backup rolls. Thus, to maximize mill efficiency, many changes in slab dimensions and the steel composition would normally be required. However, the BOF process is still very much of an art, and every time there is a change in grade there is uncertainty with regard to the ability to satisfy grade standards. Hence, the BOF scheduler wants to minimize the number of grade changes. For similar reasons, the CCM scheduler wants to minimize the frequency of changes in slab dimensions, also in conflict with the HSM scheduling objectives.

A natural solution to the problem is to decouple the HSM from the preceding processes through a slab storage facility, the slab yard of Figure 1. However, such factors as in-process inventory costs and costs associated with weathering limit the time that slabs are stored.

The objective of the production scheduler is to coordinate the local schedulers/controllers so that the system operates at, say, minimum cost consistent with delivery schedules, technological constraints and coupling requirements.

Another example of interaction is shown in Figure 2, which depicts an expansion of the HSM process into a furnace subsystem and a rolling mill subsystem. A coupling variable of interest is the slab temperature, since the efficiency of both subsystems is affected by this variable. Thus, an increase in the slab temperature will tend to increase the fuel requirement per slab, and may also decrease the furnace capacity. On the other hand, the higher slab temperature may result in less power consumption by the rolling mill; it may also have an effect on the throughput rate. Clearly, there is a need for coordination, i.e., specification (at a higher level) of the slab temperature to be achieved by the furnace controller, so that overall performance of the HSM system is maximized. Note that the furnace subsystem controller can proceed to optimize furnace operation (say, to minimize fuel consumption) with the specified slab temperature acting as a constraint. Similarly, the mill controller may optimize mill performance based on a feed forward of actual slab conditions (including temperature), with given final strip conditions as constraints to be satisfied.

These experiences and observations suggest a multilevel hierarchical control structure (Figure 3). The plant to be controlled is generally complex, nonlinear, multivariable, and subject to many kinds of constraints. As a result, it may be extremely difficult to obtain a solution for the overall control problem (e.g., to derive a control algorithm for optimum system performance). The strategy is obvious: we decompose the plant system into a set of less complex subsystems, each with its own controller. Note that, in addition to the control

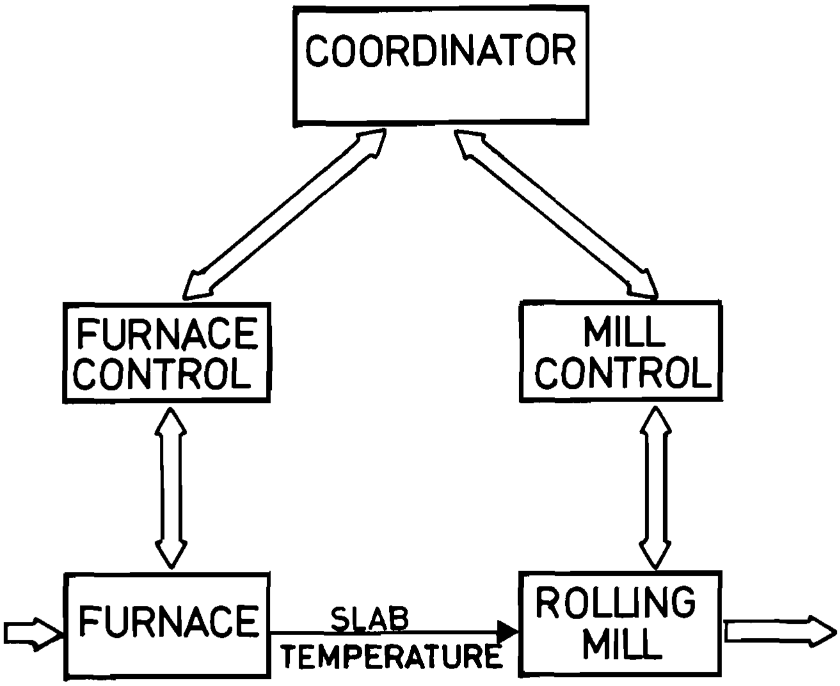


Figure 2. Expansion of the hot strip mill (HSM) subsystem.

inputs, each subsystem is subject to interaction inputs generated by other subsystems, and also to various external disturbance inputs. The local controller responds to information describing the state of the subsystem, as interpreted through a local model and a local objective function.

Since the subsystems are complex, decentralized control as described will not necessarily be compatible with overall system objectives. Thus, it is necessary to coordinate the actions of the local controllers via a second-level controller. The coordinator defines targets, constraints or other means for influencing the first-level controllers, based on information from the system which, in effect, relates to the neglected interaction variables. This two-level structure expands readily to n-levels, as shown in Figure 4.

There is a large body of literature on multilevel theory for decomposition and coordination. We shall not go into it here except to comment that, while there is broad applicability of the underlying concepts of the theory and its qualitative aspects, there remains a substantial gap between its quantitative and analytical contributions and practical applications.

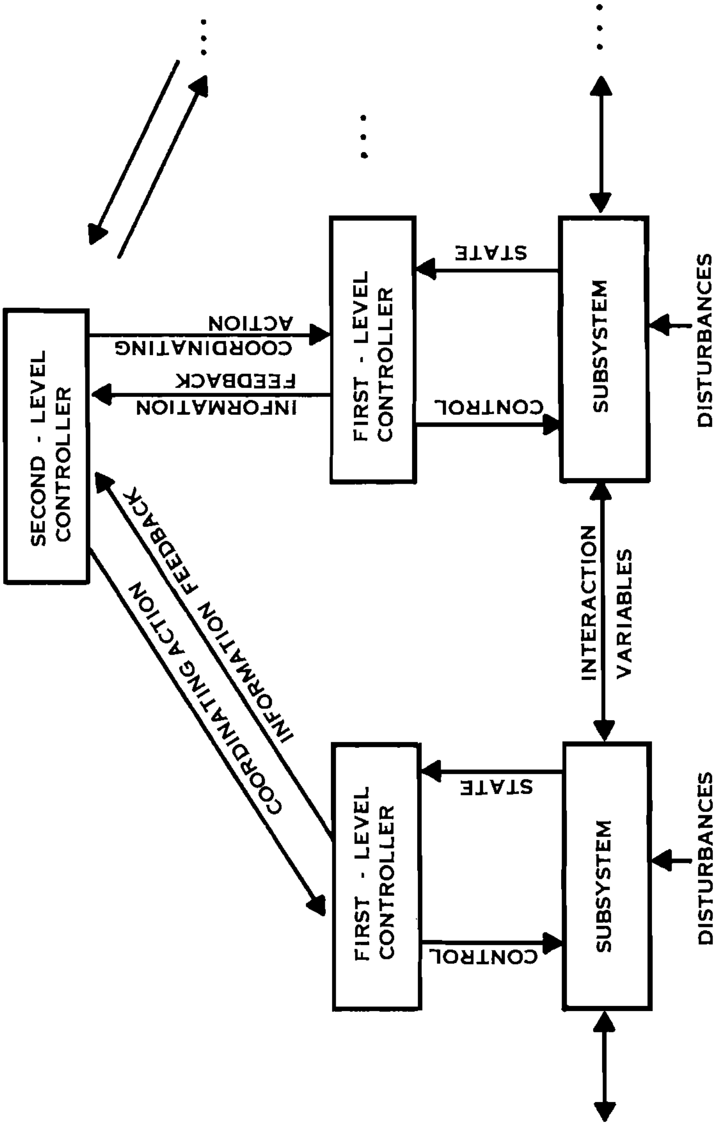
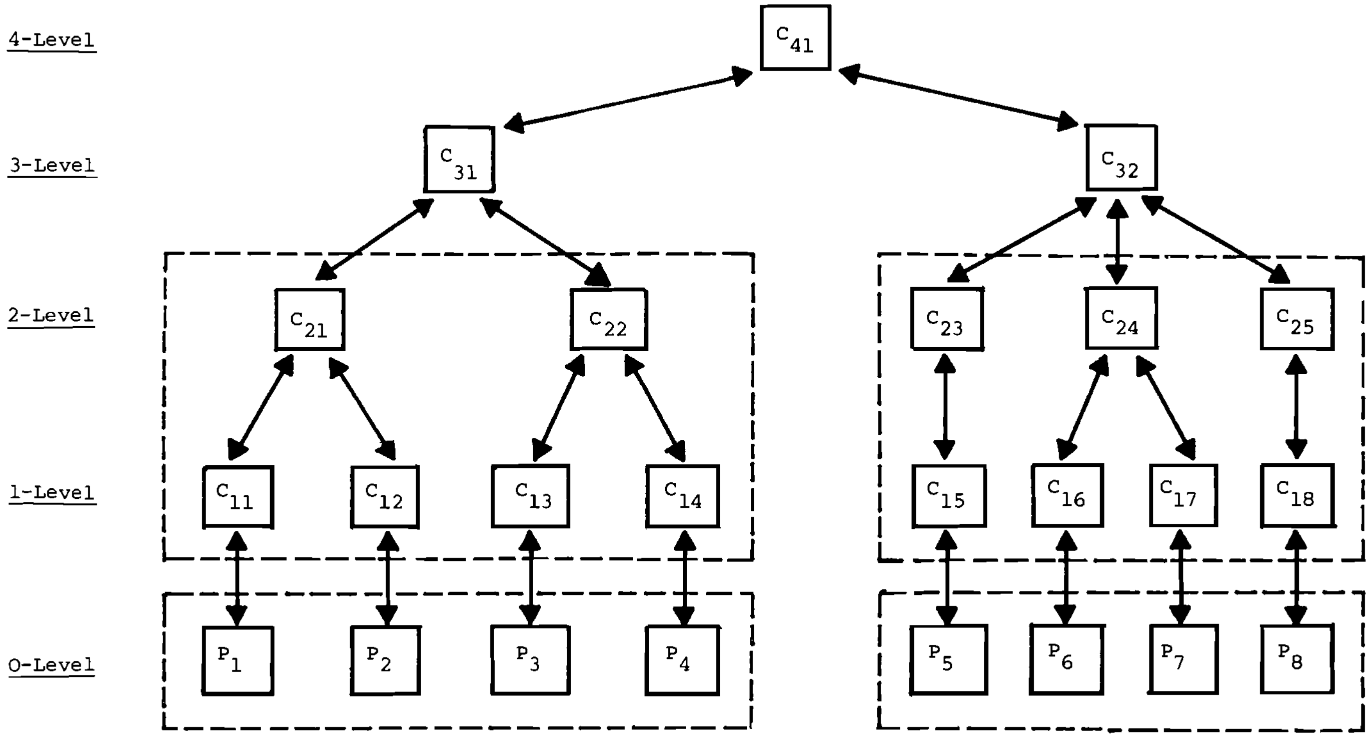


Figure 3. Two-level control hierarchy.



C_{ij} = j^{th} controller at the i^{th} level.

P_i = i^{th} controlled sub-process.

Figure 4. Multilevel control hierarchy.

In summary, the multilevel control hierarchy converts a large complex problem (that cannot be handled) into a set of more easily managed small problems.

In this process, the system is decomposed along lines of weak interaction, and the resulting subsystems are coordinated to reconcile local control objectives to overall goals. Inherent the structure are feedbacks that compensate for changes in interaction variables, disturbance inputs, and time-varying parameters. Moreover, the subsystem controllers act to satisfy local constraints and to optimize with respect to local performance criteria. In the multilevel structure, each controller serves to maintain aggregated variables at values determined by its supremal unit, and, in turn, specifies the constraints, criteria, etc., for its infimal units.

In examining the problem of integrated systems control as applied in the steel industry, we noted a spectrum of control functions (where control is interpreted in its broadest context) characterized by temporal attributes. Thus, Figure 5 shows a temporal ordering of decision-making and control functions commonly identified in terms of planning, scheduling and control. The time scales associated with these functions range from a few minutes (characterizing the response times of the technological processes) in the case of process control, to periods of several years for long-range planning.

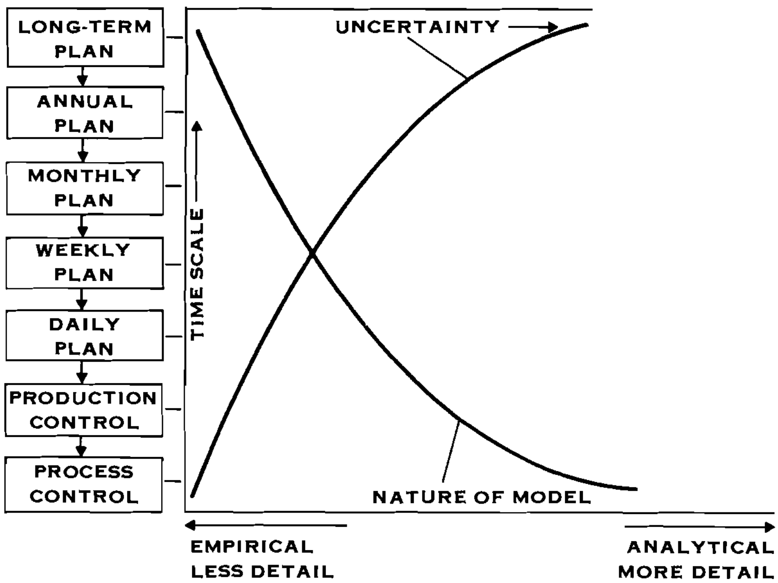


Figure 5. Control functions ordered according to time scale.

There are also orderings with respect to the nature of the models and the degree of uncertainty embedded in the information processing, as shown qualitatively by the curves in Figure 5. These attributes have direct bearing on the conceptual formulation of the temporal control as characterized by Figure 6.

Referring to Figure 6, a multilayer control structure is defined where the distinguishing feature is the period of control action T_k associated with the k^{th} layer controller, with the assumption that

$$T_{k+1} > T_k , \qquad k = 1, 2, \ldots, L-1,$$

where L denotes the total number of layers in the hierarchy.

Each controller has as inputs the current state of the plant and its environment, relevant to the local decision-making problem; targets and constraints imposed by the supremal controllers; feedback from the infimal controller that describes the results of prior control actions and serves as a basis for updating subsequent control actions; and identified contingency events that call for an urgent or special response. The output of each controller may include decisions and actions to be implemented directly on the system, targets and constraints for the next lower-layer controller; and criteria for corrective action and feedback from the infimal controller. The controlled system communicates to the controllers via sensors and information processing elements (e.g., means for filtering, prediction and aggregation of data). The feedback path from controllers to the plant is completed through various actuating means ranging from completely automated devices to operator actuation via appropriate man/machine interfaces.

As an illustration of how this conceptual structure fits certain aspects of steelmaking practice, we might consider the k^{th} layer to be concerned with the annual planning process. The plan is generated based on general policies and goals set by the long-range plan; on information from sales and market groups on which forecasts of demand and supply are predicted; and on information from the plant identifying any significant changes relating to production capabilities and constraints. An output of the annual plan defines the guidelines for the monthly plan in terms of, say, production goals for the next month. It may also define for the infimal decision maker the criteria for assessing the validity of the model, used in the light of actual experience.

The feedback is an important part of the hierarchical structure. Deviations of actual behavior from that predicted by the model may be compensated in a variety of ways: small deviations are handled by a modification of previously determined target values; large deviations may trigger a recalculation of the supremal decision problem (analogous to scheduling with

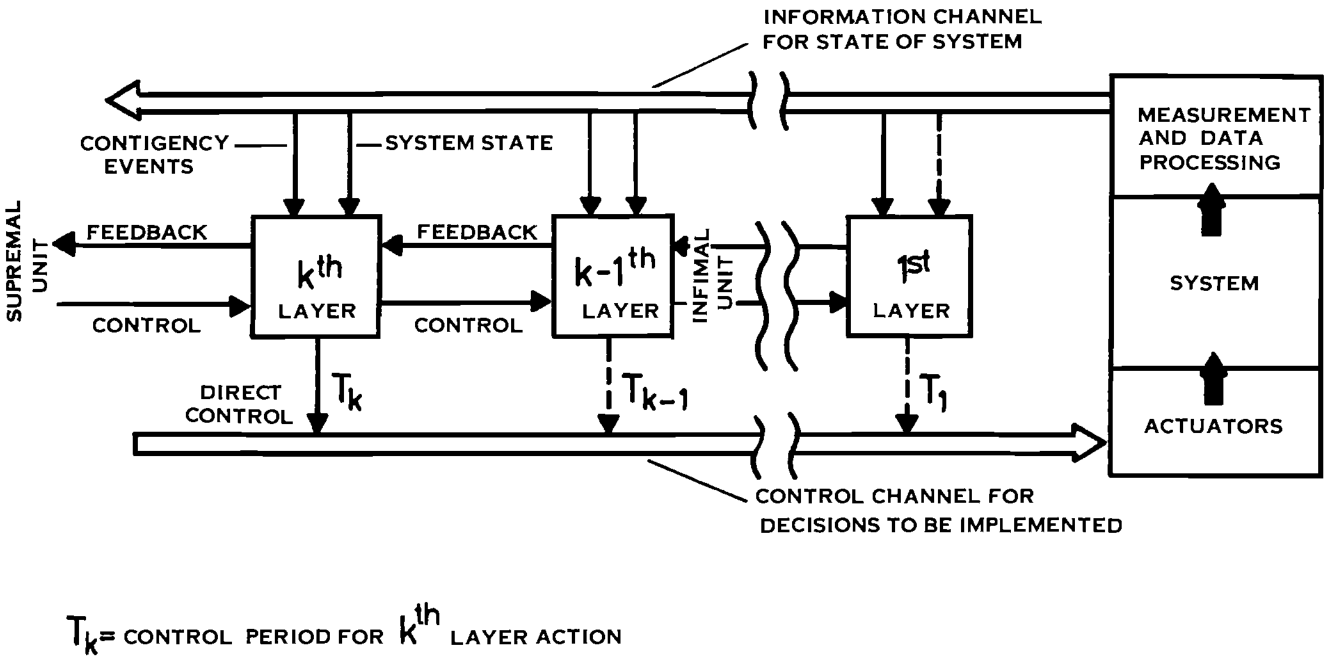


Figure 6. Temporal multilayer control hierarchy.

rolling horizon); and abnormally large and persistent deviations may lead to an adjustment of the model parameters (and perhaps structure).

We note that certain decisions are to be implemented directly by the k^{th} layer, e.g., ordering raw materials and contracting for labor. Finally, provisions must be made for emergency inputs, e.g., a strike or a major equipment breakdown that would require immediate and urgent reassessment of the previously defined plan.

Integral with the temporal hierarchical structure is an ordering with respect to the degree of aggregation of the model used and the information provided. In general, the more variables explicitly incorporated in the model, the more closely the model will reflect the actual behavior of the system, at the expense, however, of greatly increased complexity. This suggests the suppression of variables whose effects on system performance tend to average out over the control period, and the aggregation of the remaining variables with respect to the decision-making horizon. Thus, we want to define the model for the k^{th} layer control function and the associated period T_k, so that the net effects of deviations of the model variables from those actually observed for the operating system, averaged over the period T_k, do not exceed some established error tolerance. Note that T_k will generally be restricted to some finite set of feasible periods determined by other considerations, e.g., conformance with the normal work day or work week.

As an example of the foregoing, we cite the heating furnace previously referred to. At the process control layer, the fuel input rate to the furnace is varied so as to maintain a specified temperature profile. The model used in determining this profile, however, tends to aggregate the effects of miscellaneous disturbances and the resulting transients; the temperature targets are based on the nature of the load and mean operating conditions. At the scheduling layer, the model assumes a mean furnace temperature profile, but determines the cycle time for the furnace as a function of the charge. Finally, the planning model aggregates the cycle time in its determination of furnace production capacity.

Of course, the model simplifications are predicated on a variety of implied conditions and constraints, e.g., the technological characteristics of the equipment, the distribution of load characteristics, the nature of external inputs, the performance criteria, etc., remain relatively invariant. Any significant change relative to these assumptions will call for an updating of the affected models.

In summary, the temporal multilayer control hierarchy partitions the control problem according to relative time scales.

The structure provides a *basis for aggregation* of models and variables; a *means for reducing the effects of uncertainty* with respect to future inputs and events; a *mechanism for feedback* of experience; a *criterion for distributing information/data* according to local needs; and *a basis for allocating local details and control tasks* to appropriate units in the hierarchy.

The multilayer functional hierarchy (Figure 7) represents a third ramification of the decision-making/control hierarchy. The functions represented here are basic to all manifestations of real-time control processes; these are identified below.

The *first-layer* (direct control) *function* implements the decisions of the second-layer (optimizing) function. It also serves to suppress both various disturbance inputs with respect to the second-layer problem, and transient effects so that static (rather than the more complex dynamic) models may be used for the higher-layer problems to good approximation.

The *second-layer optimization problem* is solved in terms of a simplified model of the system. Part of the simplification is realized by restricting consideration to only the dominant disturbance effects relevant to the performance objective.

The *third layer* (adaptive) *function* provides for updating of the parameters of the model to reflect current experience with the operating system. This means that factors that are not of primary significance, or that tend to vary slowly or change infrequently, can be eliminated from the problem formulation since these factors (disturbances) may be compensated through the adaptive function.

Finally, a *fourth-layer* (evaluation and self-organization) *function* is identified as the mechanism for inputting into the system external considerations, e.g., economic factors, contingency occurrences, and plant changes, as well as general evaluations of system performance that may lead to modifications of the structure of the control system or of the models used.

There tends to be the same general ordering with respect to time scale and various other attributes, as mentioned earlier with respect to the temporal hierarchy.

To summarize the functional multilayer control hierarchy: the original problem is replaced by a set of simplified and approximate subproblem formulations; integration of the subproblem solutions to satisfy the objectives and requirements of the original problem is then achieved via information feedbacks from the operating system.

Finally, we have abstracted the essential features of an integrated control system for a modern Japanese steel works (Figure 8). This installation represents the leading edge in current technology; however, it is not atypical of current

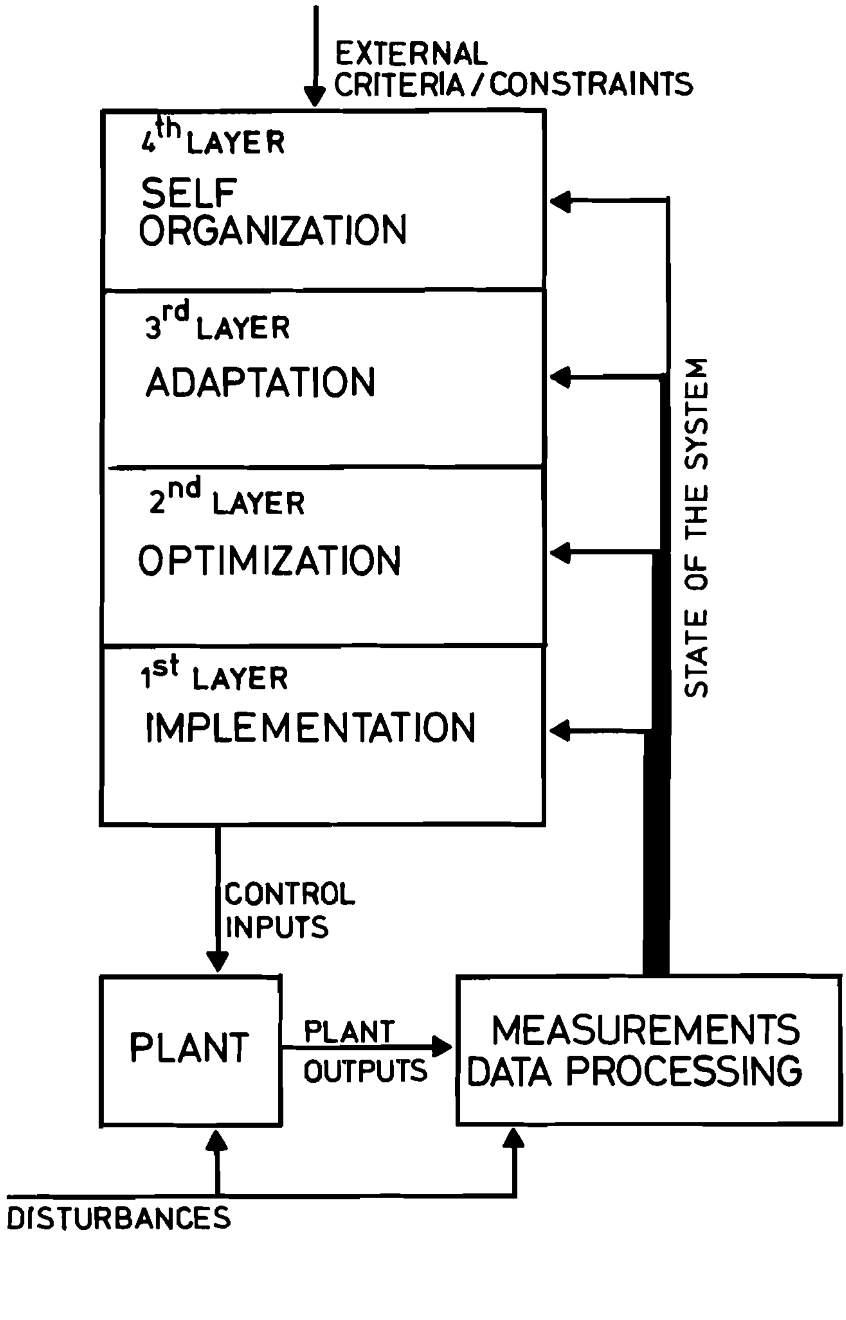


Figure 7. Multilayer functional control hierarchy.

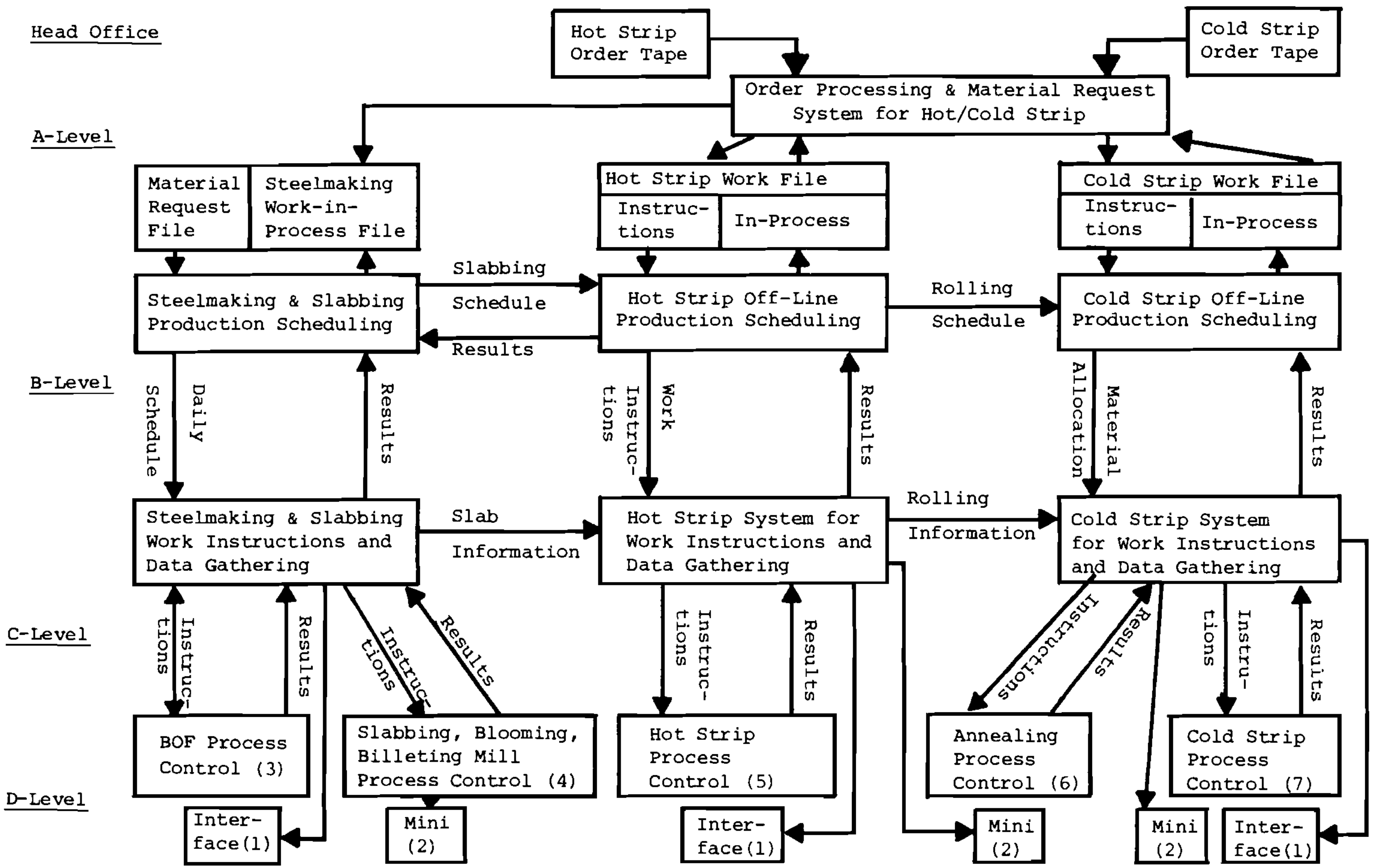


Figure 8. Part of integrated computer control system for steel works.

Notes:

(1) Man Machine Interface: Includes keyboard, printer, display panel, auto I/O signal.

(2) Minicomputer: Positioning control and sequence control.

(3) BOF Process Control: End-point control, charge calculations, operating instructions, production control information, and technical report.

(4) Slabbing, Blooming, Billeting Mill Process Control: Scheduling, combustion control, mill setting and sequence control, and production control information.

(5) Hot Strip Mill Control: Reheat furnace control, mill pacing, mill setting, adaptive control, spray control, coiler setup, and technical report.

(6) Annealing Process Control: Combustion control, timing control, production control information, and technical report.

(7) Cold Strip Mill Control: Mill setup, adaptive control, tension control, automatic sequence control, and technical report.

developments in the industry. Figure 8 embraces only a part of the system; most of the detail has been deleted to point up system aspects relevant to our discussion as they have been manifested in real applications. In particular, the hierarchical structure is explicit. The information flow paths are well defined, with instructions/controls proceeding down the hierarchy and information and feedback on results going up. Embedded in the system are adaptive functions at every level--some formal and explicit, others informal and implicit. Moreover, the system is highly computerized, but this does not mean that it is completely automated. The human being plays an essential role at all levels of the structure: as decision maker where judgmental and experience factors are difficult to quantify and model; as overseer to ensure that abnormal occurrences are properly perceived and appropriate corrective actions are taken; and as one who carries on, in general, all tasks and responsibilities to which his talents are particularly suited.

Thus, references to the control and decision-making functions in the various hierarchical structures were not meant to imply that these functions were to be carried out automatically. Indeed, we assumed, in general, a working relationship between the human being and the computer-based system. This requires an effective set of interfaces for providing the operator/decision maker with both ready access to all pertinent information for interpreting the state of the system, and means by which he may input his actions and decisions for implementing the system.

Benefits attributed to the integrated systems control of a part of the steel works (the heavy plate mill) represented in Figure 8 include a 30 percent reduction in operating costs for the planning and scheduling departments; a 10 percent decrease in slab surpluses due to improved planning accuracy; a 20 percent decrease in lead time required for processing orders; a 30 percent improvement in yield; better uniformity in the product quality; general improvement in the accuracy of management decision-making; and a large increase in the annual productivity in tons of steel per employee--750 cited for integrated steel plants in Japan, compared with about 300 for conventional plants elsewhere.

The steel case study was very instructive. It reinforced some of our prior conceptual thinking with respect to the hierarchical control structure; it also motivated new insights and formulations of the structure.

The original plan was that steel would be the first of several case studies, e.g., a mechanical engineering system and a chemical processing system--each expected to point up new aspects of the problem of integrated systems control. From this series of experiences, we expected to be able to extract some general concepts and guidelines applicable to a broad class of industrial systems.

Finally, hierarchically-structured integrated systems currently exist and others are being implemented. However, their design tends to be ad hoc and intuitive. We would like to think that the development of more rational and analytically based methods for systems design would lead to more complete and efficient integration. We would like to see the following: criteria for decompositon; means for coordination applicable to systems operating in real time; criteria for model simplification and aggregation appropriate to its hierarchical level criteria for determining the periods of control action for each layer; integration into the hierarchical system considerations of information flow rate requirements and data base organization and management.

Discussion

(G. Surguchev, Rapporteur)

Three main issues were raised during the discussion on the steel case: evaluation of results achieved, proposal for future activities, and general considerations.

Most of the discussants stressed the importance of the results of the steel case. One discussant from the USSR stated that the Special Scientific Council for Problems of Integrated Industrial Control Systems in his country greatly appreciates IIASA's activities that have resulted in a more precise formulation of integration. He mentioned several factors that should be considered in applying this concept: integration of technical and economic information, information processing techniques (e.g., real time methods), hierarchical structure, and control objectives.

A discussant from Poland stressed that from the point of view of the Polish Academy of Sciences, the state-of-the-art review of integrated systems control in the steel industry is useful to the work of IIASA's National Member Organizations (NMOs). Some additional comments were made about IIASA's future activities in integrated control systems. It was suggested that the work on integrated industrial control systems be combined with that on industrial complexes. The chemical industry was proposed as the next case study, since it has strong links with other problems being studied by IIASA. The view was expressed that the Advisory Committee on integrated industrial control systems would support this activity. It was stated that Poland strongly supports continued research on integrated industrial systems; and that such research is of vital interest to all member countries. He proposed that IIASA Study integrated management and control of large chemical, petrochemical, and allied complexes.

Attention then focused on present and planned IIASA activities in automated management systems. Two activities--to be carried out in parallel--were discussed. One is the comparative review of large multi-locational automated management systems. The systems studied would have comparable functions and complexity, and would include enterprises in the East and the West. For example, manufacturing enterprises in the automobile industry could be studied. This work has already begun.

The second task would involve collaboration with the United Nations Industrial Development Organization (UNIDO) on activities to solve development problems of automated management systems for a group of multi-locational enterprises in Yugoslavia called Masinogradsija, Beograd (MAG). The study would include defining possible alternative means for increasing the managerial capabilities of this organization.

Reference was made to an earlier suggestion that IIASA devote more attention to transforming existing industrial regions, rather than creating new ones. In most NMO countries, there was a need for transforming the urban jungle created by the first industrial revolution into a new kind of industrial region appropriate to the second industrial revolution. For instance, the strip of factories and industrial settlements near San Francisco, the "Silicon Valley", is an interesting example of the positive and negative features of the spontaneous development of a new industrial region.

Concerning computer-based management, it was felt that IIASA should regard this as a separate issue from the computer control of production.

A number of general remarks followed. Several statments were made in connection with developing mathematical models of industrial complexes. The human element is essential for both model development and implementation, not only for complex regional development but also for the development of technological models such as chemical processing models. While the complex application of the models is very useful, it should not be the only basis for decisions. Human judgment based on experience must also be involved. As a rule, automated decision-making in large-scale complex systems is not a reality at present.

It was felt that the objectives set out in the IIASA Charter could be achieved by studying the spread and intensification of industry as well as scientific and technological developments, in the light of the problems they have generated and will generate. In this way, feedback will be obtained on the effects of science, technology, and industry. IIASA's approach, however, has often been to look at many different effects and very few cases. This has sometimes resulted in pieces of disjointed knowledge, much of which is valuable but lacking in unity. Thus there is a need for integrating these efforts.

Support was expressed for an earlier suggestion about closer ties between IIASA and industry. Before applying the science of management, it is best to understand that which is to be managed. Closer contacts would therefore be of mutual benefit to IIASA and industry.

SYSTEM AND DECISION SCIENCES

Introduction

M.L. Balinski

THE PAST

This brief report is by way of introduction to the area known as System and Decision Sciences, its antecedents and planned development.

The System and Decision Sciences area arises from what were the Computer Science and the Methodology projects.

Computer Science, headed from its beginnings to now by Alexandre Butrimenko, and whose work is continuing under his direction, concentrates on computer networking and its implementation as reality for IIASA and various computer centers of the IIASA National Member Organizations. It will be described in some detail later in this volume by Butrimenko.

Methodology traces its beginnings to George Dantzig's--and mathematical programming's--arrival at IIASA in September 1973. With him arrived Alan Manne, then, slightly later, in January 1974, Tjalling Koopmans, as well as some young and excellent researchers. Howard Raiffa was here too, and he brought decision analysis and multiple attributes. These poles of methodological interest and activity--optimization and multiple-objective decision-making--had persuasive influence throughout the applied projects of the Institute. The budworm has suffered the consequences of having ecologists' utility functions constructed, simulated, optimized. The Energy program has at its roots linear programming models describing potential transitions from society's use of fossil to nuclear fuels.

This prescribed two methodological research foci, which will be described to you in some greater detail in this volume by two of the principal actors, George Dantzig and Ralph Keeney. The leadership of the project then passed on from Dantzig to Koopmans. He was instrumental in giving strong impetus to the qualitative, structural study of models using topological concepts and the fixed-point algorithms recently devised by Scarf and others. This, in turn, prompted the discussion of a concept, until lately ill-defined, known at IIASA as "resilience". Originally conceived by C.S. Holling and his Ecology project as meaningful and important for ecological phenomena, resilience was taken as a qualitative mode through which to try to understand certain planning problems by the Energy project. The methodological task came to be that of defining the relevant concepts accurately, precisely, mathematically. The global theory of differential equations gives the framework for these definitions, which are related, in turn, to a bright new child of the mathematical world, catastrophe theory. The concepts generalize more classical stability ideas. Responsible for this work were Hans Richard Grümm, whose presentation appears in this volume, David Bell, John Casti, and Yuri Rozanov.

This phase of activities found its culmination, as it were, in two workshops. The first, held in the summer of 1975, and organized by Koopmans, assembled mathematicians, ecologists, physicists, chemists, and climatologists under the title *Computing Equilibria and Regions of Stability*. The second, realized by Keeney and Raiffa, entitled *Decision Analysis With Multiple Conflicting Objectives*, brought together some theoreticians and real users of that theory.

In the interim, as the leadership passed on, in turn, from Koopmans to William Jewell, and with the growth of IIASA, the broadening of its interests, and an increasing and continuing interaction of applied mathematicians with applied projects, came also a broadening "coverage" of representative methodological skills in the staff of the Methodology project. This is good for one of our main roles, that of consultant to other projects. But it is bad in two allied directions. To do good methodological research it is essential to limit the diffusion of interests, and rather to have some commonality of interest. And to attract first rate consultants, there must be a congenial research atmosphere, one in which there are common foci of research, just as there was at the beginning. So we face the classical confrontation of breadth versus depth.

THE PROBLEM

The problem of the System and Decision Sciences area at IIASA is to be intimately involved in the ongoing work of the applied projects and, at the same time, to do first rate methodological research. One constraint is the modest size of staff which precludes having in residence more than just a few of the specialties explicitly or potentially necessary to treat problems arising in applications. Another is the peculiarity of IIASA as a research institution: it has no permanent members. This, of course, resolves one of the potential think-tank problems: that of research groups becoming stale. Rather, appointments are made for periods varying between three months and two to three years. This means, in my opinion, that no really long-term research projects can be meaningfully undertaken. And further that there will always be a changing intensity of interest in research to be undertaken. Typically, a focus of research will be identified, built up, will last a year or two, beginning and/or ending with a workshop or a meeting bringing together an international group of scientists with expertise in the area, then will phase out. One of the hopes and expectations is that the international gathering of the group itself, and perhaps of the attendees of the professional functions organized here, will continue to interact in the future, independently of IIASA, as individuals or as representatives of their respective institutions.

In this perspective, the System and Decision Sciences area should form several research groups, each having a "permanent staff" (appointees with contracts of at least one year) of some three or four people. The axioms describing them should be: a subject that is relatively new and holds much promise for exciting results; a subject that is not central to any existing research institute (avoiding competition); a subject that is attracting the attention of scientists in many nations; and a subject relevant to applied tasks. Finally, to meet our consulting role, a staff member of any such group should have strong motivations to do real applied work.

I am aware of the potential cardinal sin of the mathematician--though I make no personal claims to purity--that was so neatly described by Karl Marx, then 17 years old, in his final examination theme: "And so we must be on guard against allowing ourselves to fall victims to that most dangerous of all temptations: the fascination of abstract thought." But, in my estimation, groups as proposed must run this risk since, otherwise, no first rate methodological thinkers will agree to come to IIASA.

THE PLANS

We are proceeding to satisfy these axioms, given the constraints, in the following way.

A group of some three to four people in the area of nondifferentiable optimization (NDO) is being formed. NDO is concerned with the minimization of a real-valued function that is not necessarily differentiable, not because of anomalous behavior but rather because of some inherent property. A general class of studied problems is $\min\{f(x)/x \in X\}$ where $f(x) = \max\{g(x,y); y \in Y\}$. No matter how smooth $g(x,y)$, f is almost surely significantly nondifferentiable. A particular instance is $f(x) = \max\{g_i(x); i = 1,\ldots,m\}$, or even $f(x) = \max\{x, -x\}$.

The Chebycheff approximation problem belongs to this class. Of perhaps greater interest to IIASA, in view of applications and past history, is the potential use of ideas for NDO in handling large-scale column-generation or decomposition problems. For often the problem $\min\{f(x); g_i(x) \leqq 0\}$ is equivalent to minimizing $f(x) + K \sum_i \max\{0, g_i(x)\}$ for all sufficiently large K. This group will be a reality at IIASA beginning in September of this year. Further, I am happy to be able to say that the reaction from the best people in the NDO area to IIASA's developing a group has been positive, indeed enthusiastic.

Another group is being formed in the area of fair division problems. The proverbial just share of cake, discussed by Steinhaus, is a continuous version of a fair division problem, taken from a game theoretic point of view. A discrete version is the apportionment of people or objects proportional to stated populations. The essential problem here is to arrive at an acceptable definition of "fairness". Many seemingly acceptable notions founder on the rocks of some property. A fruitful approach is the axiomatic one which transposes one level of intuition concerning fairness itself to another, more basic set ot properties. An allied question is the analysis of power inherent in decision-making bodies as a function of their formal structures. In a word this represents the combinatorial, or ordinal, approach to group decision-making, the point of view which received considerable impetus from Arrow's Impossibility Theorem, in contrast with the cardinal von Neumann-Morgenstern utility approach to individual or joint decision making which has, to date, received so much attention at IIASA. It is all directed to decision given multiple conflicting objectives, but the assault is from a different quarter. I feel the coming need for a sane and just view of such problems in a world of nations facing the prospect of limited food, energy, and other resources as well as of increasing wastes which must all be shared. Again, the experts in this domain have written of their strong support and desire to participate in this activity. Research is already under way, and a full-fledged group is hoped for in September.

A third group is being planned in mathematical economics. By this I mean a group of economists who are good users, good understanders, good interpreters of mathematics for the social sciences, and who have taste and experience in the formulation, development, and analysis of models for real problems. This group does not satisfy the four axioms, at least not yet. The need for it seems evident at IIASA. Econometric modeling is in increasing demand. International trade of energy, food, and resources must be analyzed and understood. Yet we have precious few economists with the background necessary to deal with such problems. A clearer methodological focus must be identified to form a proper group, but this can only be done in an opportunistic fashion which unfolds as a function of the researchers who are available and willing to come to IIASA.

These groups, together with that of Computer Science, will be our answer to the need for some depth in research. But there are continuing needs for coverage. The resilience work, in theory and application, needs to be carried forward in cooperation with outside institutions, *and is.* Mathematical programming, in its more traditional interpretation, is needed, and *is represented.* The potential to apply control theory to models arising from applied work must exist, *and does.* Further, each of the members of the various groups is not, and will not be, a narrow specialist. Each has a different background, a different range of abilities and knowledge. In addition, there is a need for some provocative individuals, people who have daring ideas, who challenge, excite, annoy, and prod. Together, individual researchers and members of sub-groups provide our answer to the need for breadth in systems analysis expertise.

I hope that this approach to solving the problems of the System and Decision Sciences area at IIASA will indeed realize the vision of Mark Twain: "There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact."

A PILOT Linear Programming Model for Assessing Physical Impact on the Economy of A Changing Energy Picture[†]

G.B. Dantzig

INTRODUCTION

This paper reports on some of the ongoing work on models of energy systems at the Institute for Energy Studies and the Systems Optimization Laboratory at Stanford University. It deals with a dynamic, linear programming model on a pilot scale that describes in physical terms technological interactions within and across the sectors of the American economy, including a detailed energy sector. The general aim of the model is to provide information on what the country could achieve in physical terms over the long term (say, 30 years), in the face of the changing energy picture.

Mathematical programming models can be used to link the activities of the economic sectors with those of a detailed energy sector, and to describe interactions over time. They also provide comprehensive and effective means for evaluating the nature and extent of the impact--on the economy in general, and on the living standards in particular--of the realizations of various scenarios concerning the availability and mix of raw energy and the type of conversion technology used [2]. Simple, rough calculations below show that any such model can become large and perhaps unmanageable if sufficient care is not exercised in its development.

The input-output matrix provides a convenient vehicle for incorporating into a mathematical programming model the technological and many of the economic interactions of the economy. Despite its shortcomings, such as constant returns to scale, fixed technology and time delays involved in data collection and publication, the matrix is attractive because it provides an internally consistent and a single, comprehensive data source. In its standard published form, it is available as an 87-sector matrix. The energy sector may be modeled by approximately 150 equations per period, including the capacity constraints on activity levels of the energy processes and the inter-period capacity

---

[†]S.C. Parikh, Stanford University, collaborated in writing this presentation, which is based on [1].

carry-over constraints (see for example [3]). An order of magnitude for the number of constraints per period in an integrated model, with a reasonable level of detail, is therefore computed to be 400: 87 for industrial activity, 2 times 87 for capacity constraints on industrial activity levels and for capacity carry-over from one period to the next, and about 150 for the detailed energy sector. A 20- to 25-period model (e.g., a 25-year annual model, or a 75-year triannual model) would therefore have approximately 8,000 to 10,000 constraints, and many more if more detailed input-output matrix and energy sectors were employed. While linear programming models of this magnitude are not impossible to solve, they would be among the largest models built to date. More importantly, preparation, testing/validation, and production runs for such a model would most likely consume both substantial sums of money and substantial amounts of time.

The aim of this exercise is to draw attention to the potential model size resulting from indiscriminate modeling and the difficulties that may arise; it is not to suggest that one build such large models. It is therefore essential that a critical and scientific assessment be made of the exact nature of the formulation and the scope and limitations of such models. In particular, it is important to obtain answers to questions along the following lines:

Formulation. What aspects should be modeled (endogenous), what aspects should be assumed (exogenous), and what information should flow between periods? What linkages between the energy sector and the economy should be formulated, and how?

Availability of data. What are the data requirements of the model? Are such data available? If not, is it possible to obtain satisfactory quick-and-dirty estimates to satisfy the immediate needs? What types of studies are needed to develop better quality data over a longer term?

Information from the model. What meaningful information can the model provide? What are the different objective functions that can be evaluated? At what level of detail should the model be formulated to provide the information desired?

Computation of solutions. Can the model be (efficiently) solved on the computer? What would be the computational costs? What refinements or special purpose algorithms exist (that perhaps require further research and) that can substantially reduce the computational costs?

These and other similar considerations point to a need for developing and experimenting with a much smaller model that incorporates many, if not all, of the essential features of its larger counterpart. Our PILOT Model is an attempt to satisfy this need. We believe that it will be small enough so that when implemented on the computer, it will have the agility for extensive experimentation. On the other hand, we expect that it will incorporate the most recent available data of sufficiently good quality (albeit in an aggregated form) that the model can also be used to generate meaningful scenarios showing how the economy might be affected if the energy picture evolves in a specified way.

In what follows, we first describe the model. Next, we give a brief and general mathematical statement of the model. Finally, we briefly review the current status of the model, its mathematical structure, and possible solution approaches.

DESCRIPTION OF THE MODEL

In the model, a 23-sector input-output matrix represents various industrial processes of the economy (Figure 1). The net output of industry, together with net imports, meets the national bill of goods for consumption, capital formation and government services. The energy demands of the economy are met by the activities of the energy sector. The nature and extent of the capacity expansion in both the energy sector and the rest of the economy are endogenously determined. Finally, the exogenously given work force provides the manpower needed to sustain industrial production, energy processing, and capacity expansion.

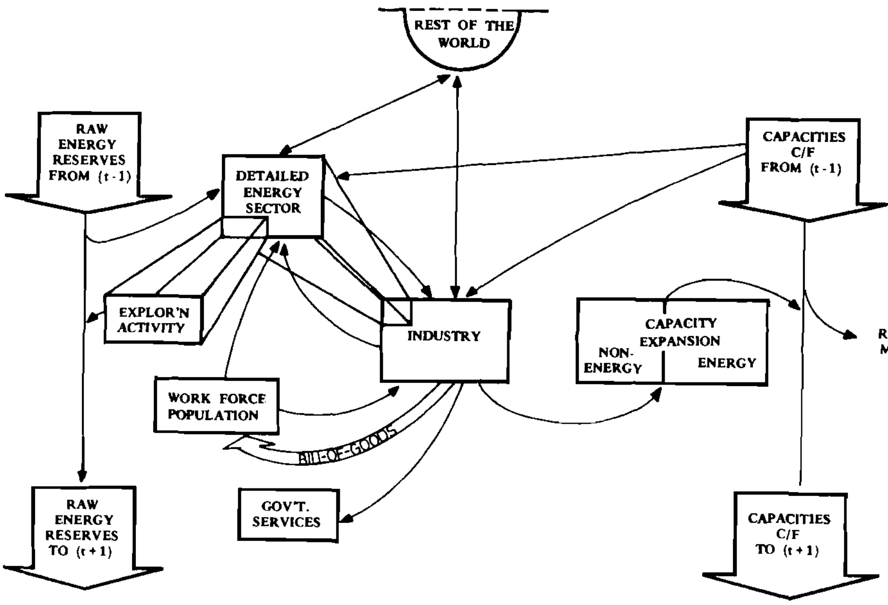


Figure 1. Schematic representation of the main linkages in the PILOT Model.

The detailed energy sector in the model includes the technological description of the raw material extraction and energy conversion processes (Figures 2 and 3). Uranium mining, milling, conversion, enrichment and fabrication, light water reactor (LWR), fast breeder reactor, and spent fuel reprocessor are among the nuclear fuel-based processes in the model. Oil and gas exploration and production, oil refining, gas transmission, coal mining, power generation using coal, oil, and gas, and coal gasification and liquefaction are among the fossil fuel based processes in the model. The operating levels of the processing units are limited by the available capacities and proven reserves in any period. The proven reserves may be augmented by the exploration activity. And, raw material imports/exports make up the difference between domestic production and usage.

Among the linkages that interconnect the energy sector and the rest of the economy are (Figure 1): energy demands of the economy, total manpower available to all sectors (including energy) of the economy, favorable balance-of-payments requirement, and bill-of-goods needed for energy processing and capacity expansion.

To mitigate many of the distortions caused by price changes and inflation, the industrial process of the national economy and the detailed energy sector will be represented in terms of physical flows. For the energy sector, this is relatively easy because its activity can be treated in Btu terms. For the non-energy sector, however, it is more difficult because most industries produce a heterogeneous product, thereby creating a need for developing a weighted index of the component physical outputs; and the input-output transactions are compiled in dollar terms, and money quantities depend on prices as well as on physical flows. Moreover, the component prices unfortunately vary relative to one another over time, and so do the relative magnitudes of the component outputs. If these relative price and output variations among the components are assumed to be absent, then a weighted index can be conveniently obtained by defining a composite product for the heterogeneous industry, using base-year prices as weights for base-year outputs. (Unless specific allowance is made, this assumption is implicit in any temporal input-output model.) The dollar transactions are therefore reinterpreted as physical units of the composite product.

Whereas the input-output matrix represents the operating coefficients of the industrial processes of the economy, the capital coefficient matrix represents the amount of industrial products needed for a unit of (output) capacity expansion in any industrial (or energy) sector [4]. Because a portion of the available capacity is retired at the end of each period, some capacity addition would be required in any scenario just to sustain the capacity of a process at a fixed level. This feature of the model also makes possible the process substitution. Thus, in the detailed energy sector where we expect to incorporate data of the new energy conversion technologies--such as coal gasification

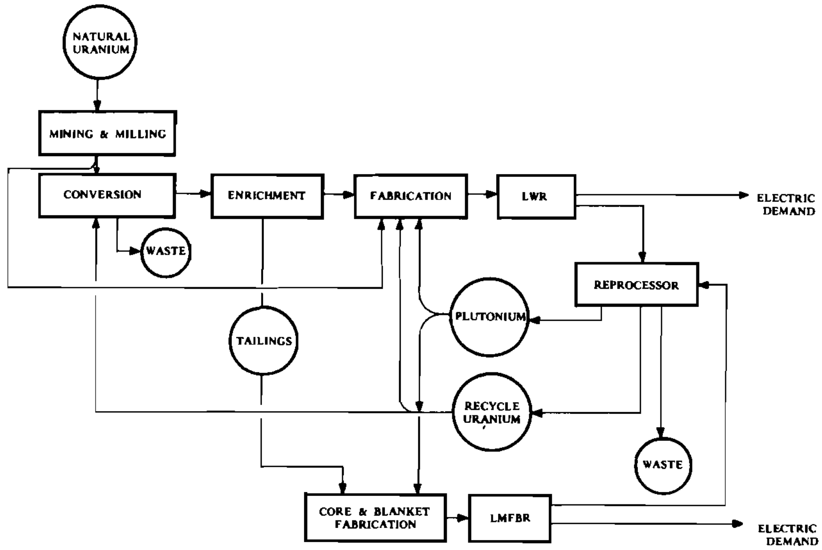


Figure 2. Light water reactor (LWR) and liquid metal fast breeder reactor (LMFBR) and technology in the energy sector of the PILOT Model. (Suggested by T.J. Connolly, Stanford University.)

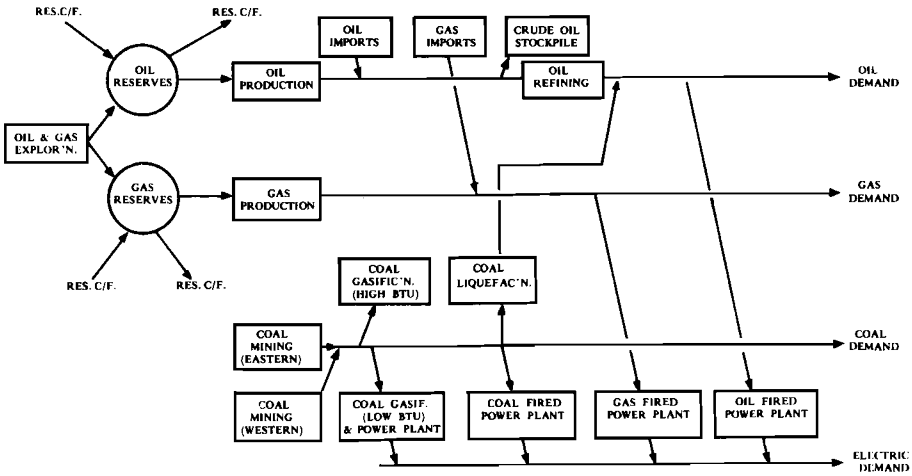


Figure 3. Fossil fuel based activities of the energy sector of the PILOT Model.

and liquefaction, fuel cells, and fast breeder reactors--it will be possible to examine scenarios where the distribution of capacities across the energy conversion processes evolves over time to reflect the impact of a particular set of assumptions specific to a scenario. On the other hand, to avoid the effort and difficulties involved in compiling reliable data of a similar nature for each of the other sectors of the economy, these will be initially represented by a nonvarying input-output matrix without substitution.

One of the primary linkages between the economy and the detailed energy sector is that of the energy sector meeting the demands of the economy. These energy demands are made up of the following four components: energy required for industrial processing, energy for personal (family) consumption, net exports of processed energy, and energy required to provide government services. In the model, these demands are transmitted to the energy sector in terms of the following four final energy forms: oil products, gas products, coal, and electricity. (An alternative level of information detail would consist of eight final energy forms that use the data developed in [5]; see also [2,6]. We may experiment with this form of linkage at a later date.) Moreover, this same set of demand variables is employed to compute the amounts of industrial goods and services required for energy extraction and processing. (Using data similar to those developed in [7], it is possible to incorporate a full-blown operating coefficient matrix to more accurately provide this linkage.) The latter linkage also requires a modification of the input-output matrix.

The activities of the detailed energy sector are represented in two groups: nuclear, and non-nuclear. The non-nuclear group contains for the most part the fossil fuel based activities. It also includes fuel free activities such as hydroelectric and geothermal.

Figure 2 schematically shows the electric power generation related activities of the nuclear fuel cycle in the model. Natural or recycled uranium goes through chemical conversion and physical separation and enrichment before it is fabricated into the fuel elements for the LWR. Fuel elements could also be fabricated from recycled plutonium and uranium. The spent fuel may be reprocessed to recover the plutonium and uranium. The liquid metal fast breeder reactor (LMFBR) operation is similarly defined in the model.

Figure 3 shows the activities of the fossil fuel based energy processes in the model. Exploration for either oil or gas results in additions to the reserves of these raw energy forms. Oil and gas production and coal mining activities provide the raw fossil fuels that are then processed into final energy forms. For oil, this involves a refining activity that produces oil products (e.g., gasoline, heating oil) for satisfying final demands, and oil products (e.g., residual fuel oil) for use in electric power generation. Because of the nature of the linkage by which the energy sector meets the energy demands of the economy, the detailed yield structure of the refinery operations is not represented here. Natural gas is transmitted either to meet the final demands or to generate power. For coal, three alternative uses are defined in the model: to meet the coal demands of the economy, to generate power, or to produce synthetic oil and gas.

One of the most important linkages in the model requires that all capacity building be constrained by the capability of the economy to build capacity, either for capacity expansion or for replacement of the retired equipment [4]. Thus, in the model the distribution of the capacities across the exploration, production, and conversion processes of the energy sector tends to evolve gradually over time. If there were too drastic a change in the capacity distribution, an unusual amount of the economy's capability to build capacity would be drained, leaving an insufficient ability to build capacity of the other industrial processes. On the other hand, the economy could expand its capacity expansion industries (e.g., construction, industrial machinery) at an unusually rapid pace to meet the need for accelerated changes in capacity distribution. However, this expansion may be at the expense of reduced ability to produce consumer goods, thereby possibly reducing the standard of living in the short run.

This descriptive model could be used in conjunction with a linear or a nonlinear objective. The objective could be a utility function to measure the standard of living achieved over time, to minimize dependence on foreign ore, to maximize energy output, or to maximize employment. Our intent is to develop on a pilot scale a reasonably accurate general description of the American economy and a more detailed description of the energy sector, so as to facilitate studies of the physical potential of the economy under alternative objectives, changing availability of various forms of energy, changing desirability and economic feasibility of energy conversion technologies, and so forth.

The oil embargo of 1973-1974 revealed that changes in the energy picture *can* have a short-term effect on the standard of living (e.g., mile-long waiting lines at the gas stations), and *may* have a long-term effect on the standard of living (e.g., drastically increased prices). Such higher prices may reflect not only the political realities of the world's raw energy markets, but also the greatly increased physical effort on the part of the American economy to provide from domestic sources the energy needed to operate the economic machinery.

How will the standard of living be affected over time? Our first attempt at incorporating the standard of living in the model is as follows. We define consumption profiles of families at various income levels. It is known, for example, that a low-income family spends less dollars on food, although a greater percent of its dollar expenditure is spent on food relative to that spent by a high-income family. Whereas a high-income family spends more on housing, the housing expenditure represents a large percent of total expenditure. We expect to define about five to seven such profiles. One possible objective function is to maximize the "gross national consumption" (GNC) or, equivalently, the "average per capita national consumption".

The purpose of an objective function is to project a path for the economy that pushes against its capacities--it is not to project a depression economy. However, in examining the question of the objective, one is immediately faced with the prospect of finding a generally acceptable utility (or welfare) function for the entire country--a not too promising task, to say the least. A more plausible approach is to incorporate information on national welfare in the objective function and the constraints. The maximization of gross national consumption, as defined by the income level profiles, is one possibility. In any case, one fact is certain. Much experimentation is required before a satisfactory objective function approach can be realized.

GENERAL MATHEMATICAL STATEMENT OF THE MODEL

In the model, there are *inter-period* and *intra-period* constraints (Figure 4). These are briefly outlined below. A more detailed description can be found in [1].

The *inter-period* constraints connecting periods t and t+l appear below the lower dotted line in Figure 4. These are capacity balance constraints, manpower skill adjustment limit constraints, and constraints related to raw energy reserves, cumulative exploration and production, and intermediate energy stocks. The capacity balance (or capacity c/f*) constraints specify that the available capacity in period t+l of any activity equals its capacity in period t, less retirements plus capacity built. Next, the manpower is assumed to be made up of several skill groups, e.g., unskilled, skilled, engineers, and managers. The manpower skill adjustment limit constraints (i.e., manpower c/f) specify the educational and training limitations. This set of constraints, together with the *intra-period* constraint that the sum over all skill groups cannot exceed the sum of the available work force, provides for changes in the size of skill groups to satisfy the manpower needs.

The following three sets of inter-period constraints are intended to keep an accurate record of the energy reserves, cumulative exploration (and production), and stocks. The reserves

---

*Carried forward from previous period.

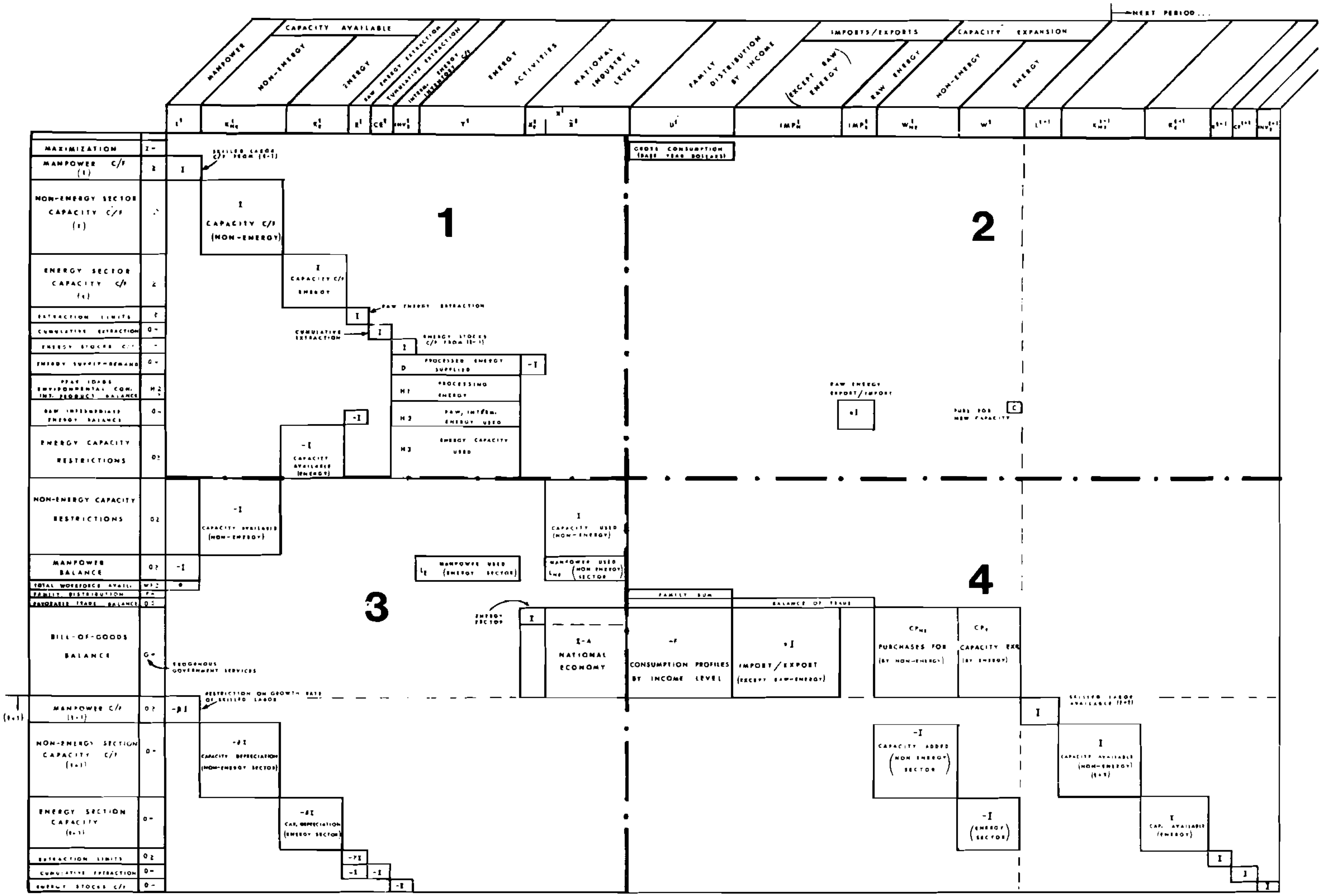


Figure 4. PILOT Model of the economy and a detailed energy sector (by S.C. Parikh, SOL Laboratory, Stanford University).

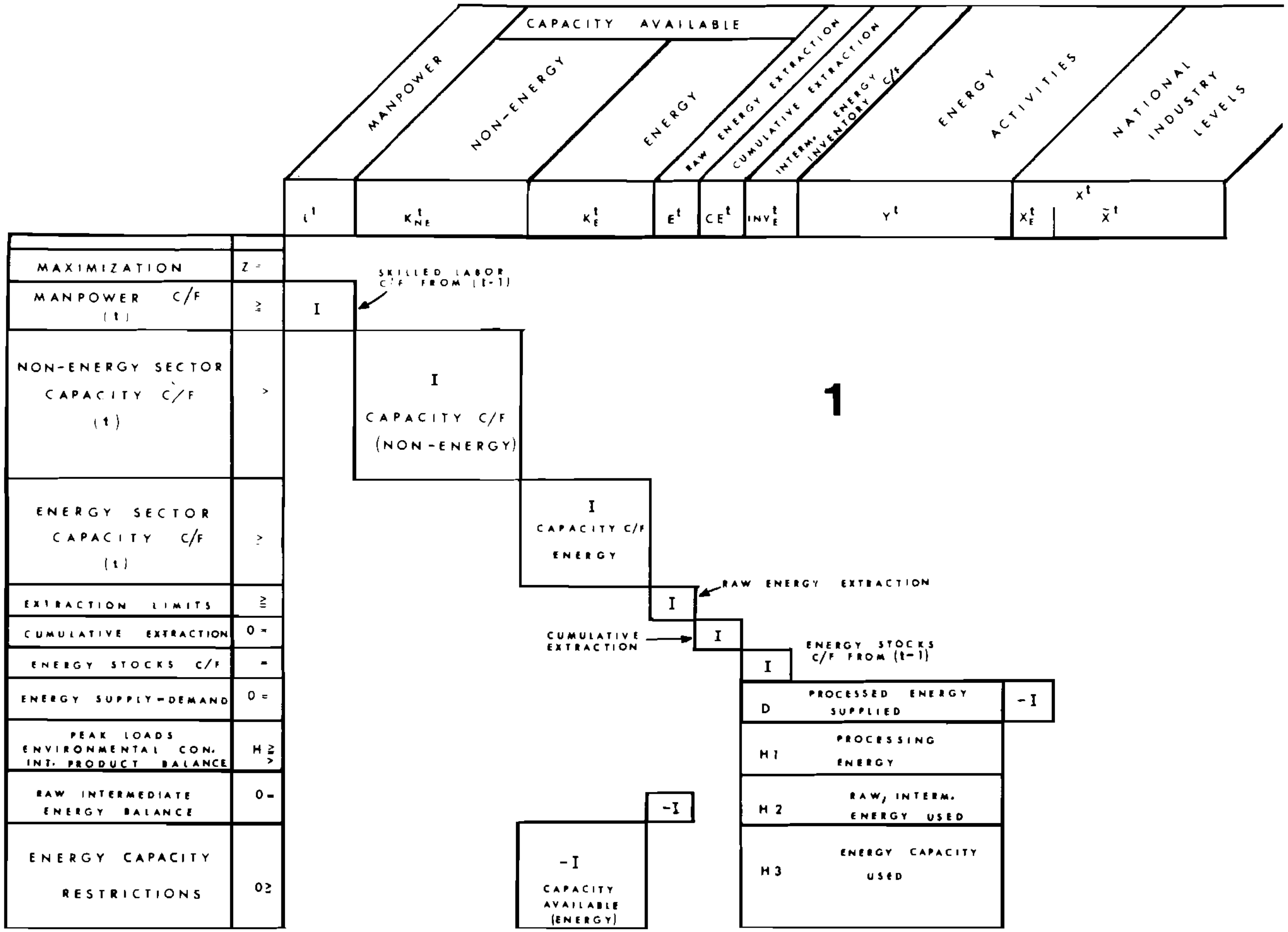


Figure 4. (Detail).

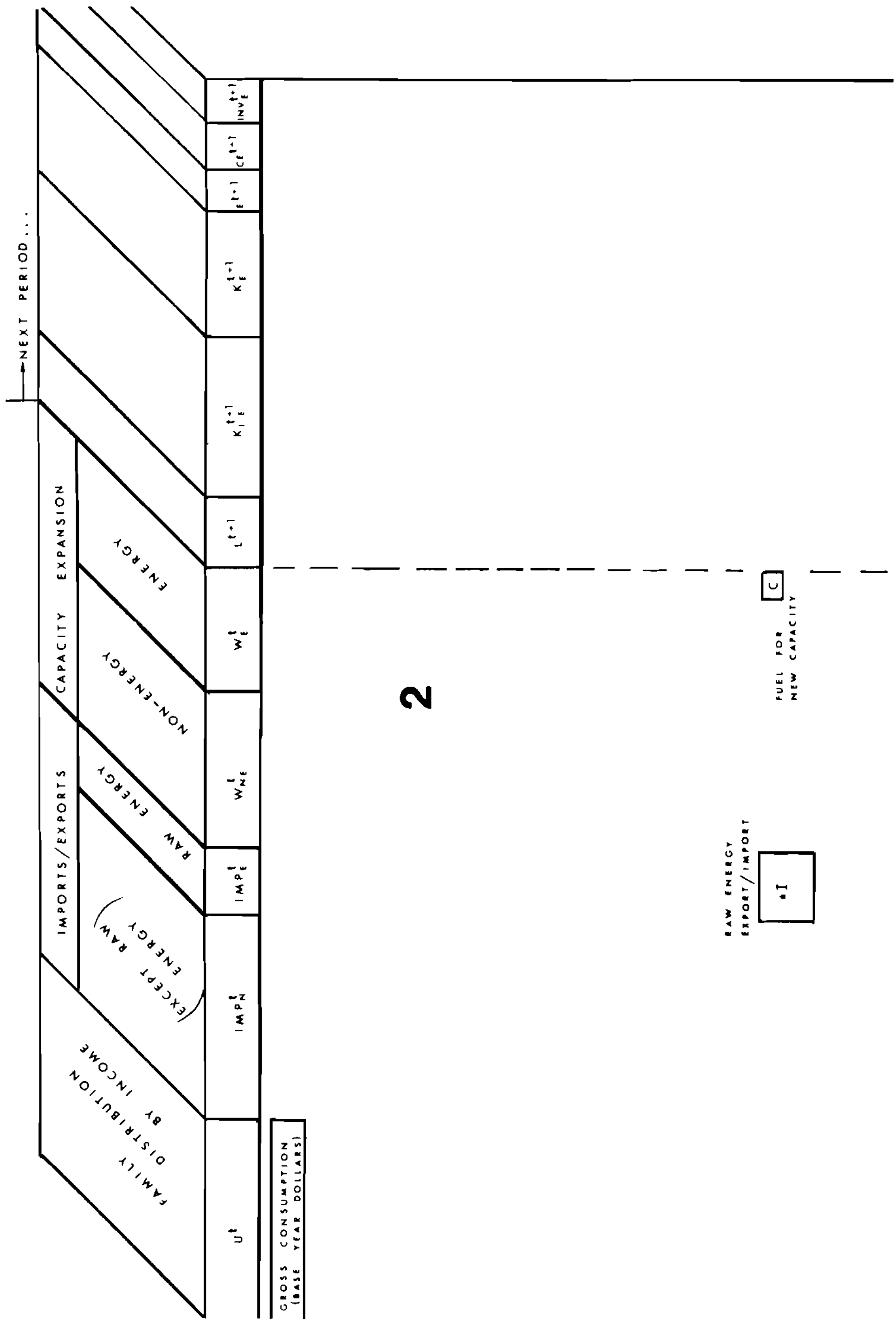


Figure 4. (Detail).

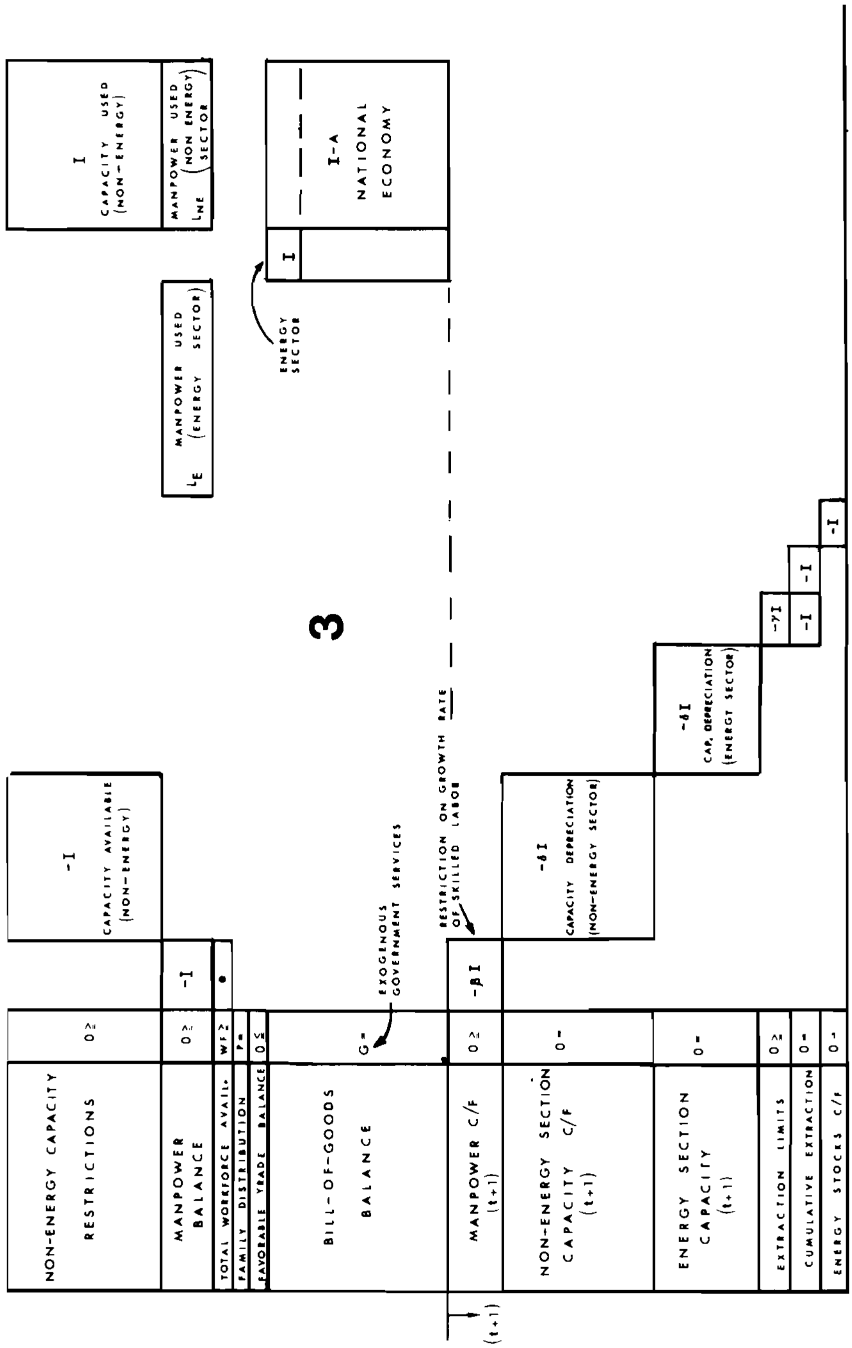


Figure 4. (Detail).

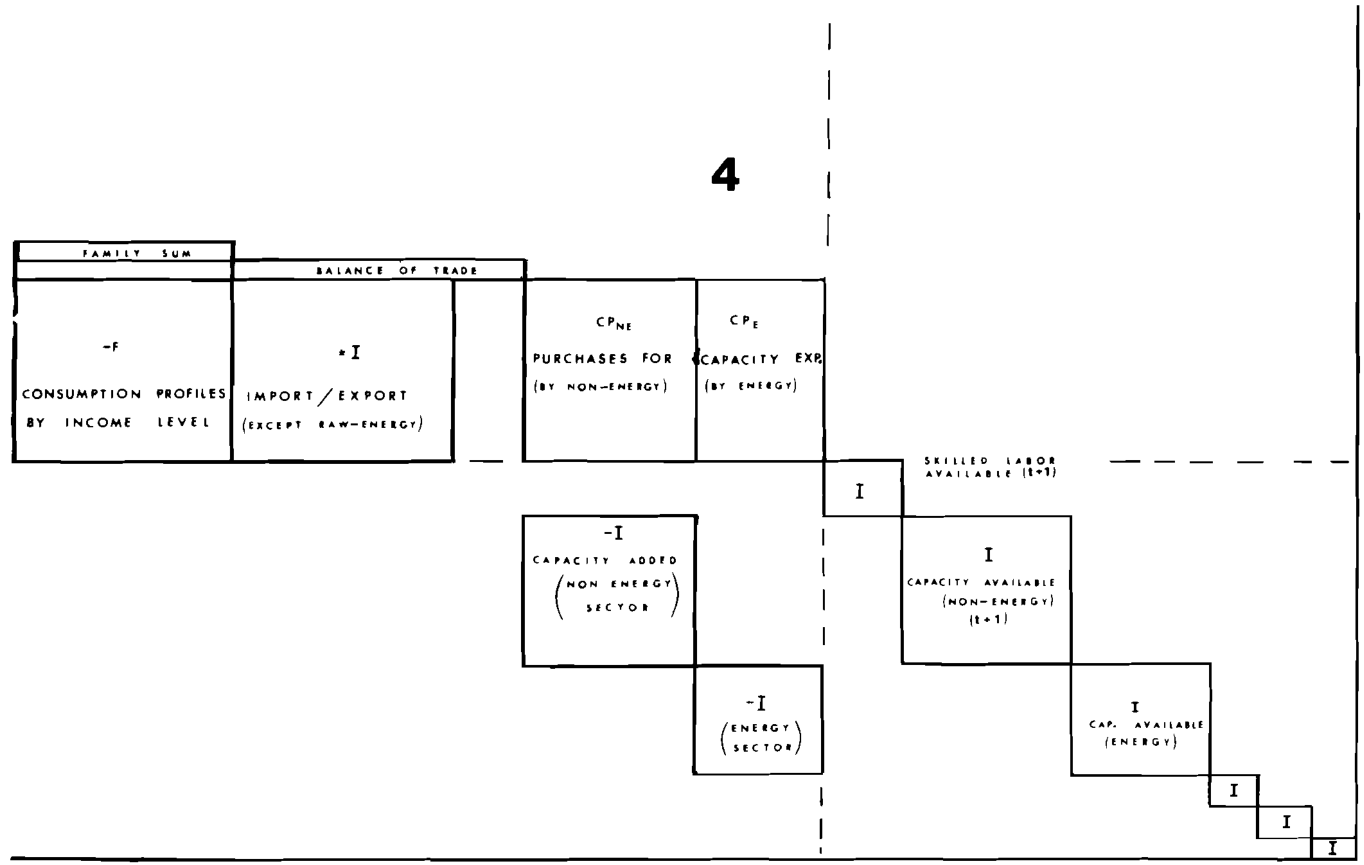


Figure 4. (Detail).

constraints specify that

$$\begin{bmatrix}\text{Reserves in}\\ \text{period t+1}\end{bmatrix} = \begin{bmatrix}\text{Reserves in}\\ \text{period t}\end{bmatrix} - \begin{bmatrix}\text{Raw energy}\\ \text{extracted}\\ \text{in period t}\end{bmatrix} + \begin{bmatrix}\text{Additions to}\\ \text{reserves in}\\ \text{period t}\end{bmatrix}$$

Cumulative exploration in, say, feet drilled (and production in, say, Btu's extracted) is determined as follows:

$$\begin{bmatrix}\text{Cumulative exploration}\\ \text{at the beginning of}\\ \text{period t+1}\end{bmatrix} = \begin{bmatrix}\text{Cumulative exploration}\\ \text{at the beginning of}\\ \text{period t}\end{bmatrix} + \begin{bmatrix}\text{Exploration}\\ \text{during}\\ \text{period t}\end{bmatrix}$$

The production of an energy form may be direct, as in the case of oil, gas, uranium, etc., or it may be a byproduct of some other activity, as in the case of plutonium. Finally, the stock (inventory) balance constraints for the ith energy form are

$$\begin{bmatrix}\text{Stocks at the}\\ \text{beginning of}\\ \text{period t+1}\end{bmatrix} = \begin{bmatrix}\text{Stocks at the}\\ \text{beginning of}\\ \text{period t}\end{bmatrix} + \begin{bmatrix}\text{Amount produced}\\ \text{during}\\ \text{period t}\end{bmatrix} - \begin{bmatrix}\text{Amount used}\\ \text{during}\\ \text{period t}\end{bmatrix}$$

Whether a constraint from these three sets is included in the model for a particular energy form depends upon its need and/or validity. For example, one may leave out the stock balance constraint for natural gas, by arguing that gas could be extracted only if needed during the period. On the other hand, the exploration constraint for plutonium is invalid. The constraints from these sets in Figure 4 are presented only for illustration.

The sets of *intra-period* constraints appear between the two horizontal dotted lines in Figure 4. The first set (involving matrix block D) provides for meeting the energy demands of the economy from the energy sector. The next two sets (involving matrix blocks H1 and H2) represent various energy processing aspects. The environmental aspects of energy extraction and conversion could also be included here. The next two sets (involving matrix block H3, and variables x^t, K^t_{NE}) specify the operating capacity limitations of the energy and the non-energy processes. The next set (involving the variables L_{NE}, and L_E) specifies the manpower constraints that for each of the skill groups, the manpower used cannot exceed that available. The next constraints state that the manpower sum across skills cannot exceed the total available work force. The family sum equation is used in conjunction with the objective function described below. The balance of trade equation computes the trade balance in each period for the purpose of incorporating a favorable trade balance requirement. Such a requirement may be imposed individually in each period, or collectively in several periods. Finally, the bill-of-goods balance equations specify that the industrial output, together with imports (IMP), meets the final demands consisting of personal consumption (Fu), exports (EXP), capacity expansion ($CP_{NE}W_{NE} + CP_EW_E$), and government expenditures (G).

Now consider the form of the objective function in the model. Broadly speaking, the objective of the model is to maximize the discounted vector bill-of-goods received per person, summed over time. Suppose that in the base year, the physical bill-of-goods for people with consumption level M_k (income less taxes and savings in base-year dollars) is:
$b^k = [b_1^k, b_2^k, \ldots, b_n^k]^T$, $k = 1, \ldots, K$ and with $M_1 < M_2 < \ldots < M_K$. Let u_k^t be the unknown number of people in period t that receive b^k. Then, $u_1^t + u_2^t + \ldots + u_K^t = P(t)$, the population at time t. The total bill-of-goods for period t is Fu^t, where $F = [b^1, b^2, \ldots, b^K]$, and $u^t = [u_1^t, u_2^t, \ldots, u_K^t]^T$. Initially, the overall objective will be to maximize discounted gross national consumption (GNC) over time, i.e., to maximize $\Sigma_{t=1}^T \lambda_t$ GNC(t), where
$GNC(t) = M_1u_1^t + \ldots + M_Ku_K^t$, and λ_t = weight in period t for discounting. Note with caution that the treatment of the objective fundtion may change, even drastically, as experiments are performed on this model and numerical results become available. For a discussion of the use of production functions, demand functions and other forms of the objective, see [8,9].

Finally, unless specific allowance is made, an optimal solution to the model may turn out to be such that all (or most) capacity is depleted by the end of the time horizon T. Such unrealistic end effects can be avoided in several ways. One is to put a much higher weight, λ_T, on GNC(T), the gross national consumption in the last period. Such a weight conceptually would reflect the present value of consumption beyond T. Another way is to specify the terminal capacities generated by an equilibrium model or by a steady growth model. For the energy sector, this specification could be in gross Btu terms across several processes, thereby allowing for changes in capacity distribution across processes.

FURTHER REMARKS

The model formulation and data source identification are almost complete. Currently, the data are being aggregated and a model is being prepared for computer solution. We expect that the model will have about 125 equations per period. For a 30-year triannual model, there will be about 1,250 to 1,400 equations, including the specification of initial capacities and end effects. Initially, the model will be solved using the straight simplex method of the MPS/370 system.

To pave a way for economical solution of similar, much larger problems with the 8,000 to 10,000 rows referred to earlier, it is also expected that the PILOT Model will provide us, at the Systems Optimization Laboratory, with a prototype for research in solving large-scale linear programming models of energy systems.

The PILOT Model belongs to a class of models having a staircase structure (Figure 5) that often arises in dynamic linear programs. For such time-phased problems, the number of iterations to optimum may be as high as ten times the number of rows, as opposed to the widely experiences two or four times tne row count in unstructured problems [10].

Several special purpose algorithms are under development that take advantage of the staircase structure for efficient solution. Computational results on some of the methods show that this is a partly-proven and a promising research area (see for example [11,12,13]).

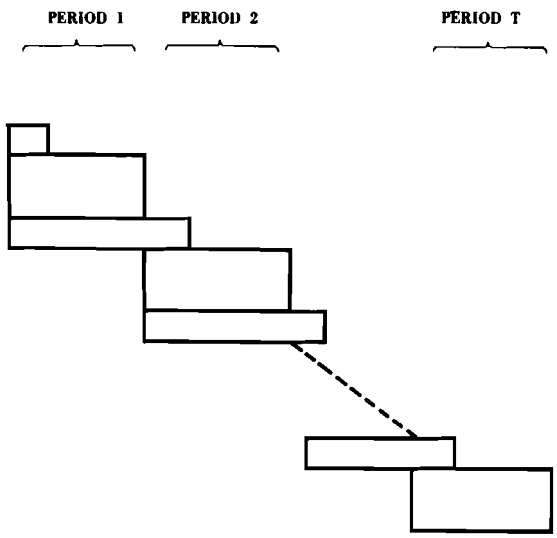


Figure 5. Staircase structure of the PILOT Model.

References

[1] Dantzig, G.B., and S.C. Parikh, *On a PILOT Linear Programming Model for Assessing Physical Impact on the Economy of a Changing Energy Picture*, Technical Report SOL 75-14R, Systems Optimization Laboratory, Stanford University, Stanford, Calif., 1975.

[2] Hoffman, K.C., A United Framework for Energy Systems Planning, in M.F. Searl, ed., *Energy Modelling: Art, Science, Practice: Working Papers for a Seminar on Energy Modelling*, Resources for the Future, Washington, D.C., 1973, 108-143.

[3] Marcuse, W., L. Bodin, E. Cherniavsky, and Y. Sanborn, *A Dynamic Time Dependent Model for the Analysis of Alternative Energy Policies*, Brookhaven National Laboratory, Upton, N.Y., 1974.

[4] Batelle Memorial Institute, *An Ex Ante Capital Matrix for the United States, 1970-75*, unpublished research report.

[5] Knecht, R.L., and C.W. Bullard, III, *End Uses of Energy in the U.S. Economy*, Center for Advanced Computation, Document No. 145, University of Illinois at Urbana-Champaign, Ill., 1975.

[6] Manne, A.S., *U.S. Options for a Transition from Oil and Gas to Synthetic Fuels*, Kennedy School of Government, Harvard University, Cambridge, Mass., 1974.

[7] Just, J., B. Borko, W. Parker, and A. Ashmore, *New Energy Technology Coefficients and Dynamic Energy Models*, Vols. I and II, Report MTR-6810, Mitre Corporation, Bedford, Mass., 1975.

[8] Dantzig, G.B., *Formulating a PILOT Model for Energy in Relation to the National Economy*, Technical Report 75-10, Systems Optimization Laboratory, Stanford University, Stanford, Calif., 1975.

[9] Dantzig, G.B., *A Note on the Objective of the PILOT Model*, Technical Report 75-20, Systems Optimization Laboratory, Stanford University, Stanford, Calif., 1975.

[10] Beale, E.M.L., Sparseness in Linear Programming, in J.K. Reid, ed., *Large Sparse Sets of Linear Equations*, Academic Press, London, 1971.

[11] Dantzig, G.B., *Linear Programming and Extensions*, Princeton University Press, Princeton, N.J., 1963.

[12] Glassey, C.R., Nested Decomposition and Multi-stage Linear Programs, *Management Science*, 20 (1973), 282-292.

[13] Ho, J.L., *Nested Decomposition of Large Scale Linear Programs with Staircase Structure*, Technical Report SOL 74-4, Department of Operations Research, Stanford University, Stanford, Calif., 1974.

Computer Networking

A. Butrimenko

During the last few years, the development of the computer world has been characterized by the creation of national and international computer networks. Expectations of better and more effective use of computers are related to the creation of computer networks. Development of computer networks began almost simultaneously during the 1960s in the USA and the UK. Currently, almost all countries in Europe and North America possess or have built a computer communication network. A large-scale experiment in the USA--the ARPA network--has significantly influenced these developments. A geographical map of this network is shown in Figure 1.

The question arises: except for the progress made thus far in data transmission and the interconnection of computers, are there further reasons for these expectations? The first and most obvious reason is the cost savings and improved services that can be realized with the use of computer networks. Figure 2 shows some results of a University of Illinois study of cost savings in a computer center after the ARPA network had been set up [1]. Let us look at how these improvements can be achieved. First, we must distinguish between the two parts of the computer network: *computer centers*, and *the communication network* (overhead needed to connect the centers) that is usually based on the packet-switching technique.

From a methodological point of view, computer networks and packet-switching communication have a similar basis, namely, resource sharing.

The first and probably most essential requirement for the success of the computer network is that the two resource-sharing techniques--time sharing and packet switching--occur simultaneously and thus be combined in one system, namely, the computer communication network.

As in any resource-sharing system, economy of scale increases with the number of users and resources involved. Let us look at existing terminal users. Figure 3 shows the comparative growth of terminal population in the USA and Western Europe over the period 1970-1985 [2]. User population development is also characterized by significant changes in the share of the market of mini, small, medium, and large computers, as illustrated in Figure 4 [3]. Moreover, the classes of computers are themselves undergoing change. Table 1 shows the expected capabilities of four future computer classes.

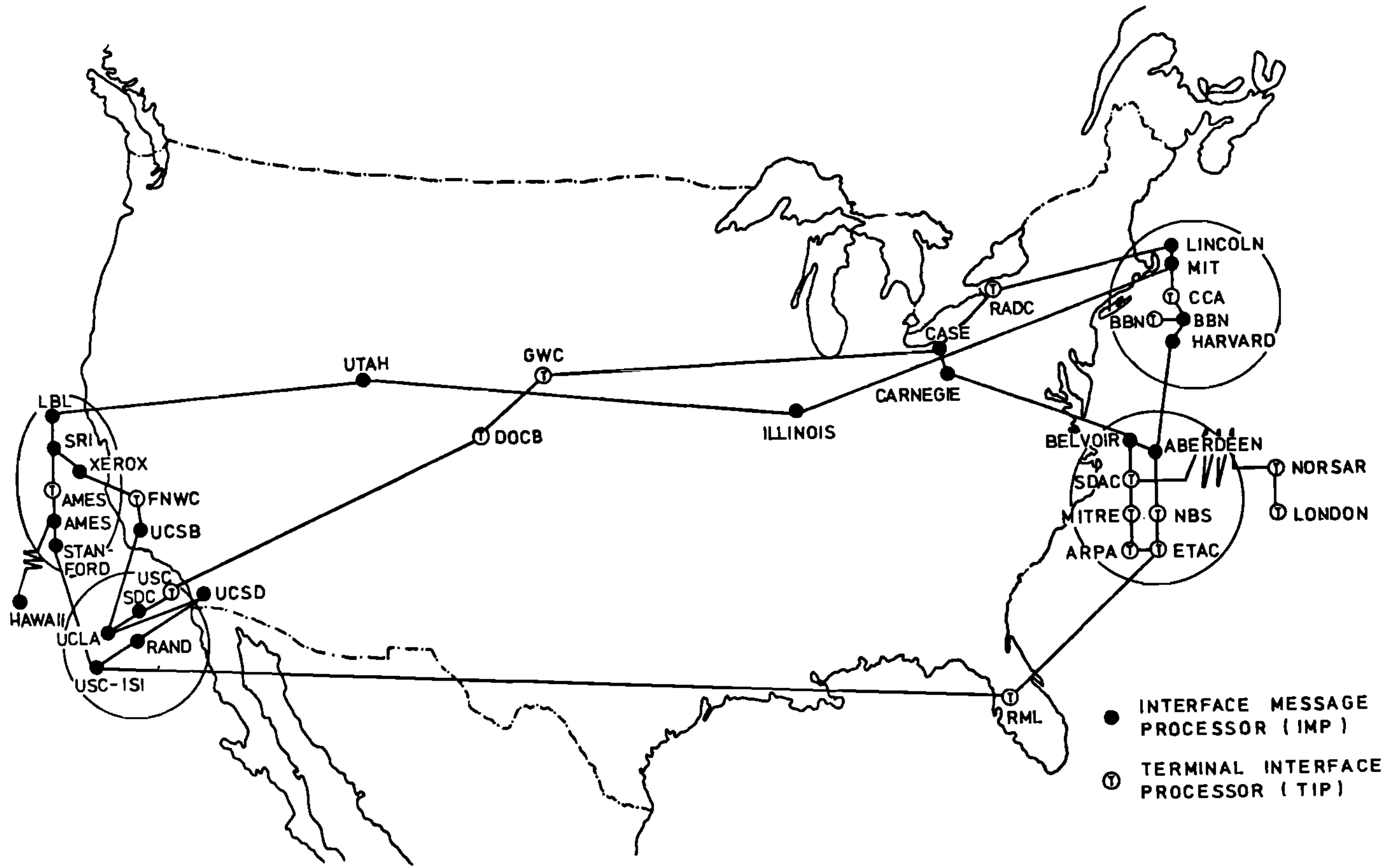


Figure 1. ARPA network.

BEFORE SPRING 1972	AFTER SPRING 1972
B6700	ARPA Network
$40,000/Month	$16,000/Month
To Have the Same Service Would Require an Increase of	Labor Costs Reduced By a Factor of
►100 TO 200%	► 2 TO 5%

Figure 2. Results of study of a computer center by the University of Illinois.

Source: [1]

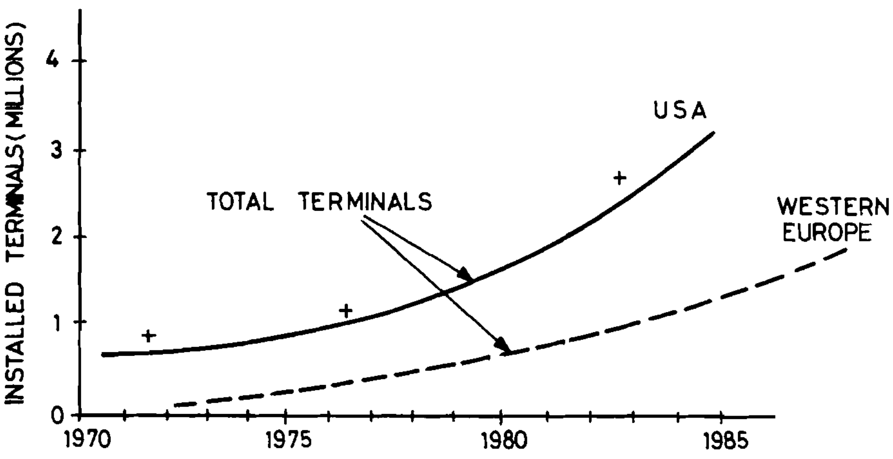


Figure 3. Comparative growth of terminal populations, USA and Western Europe, 1970-1985.

Source: [2]

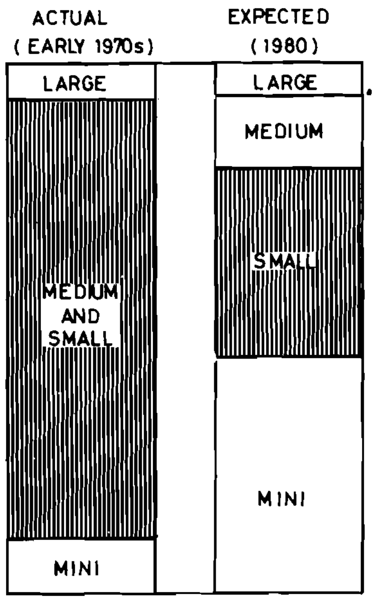


Figure 4. Changes in share of market of different-sized computers.

In addition to the rapid *increase* in the number of remote users, many institutions are now able to acquire computers, thus contributing to the growth of potential members of the computer network community. This development is also seen in the rapid *decrease* in the costs of computers. For the period 1977-1985, the costs for minicomputers are expected to decrease from $10,000-20,000 to $7,000-10,000, and for large computers from $1.5-2.5 million to $1-2 million [4].

Let us look at some details of resource sharing through a computer network. The major shared resources are personnel, programs, and data. Resources can be divided into those available at computer centers, and those associated with a data communication network. Resources in *computer centers* are *hardware* (processors, storage, devices), *software* (programs, compilers, data, etc.), and *personnel*. Resources in a *data communication network* consist of *lines*, *nodes*, and *personnel*.

Table 1. Future computer classes.

	Microcomputer		Minicomputer		Monocomputer		Multicomputer	
	1977	1985	1977	1985	1977	1985	1977	1985
Typical use								
On-line (users)	1 or	5-10 or	6-10 and	10-20 and	10-20 and	20-40 and	Complete intermixing, job determines limit	
Batch (streams)	1	1	1	1	4-6	6-8		
Main memory (bytes)	4-8KB*	32-64KB	32-64KB	0.2-0.5MB**	0.5-2MB	2-4MB	2-16MB	8-64MB

*Kilobytes.

**Megabytes.

Source: [4]

Let us examine the relationship between hardware and software. Cost trends in hardware and software for the period 1955-1985 are shown in Figure 5 [5]. A study conducted by the IBM World Trade Corporation [6] shows that in 1965, personnel costs were already higher than hardware costs, and this tendency will continue (Figure 6). Thus, economically, the most significant part of *shared resources* is personnel, followed by software, and lastly by hardware.

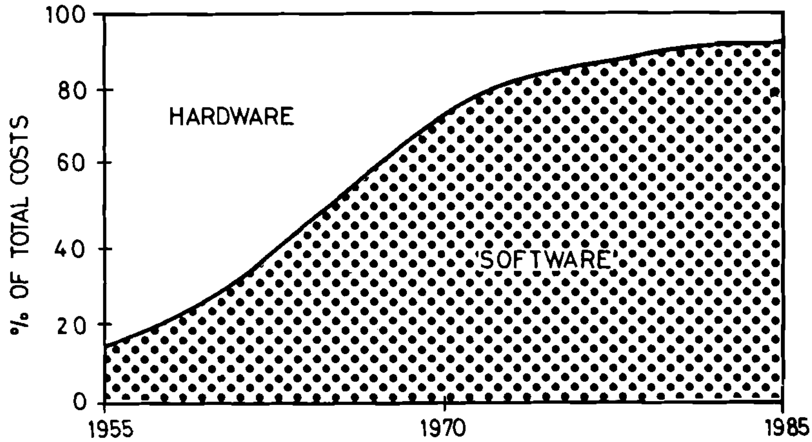


Figure 5. Hardware/software cost trends, 1955-85.

Source: [5]

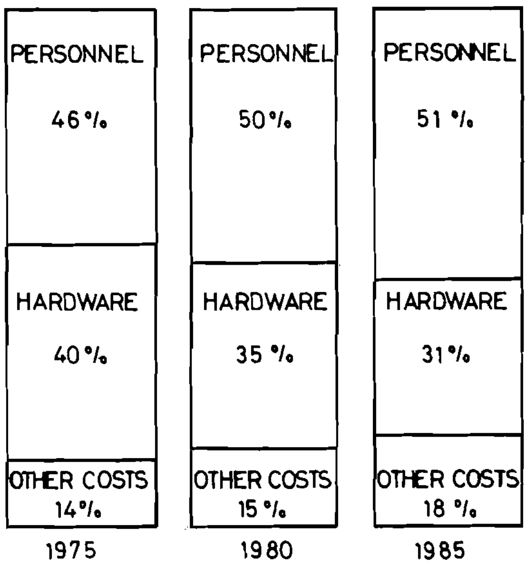


Figure 6. Typical data processing budget.

Figure 7a gives a breakdown of costs of resources (expressed as percentages of rental costs) of a computer center and a data communication network. We can see that the data communication network (overhead) itself (4.3 percent) represents a relatively small part of the costs involved in the entire system. A similar breakdown of the budget of a data communication network shows the cost of personnel to be 42 percent, of lines 32.5 percent, and of nodes 25.5 percent (Figure 7b).

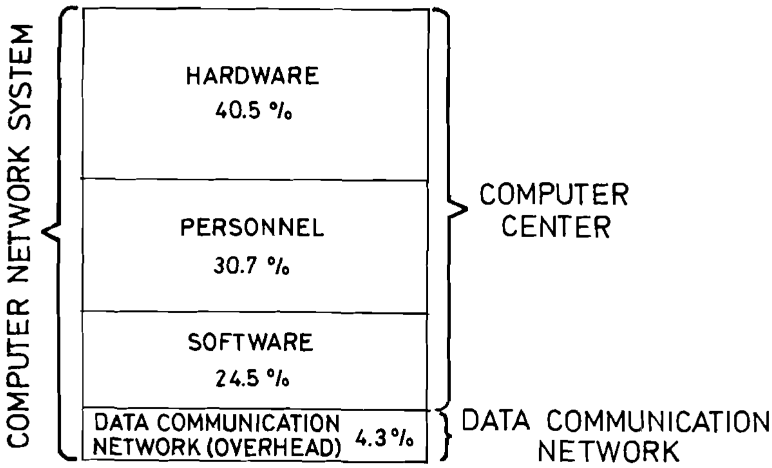


Figure 7a. Costs of computer network system (expressed as percentages of rental costs).

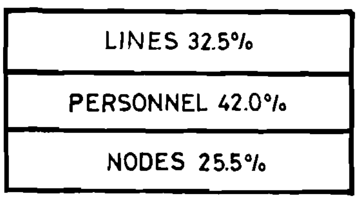


Figure 7b. Costs of data communication network (expressed as percentages of rental costs).

A noticeable breakthrough in communication technology was achieved as a result of the packet-switching technique. Figure 8 shows schematically the difference between well-known channel switching (e.g., telephone communication), and packet switching. Packet switching is economically preferable for a number of reasons--in particular improved resource sharing. Because of data transmission, pieces of information packages can be delivered with a certain delay; queueing is therefore possible, resulting in significant improvements in line usage. (This is practically impossible by voice communication.) Moreover, because information is in the form of data, it is possible to use high-speed lines. This is impossible where there is a deficiency in the channel-switching technique for high-speed channels. The third and most significant reason is that the application of modern computer technology makes data processing in communication nodes very economical. Figure 9 demonstrates the cost differences for packet switching, using the ARPA network as an example [7]. As regards the breakdown of expenses for data network operations (Figure 7b) mentioned earlier, we can expect some decrease in the costs of nodes and lines, and probably of personnel.

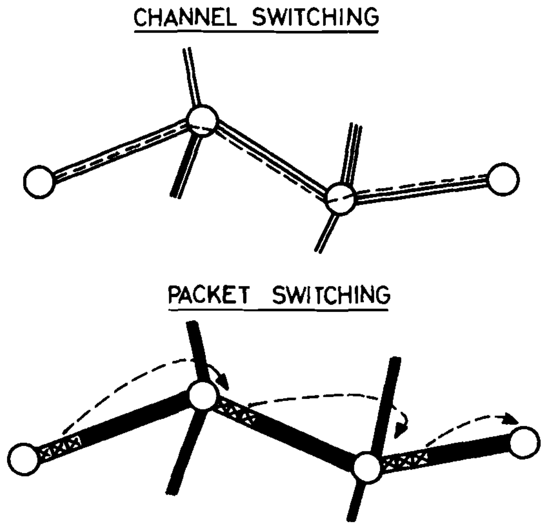


Figure 8. Channel and packet switching.

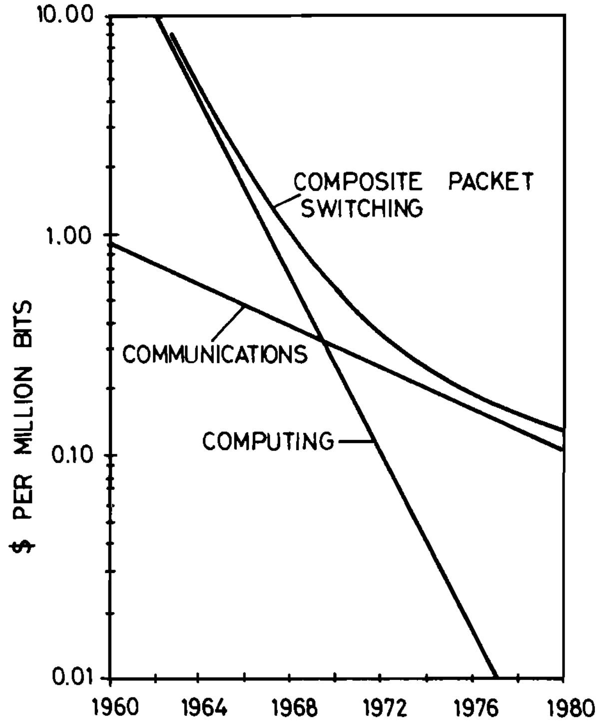


Figure 9. Costs of data transmission.

We can now state that economy of the computer network system is achieved as a result of sharing the resources of computer centers and the data communication network.

The nature and scope of IIASA's activities have been discussed in previous presentations.* Here we shall focus attention on the need for the IIASA Computer Network, which has developed as a direct consequence of the kind and mode of operations at IIASA.

IIASA began a practical networking activity in 1974 by initiating a series of experimental connections. Since then, connections have been made from IIASA to Moscow, Bratislava, Pisa, Edinburgh and Budapest; from Bratislava to Moscow; and from Budapest to Paris. We recognize the ever increasing importance of this activity for IIASA, and for international cooperation in various fields.

---

*See, for example, presentations by J. Gvishiani and by R.E. Levien in Volume 1.

In December 1975, IIASA established Steering and Technical Committees, composed of representatives from the participating computer centers, who meet quarterly. At the last meeting of the committees, held in Budapest in April 1976, 19 national institutions were represented, 12 of whom committed themselves to active participation in the IIASA Computer Network. Discussions centered on establishing a communication subnetwork. Figure 10 shows the hardware allocation for participation in the Network.

The IIASA Computer Network is viewed as an effective tool for the exchange of computer programs and data between IIASA and collaborating institutions. It represents a case study of the application of systems analysis in an international setting. About 60 scientists from participating institutions are involved in the development of the Network.

The first activity--a basic long-term service-oriented project--seeks to bridge the information gap between IIASA scientists and scientists at participating national institutions. Its success will lead to the close integration of larger teams at IIASA and at institutions in the IIASA National Member Organizations (NMOs), and thus will provide the means for geographically distributing the teams. Moreover, it will be possible to cover larger areas, and to establish a basis for new fields of research currently beyond IIASA's capacity and capability.

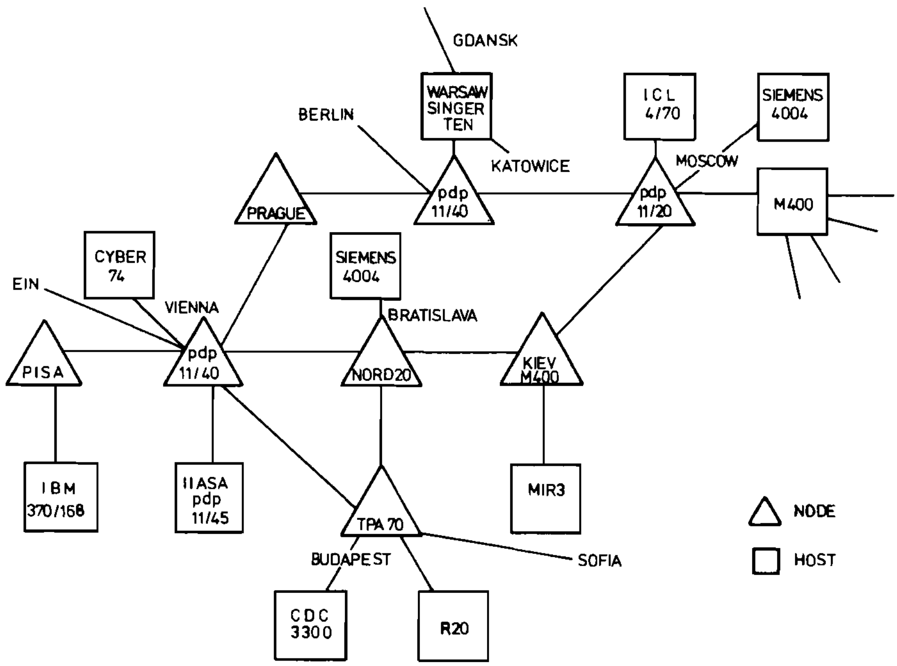


Figure 10. IIASA Computer Network.

In establishing the IIASA Computer Network, we encountered a number of problems that are--and will be--common to future European and worldwide computer networks.

Implementation of the Network is based on some guiding principles. We adopt existing standards wherever possible; where this cannot be done, we promote the development of standards for international networking, in cooperation with the International Standards Organization (ISO), the International Federation for Information Processing (IFIP), and the Comité Consultatif International Télégraphique et Téléphonique (CCITT). Our long-range goal is to connect individual centers in various countries, and to establish a base for interlinking the computer networks in the NMOs, which are obviously developing their own rules. The first stage of development concentrated on existing computers (hosts and nodes), with the goal of building a *cooperative network* of institutions rather than a *technically advanced network*. During this stage, we restricted our requirements to include only existing communication facilities (basically a dial-up telephone network) since we did not envisage heavy use of the Network at this phase. To facilitate access to the Network, we avoided as much as possible modifying host operating systems.

Let us look at some of the problems involved in the development of the Network. Figure 11 schematically shows communication procedures (usually known as protocols) that must be implemented

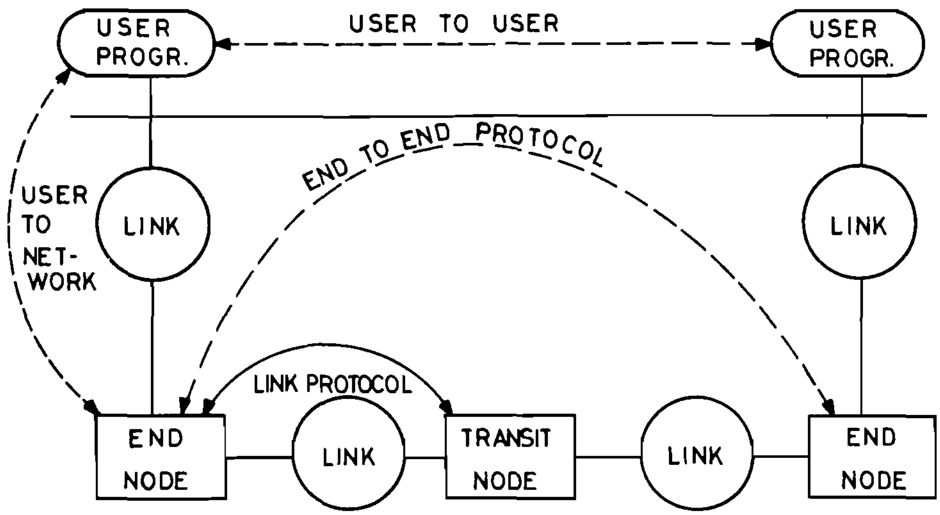


Figure 11. Protocols in the IIASA Computer Network.

at the Network. The fundamental problem is communication between two user processes, implemented at various host computers. To do this three types of protocols are needed: link, end-to-end, and user-to-user.

At the lowest level is the data link control that is needed to arrange error-free transmission of packets between two adjacent packet-switching nodes. The second level--the end-to-end protocol--supervises the transmission of the whole message; additional procedures are required for communication between the host and the Network. The user-to-user protocol makes possible communication between two remote programs.

Some of the functions that must be implemented in the nodal operating system are discussed below.

Link Protocol. The HDLC (High-Level Data Link Control) procedure is accepted and implemented on a few lines as a basic protocol for delivering data between adjacent nodes. The general scheme of the HDLC protocol has been proposed by the ISO. Some slight modifications have been necessary to adjust it to the low-quality telephone lines that are being used in the initial stage of developing the Network. These modifications concern mainly the symmetrization of the protocol for the primary and secondary nodes [8]. Analytical studies have been conducted on the optimal length of the information part of the general form of the HDLC format [9].

Packet Format. There is no standard for the packet format, but the International Network Working Group of the IFIP (TC6/WG6.1) has tabled two possible standards--called the F and the D standards. Our choice is a particular case of the D format that is completely compatible with the European Informatic Network (EIN).

Nodal Operating System. Proposals for a nodal operating system were discussed at the last Technical Committee held in Budapest. It was generally agreed to accept the Hungarian proposal for the so-called NOTA system [10], with some modifications. Work on modifying the system will be started shortly by scientists from the NMOs who will work at IIASA. We hope that this proposal will be accepted for implementation at a forthcoming meeting of the Technical Committee, to be held in Warsaw in early June.

Some other tasks must also be faced. The practical use of available computer facilities depends on the progress in establishing a communication subsystem. This can be accomplished through close cooperation with PTT (post-telephone-telegraph) authorities in participating countries. We are now involved in a detailed elaboration of communication system requirements for the IIASA Computer Network. Also, special questionnaires have been drawn up at IIASA and distributed among the Network participants, with a view to determining the most economic configuration for the Network.

At a very early stage, we recognized the need to have a clear understanding of user requirements, and to identify their interests and potentials. There are some interesting examples of remote cooperation with computer usage.

The IIASA Energy program is currently working on developing energy models, of which some have been installed at IIASA and others are being transferred to computers available to IIASA. However, it is not always possible or feasible to transfer all programs to IIASA; considerable manpower is needed. Also, not every program can or should be transferred; first it should be determined whether its use is feasible. For example, the Energy program is interested in models that have been developed and installed at the Siberian Power Institute in Irkutsk, and the latter also is interested in programs available at IIASA. Both groups have requested our help in arranging remote use of the programs through the IIASA Computer Network.

Two new tasks have been initiated at IIASA during this past year: the establishment of data banks, and program libraries. They will complement the Network activity, thereby providing remote access to the IIASA data bank and programs in the NMOs and at IIASA.

Because of the specific characteristics of the IIASA Computer Network, we have developed it on a cooperative basis. Of the computer centers in the Network, IIASA provides some form of coordination, although it does not act as headquarters for the Network. The leading role in a specific area is assigned to a particular group. For example, by common agreement, responsibility for HDLC maintenance was assigned to the Hungarian group.

Technical papers on computer science networking are issued by the Computer Science project (see, for example, [8,10].) Working groups on specific topics (e.g., communication requirements and user requirements) have also been established.

Several workshops on packet protocol have been conducted; workshops on such subjects as host-to-host protocols are envisaged.

References

[1] Sher, M.S., A Case Study in Networking, *Datamation*, 3, 3 (1974).

[2] Page, J., *The Networking of Scientific and Technical Information*, Organisation for Economic Cooperation and Development, Paris (forthcoming).

[3] Butler, R.E., *International Cooperation and Regulation for Development*, paper presented at the Conference of the International Council for Computer Communication, Stockholm, 1975.

[4] Withington, Frederick G., Beyond 1984: a Technology Forecast, *Datamation*, 21, 1 (1975), 21 ff.

[5] Boehm, B.W., *Software and Its Impact: A Quantitative Assessment*, Rand Corporation, Santa Monica, Ca., 1972.

[6] IBM World Trade Corporation, *Report of a Delphi Study: Data Communications in Europe Through 1975*, White Plains, N.Y., 1973.

[7] Roberts, L.G., Data by Packet, in *IEEE Spectrum*, 11, 2 (1974), 46 ff.

[8] Sexton, J., *IIASA Data Communication Network, Data Link Control Procedure*, CSN-0043, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[9] Masunaga, Y., *Optimization of the HDLC I-Frame Structure and IIASA Data Communication Network*, RM-76-7, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[10] Darvas, P. and A. Labadi, *NOTA: Node Task Activating for the International Institute for Applied Systems Analysis*, CSN TPA 7025 Node, CSN 0072, internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Aspects of Multiple-Objective Evaluation at IIASA

R.L. Keeney

INTRODUCTION

The purpose of applied systems analysis is to improve decision-making. This includes obtaining a better understanding of the problem, generating creative new alternatives, and improving information and communication. Ultimately, all may be used for evaluating the alternatives, either formally or informally, and for making decisions.

In prescribing which of several alternatives to select, the evaluation should depend on two aspects:

1. Possible consequences and likelihood of each of the alternatives;
2. Preferences of the decision maker for these consequences.

If one chooses to formally analyze the overall decision-making process to prescribe what should be done, the structure of the model may be depicted as in Figure 1. The system model characterizes aspect 1 above, and specifies the possible consequences of each of the alternatives. These consequences indicate the degree to which the objectives are achieved. The preference model evaluates these consequences. IIASA's research on multiple-objective evaluation addresses this part of the overall analysis.

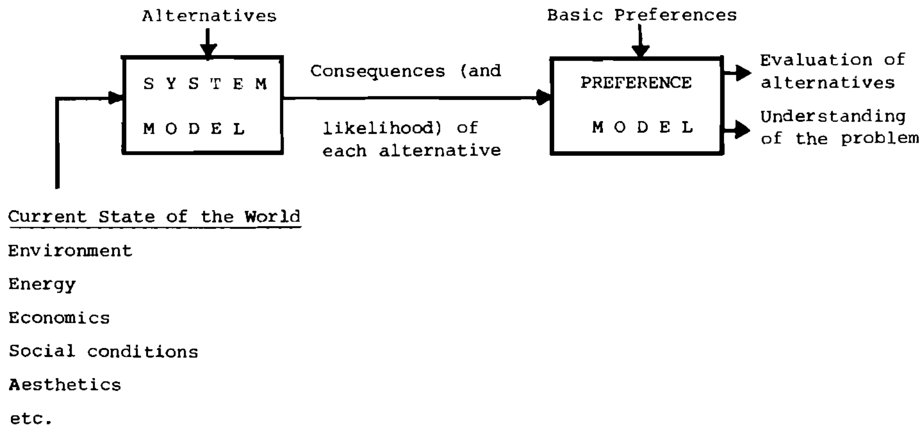


Figure 1. Model to aid decision-making.

The results of the analysis should be a thorough appraisal of each of the alternatives and an improved understanding of the implications.

THE MULTIPLE-OBJECTIVE PROBLEM

One of the underlying characteristics of the types of problems being addressed at IIASA is that they involve *multiple conflicting objectives*. Once inferior strategies, in the sense that they are dominated in all objectives, are eliminated from consideration, we can increase industrial output only at the expense of our environment; we can produce and consume more now, but only at the expense of our consumption next year and the consumption of future generations; and we can please one interest group more only at the expense of others. In each of these situations the issue that must be addressed involves trying to find some desired (fair, equitable) balance of impacts over the various objectives. Addressing this issue requires considering value tradeoffs--that is, specifying how much achievement in terms of an objective one is willing to forego to increase achievement on another objective by a fixed amount.

Unfortunately, most problems have complications that add to the complexity of the value tradeoff issues. One of these is *intangible factors*, as for example, aesthetics in environmental problems, pain and suffering in medical problems, and morale in organizational problems. Often there are no obvious measures for achieving the objectives considered important in a particular context.

A further level of complexity results from *uncertainties*. At the time one evaluates alternatives and makes decisions, it is often impossible to predict the consequences of each of the alternatives. It is often appropriate to include these uncertainties in an evaluation of alternatives.

An issue related to those above and compounding the complexity of the problem is that of *multiple decision makers*. For many of the problems of interest to IIASA, there is no single, clearly designated decision maker. Descriptively, it will be important to recognize this in models attempting to describe the overall decision-making process. Prescriptively, often the problem can be analyzed from the viewpoint of one of the decision makers in an attempt to aid his decision. However, it may be worthwhile to aggregate the preferences of many of the decision makers so as to evaluate alternatives from the viewpoint of the group of decision makers.

Collectively, the six issues mentioned above define the domain of interest of the multiple-objective evaluation cross-cutting theme. To review, these issues are:

- Multiple objectives,
- Intangible factors,
- Uncertainties,
- Impacts over time,
- Different interest groups,
- Multiple decision makers.

The multiple-objective evaluation program at IIASA has addressed each of these issues. The program itself can be categorized into three areas: methodological research, communication, and applications. After defining a minimum of notation, we will briefly survey the results of the program in each of these areas.

Let $X_1, X_2, \ldots, X_n$, designate n attributes (measures of effectiveness) that, respectively, indicate the degree to which objectives $O_1, O_2, \ldots, O_n$, are achieved. A specific level of attribute X_i will be designated by x_i, so that a possible consequence of an alternative is designated by $\underline{x} \equiv (x_1, x_2, \ldots, x_n)$. With this terminology, the output of the system model shown in Figure 1 is a probability distribution function $p_A(\underline{x})$, which specifies the probability of the various possible consequences of alternative A. This information is input to the preference model.

The preference model is a von Neumann-Morgenstern utility function. Formally, this utility function satisfies a set of axioms which imply its existence and properties (see, for example [1,2]). Informally, such a utility function is an objective function (to be maximized) with one special property: the expected utility of an alternative is the appropriate index of the desirability of the alternative. Given the probability distribution $p_A(\underline{x})$ and a utility function $u(\underline{x})$, the expected utility can be calculated in a straightforward manner.

By defining the X_i, $i = 1,2,\ldots,n$, to cover either different objectives, different time periods, or *different interest groups* the value tradeoff issues of the multiple-objective evaluation problem are addressed in assessing u. Some of the attributes X_i may have to be subjective scales which address the intangible factor issue. The expected utility property mentioned above allows one to consider uncertainties in a rigorous and logically consistent manner. If utility functions are assessed for each decision maker, utility theory may also help address the multiple decision maker issue. The basic theory is sound and rests on a foundation (i.e., the axioms of utility theory) that many individuals consider appropriate for prescriptive decision-making. Because it does address the issues of real problems and because the problems are complex, implementation of the theory is not easy. The multiple-objective evaluation program attempts both to extend the theory in ways appropriate to specific characteristics of the problems being investigated, and to contribute to the knowledge and experience concerning applications.

METHODOLOGICAL RESEARCH

Two of the methodological results recently worked out at IIASA address the issues of impacts over time and multiple decision makers.

Impacts Over Time

Very little of the methodological research on preferences over time has accounted for dependencies among time periods. And yet in many situations preferences for various levels of an attribute now depend on what they have been in the past and will be in the future--especially in the recent past and the near future. For instance, one's relative preferences for various levels of environmental pollution may well depend on the pollution levels one has been experiencing. David Bell has derived some formulations for utility functions explicitly accounting for interperiod dependencies [3].

Let $X_1,\ldots,X_t,\ldots,X_T$, be attributes representing consequences in time periods $1,\ldots,t,\ldots,T$, respectively. Then one defines $\{X_1,\ldots,X_{t-1}\}$ to be conditionally utility independent of $\{X_{t+1},\ldots,X_T\}$, if whenever X_t is fixed, then $\{X_1,\ldots,X_{t-1}\}$ is utility independent* of $\{X_{t+1},\ldots,X_T\}$. This type of assumption allows preferences in the periods 1 to t-1 and t+1 to T to depend on the consequences in the adjacent period t but not on periods further away. Bell's result proves that if $\{X_1,\ldots,X_{t-1}\}$ and $\{X_{t+1},\ldots,X_T\}$ are conditionally utility independent of each other for all $t = 2,\ldots,T-1$, then the utility function $u(x_1,x_2,\ldots,x_T)$ over all T periods is specified by the T-1 two-attribute utility functions $u_t(x_t,x_{t+1})$, $t = 1,\ldots,T-1$, and by some scaling constants. The two possible forms of the resulting utility function are given in Bell. An application of this result to the spruce budworm problem is summarized later in this paper.

Multiple Decision Makers

One important result concerning the aggregation of preferences of several individuals is Arrow's Impossibility Theorem [5]. Arrow's problem, which took as given the rankings r_j of

---

*An attribute set Y is utility independent of a set Z if preferences for lotteries on Y do not depend on the level of Z (see [4]).

alternatives by N individuals, $j = 1,\ldots,N$, was to aggregate these to obtain a group ranking r_G. He postulated five "reasonable" assumptions for aggregation, and proved that no aggregation scheme was compatible with all five. Since it used rankings, Arrow's formulation did not incorporate any concept of strength of preference, nor did it allow for an interpersonal comparison of preferences.

Arrow's result has had a monumental impact, and many people are familiar with the general ideas but not with the details. Thus many have misinterpreted his result to indicate that there is no rational way to combine the *individual's preferences* to obtain the *group's preferences*. Informally, the result does say there is no way consistent with his five assumptions to combine the *individual's rankings* to obtain the *group's rankings*. When the problem is changed from rankings to utilities, one can aggregate to obtain group preferences.

Let u_j, $j = 1,2,\ldots,N$, be a utility function over consequences $\underline{x}$ for individual j. Using five assumptions analogous to those of Arrow, and using utilities instead of rankings, it is proved in [6] that the group utility function u_G must be

$$u_G(u_1,\ldots,u_N) = \sum_{j=1}^{N} k_j u_j(\underline{x}) \quad ,$$

where the k_j are scaling constants requiring interpersonal comparison of preferences, i.e., value tradeoffs among individuals. An individual's strengths of preferences are incorporated in the utility function u_j.

COMMUNICATIONS

To facilitate international scientific exchange and communication, IIASA hosted a workshop on Decision Making with Multiple Conflicting Objectives, held at Laxenburg, Austria, on October 20-24, 1975. Approximately 30 scientists from 14 countries met to

- Review, contrast, and appraise the several basic approaches for decision-making with multiple objectives;
- Discuss applications involving multiple objectives in progress at IIASA;
- Learn of applications involving multiple objectives, conducted elsewhere, that were relevant to the IIASA program.

The proceedings of the workshop are scheduled to appear in the IIASA-State-of-the Art Series in Applied Systems Analysis.

In addition, a number of IIASA technical reports describing various methodological advances and applications of multiattribute utility have been produced; many are referenced in this paper. Also, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs* by Howard Raiffa and myself [4] was completed at IIASA and is scheduled to appear in autumn 1976. This book concerns the theory, assessment, and application of multiattribute utility.

APPLICATIONS

Here we will briefly describe four IIASA applications involving multiple objectives. Each of these focuses on some of the issues of multiple-objective problems already described.

Spruce Budworm

The spruce budworm is a forest pest that harms the forests of New Brunswick, Canada. A team led by C.S. Holling investigated the impacts of various control strategies (e.g., selective cutting, insecticides) on objectives such as area employment, logging company profits, and the recreational value of the forest. Using his theory of preferences over time described earlier, Bell [7,8] quantified in detail the preferences of Bill Clark, one of the team members. After various iterations, this procedure actually motivated the development of his theory. The most unique feature of the study involved the detailed quantification of a utility function for multiple-objective impacts over time. Recent empirical assessments in New Brunswick by Bell have indicated the appropriateness of this theory for modeling the preferences of forestry officials there.

Energy Policy

The IIASA program on energy/environmental systems under the direction of W. Foell has examined the implications of various alternatives, differing in terms of fuel source and degree of energy conservation, for the German Democratic Republic, the Rhône-Alpes region of France, and the State of Wisconsin in the USA. Buehring and Foell [9] describe a system model that indicates the impacts of these alternatives in terms of 11 attributes, including fatalities, SO_2 pollution, radioactive wastes, and energy produced. Utility functions were assessed over these four attributes for individuals in each of the three regions [10]. Utility functions were assessed over all 11 attributes for two individuals from Wisconsin. These assessments allowed comparison of different individuals' preferences. Also, one assessment is described in complete detail [11] to indicate how such assessments can be conducted.

Tisza River Basin

The Hungarian National Water Authority and IIASA cooperated in examining several alternatives for further developing the water resources of the Tisza River basin. The consequences included several intangible factors such as social impacts, international cooperation required, developmental possibilities, and flexibility to adapt the selected strategy. In working toward a clear definition of attributes to quantify these factors, it became apparent that there were subtle ways in which "double counting" could present difficulties in evaluating the alternatives. Hence, the main use of the preliminary preference model [12] is the implications that it has for better structuring the system model.

Salmon Fishing

The Canadian Department of the Environment must specify fishing policy--who can fish what, where, when, using which methods--on the Skeena River in British Columbia. The consequences of any policy impact several groups: net fishermen, lure fishermen, sport fishermen, regional interests, native Indians, and the government. To quantify the preferences of these various groups for the possible consequences, both R. Hilborn and C. Walters expressed utility functions representing what each felt were the interests of each group. Then they viewed the problem from the governmental viewpoint and specified an overall utility function explicitly addressing the value tradeoffs among the groups. These results are examined and contrasted in [13]. More recently, Hilborn [14] coordinated a workshop, involving individuals from the different interest groups, that made some initial steps to assess their own utility functions.

CONCLUSIONS

Collectively, the methodological research and applications address each of the six issues of the multiple-objective problem outlined earlier. None of them formally addresses all of the issues. Nevertheless, each contributes experience to help in this "super application" when it is attempted. The general spirit of the research is to lend insight for improving the overall modeling process (see Figure 1), which then should aid decision makers facing such problems.

A viewpoint often expressed concerning preference models is: *the entire process is too subjective, whereas models to aid decision makers should strive to be objective.* I personally feel there is no such thing as an objective, value-free analysis that models a policy decision. The crucial processes of defining the problem, specifying the alternatives, clarifying the objectives, selecting the attributes, and building the system model are all subjective. Similarly, value judgments and utility assessments are subjective, yet they are an integral part of policy problems and must be taken into account. The choice is to include them formally or informally, rather than to include them or not.

For many important policy analyses, the effort involved in formalizing the system model adds up to several man-years, whereas at most a week may be used to build a preference model. The methodological tools and assessment know-how are currently available to build sophisticated preference models. Shifting some of the effort from modeling the system to modeling the preferences could have important desirable effects. IIASA's work on multiple-objective evaluation has led to an understanding of how we could more effectively utilize this additional effort.

References

[1] von Neumann, J., and O. Morgenstern, *Theory of Games and Economic Behavior*, 2nd Edition, Princeton University Press, Princeton, New Jersey, 1947.

[2] Savage, L.J., *The Foundations of Statistics*, Wiley, New York, 1954.

[3] Bell, D.E., *A Utility Function for Time Streams Having Inter-Period Dependencies*, RR-75-22, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[4] Keeney, R.L., and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York (forthcoming).

[5] Arrow, K.J., *Social Choice and Individual Values*, 2nd Edition, Wiley, New York, 1963.

[6] Keeney, R.L., *A Group Preference Axiomatization with Cardinal Utility*, RM-75-47, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[7] Bell, D.E., *Defining and Quantifying Goals for Measuring the State of an Ecosystem*, RR-74-26, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1974.

[8] Bell, D.E., *A Decision Analysis of Objectives for a Forest Pest Problem*, RR-75-43, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[9] Buehring, W.A., and W.K. Foell, *Environmental Impact of Electrical Generation: A Systemwide Approach*, RR-76-13, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[10] Buehring, W.A., W.K. Foell, and R.L. Keeney, *Energy/ Environment Management: Application of Decision Analysis*, RR-76-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[11] Keeney, R.L., *Energy Policy and Value Tradeoffs*, RM-75-76, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[12] Keeney, R.L., E.F. Wood, L. David, and K. Csontos, *Evaluating Tisza River Development Plans Using Multiattribute Utility Theory*, CP-76-3, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[13] Keeney, R.L., *A Utility Function for Examining Policy Affecting Salmon in the Skeena River*, RM-76-5, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

[14] Hilborn, R., *Preferences for Salmon Management on the Skeena River*, PR-2, Institute of Resource Ecology, University of British Columbia, Vancouver, 1975.

Resilience and Related Mathematical Concepts

H.R. Grümm

I would like to present a methodology, a qualitative-topological approach suited for, but not completely restricted to, systems that can be modeled through differential equations. Although no one has ever written down a set of differential equations for the complete evolution of an economy or a society, such models are being applied with increasing success, for example, in ecology and climatology.

A set of differential equations describing a particular system has deeply impressed researchers for some time, since it is the best expression for causality. Let us recall Laplace's demon who, from a knowledge of all the laws of the universe (expressed by differential equations) and the initial conditions, could calculate numerically the world's past and future evolution. Long ago we realized that reality defaults from this ideal in two aspects: even if we know the laws, we do not know exactly the initial conditions, and numerical solutions are inadequate for understanding a system's structure. Thus, people began to look in a geometric way at the state space and particularly at the points or states where the system would tend asymptotically: the stable equilibria. Many methods and concepts address themselves to the problem of stability of a single fixed point. This situation is typical of a linear system such as a linear electric network. In reality, all linear systems are an approximation of a real situation close to an equilibrium.

Recently, researchers from applied fields as well as pure mathematicians have realized that, for the global treatment of nonlinear systems, the framework of local stability analysis (one single fixed point) needed to be enlarged: systems tend to more complicated structures than to fixed points--attractors, and usually there is more than one attractor. People began to think of a qualitative description of a system in terms of these and other concepts from differential topology. Two Russian scientists, Pontryagin and Andronov, defined for the first time the important concept of structural stability, which was later developed and studied to a great extent by Smale and his school. Then René Thom claimed that structural stability was an essential property of any realistic model, since small errors in a description of the system should not affect the "gestalt" of the model, defined by a notion of structural equivalence. (Note that our modeling efforts will almost never capture the fine dynamic details of a system.) Let me briefly mention three developments along these lines, and present arguments to show that they all fit into a framework of methodology, an approach I call "Beyond Numerical Integration".

Catastrophe Theory of Thom. This theory addresses itself to the qualitative changes in the configurations of stable equilibria under variations of parameters. At present, it is restricted to systems that behave as if to minimize a potential function. The beauty of the theory is that it can proceed almost without knowledge of the underlying dynamical laws. But for exactly this reason, its predictions are vague.

The use of strange attractors in turbulence and other hydrological phenomena. The chaotic behavior of a turbulent gas or fluid has always puzzled theoreticians in this field. Ruelle and Takens [1] pointed out that this behavior could well be modeled by a so-called strange attractor (which will be discussed later in this report).

The Resilience Concept of C.S. Holling. From an analysis of the behavior of ecological systems, Holling deduced the need for a concept apart from traditional stability. It was soon realized that differential topology was the appropriate mathematical language for expressing these ideas.

IIASA's involvement with these developments stemmed from two sources. First, as already mentioned, Holling brought the resilience concept to Laxenburg where it was enthusiastically accepted by Häfele who, in his description of "measures for protection against the unknown", had come to similar conclusions. An informal "resilience group" was formed at IIASA whose members remained in contact after the departure of Holling and his group. During the past year, resilience has been applied to models of the Ecology and Energy projects. Holling's intuitive ideas were put on a firm mathematical basis and extended to control problems by David Bell and myself. This interproject collaboration could be called one of the most fruitful at IIASA. The actual experience with ecological systems of Holling and his co-workers blended perfectly with the mathematical knowledge of the methodologists involved.

The second line of research was initiated by T.C. Koopmans in late 1974. He saw applications of a new class of powerful fixed-point algorithms, developed originally for economic problems, to those fields where the locations of equilibria are important. These algorithms seemed particularly useful because they would find unstable equilibria, important in describing the basins of a system; also, they could perhaps be generalized to closed orbits or to more complicated situations. Thus, on Koopmans' initiative, a workshop was held at IIASA in July 1975 that brought together mathematicians and "methods consumers", i.e., ecologists, climatologists, economists, people interested in chemical evolution, and the like. Since then, work has proceeded along the lines of "qualitative description via differential topology" in collaboration with the Massachusetts Institute of Technology, Yale University, the University of British Columbia, and other groups.

The following presentation assumes a deterministic system, described by a differential equation on a manifold, the *state space*. Extensions of the theory to control or stochastic models are in progress. Central to the ideas outlined is the *phase portrait* (see Figure 1). Under a very general assumption, the state space of a system can be subdivided into a finite number of basins, each with a particular attractor. If the system starts in a particular basin, in the future it will inevitably tend to the corresponding attractor, which can be a stable equilibrium, a stable closed orbit, or a more complicated structure, indicated in the upper left quarter of Figure 1. Here I have sketched a so-called *strange attractor*, defined by the property of not being a smooth submanifold of state space. (I was somewhat hampered in this attempt by not having a pencil of zero width.) An impressive and plausible argument is that for multi-dimensional models the presence of strange attractors is to be expected.

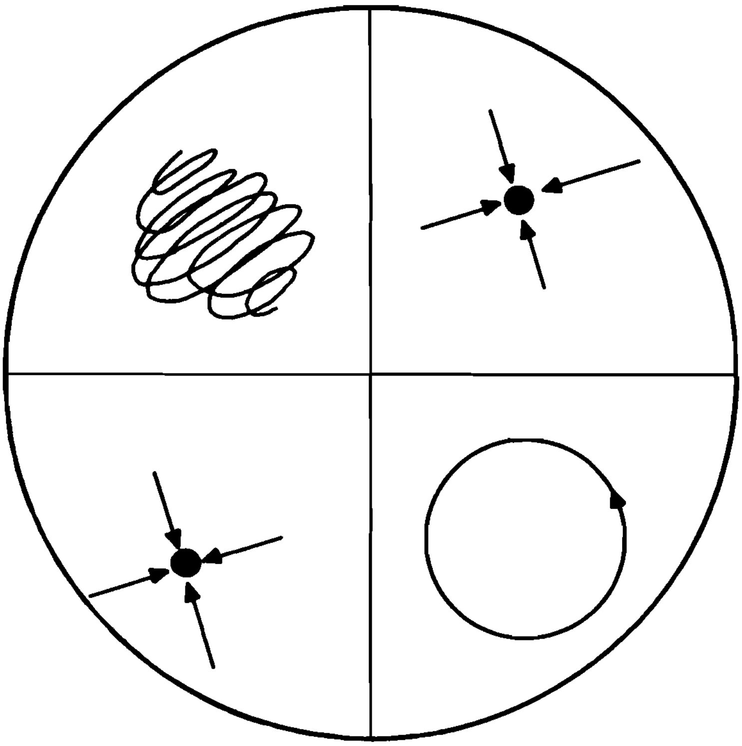


Figure 1. Phase portrait.

Attractors describe the possible modes of long-time behavior of the system: closed orbits indicate, for example, stable, periodic oscillations with a fixed amplitude. A word of warning should be inserted here: two-dimensional sketches on a screen or on paper deceive by their simplicity. A theorem by Peixoto sharply limits the complexity that a two-dimensional system can generally exhibit. The intuitive reason for this is that trajectories cannot cross in two dimensions. Thus, new phenomena and structures must be expected and actually do appear as we move on to three- and higher-dimensional situations. Although all basins are equal to the mathematician, for application we will have to put a value on each basin, reflecting our preference for ending up at the corresponding attractor.

Two lines of research have been pursued at IIASA, starting with the concept of phase portraits. The first is the rigorous definition of various resilience concepts, using the attractor-basin structure of the system. Let me recall Holling's original words when he introduced resilience: "a measure of the ability of a system to absorb changes in state variables plus parameters and still persist". To translate this, we can say that a system has absorbed a perturbation if, thereafter, it still tends toward the same attractor or toward a slightly modified one. Here, one has to distinguish between two concepts of resilience:*

- Resilience *in* state space (RISP), corresponding to changes in the state variables;
- Resilience *of* state space (ROSP), corresponding to changes in the parameters.

These two types of changes cannot be treated in the same way: the first type makes the system point "jump" in a fixed basin structure of the state space; the second type can change this very structure. Figure 2, outlining RISP, shows that a perturbation of the state variables (indicated by the dotted arrow) can transport the system to another basin where it will have different long-time behavior and trends. Figure 3, outlining ROSP, shows that a change in parameter can shift basins as well as attractors, such that the same point lies in a different basin; again the long-time behavior changes.

For ROSP, a further distinction must be made between *sudden parameter changes*, for example a new factory discharging pollutants being opened, and *adiabatic changes*, that is, changes over long periods relative to the typical time scale of the system.

---

*RISP refers to changes in a fixed phase portrait; ROSP refers to changes in its very structure.

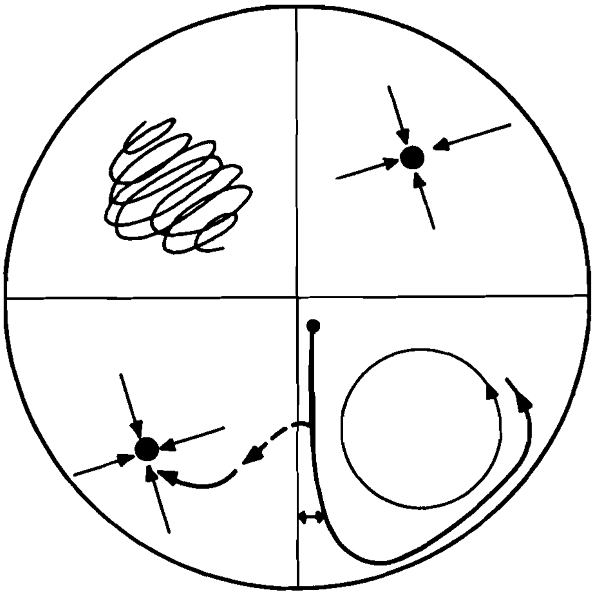


Figure 2. Resilience in state space (RISP).

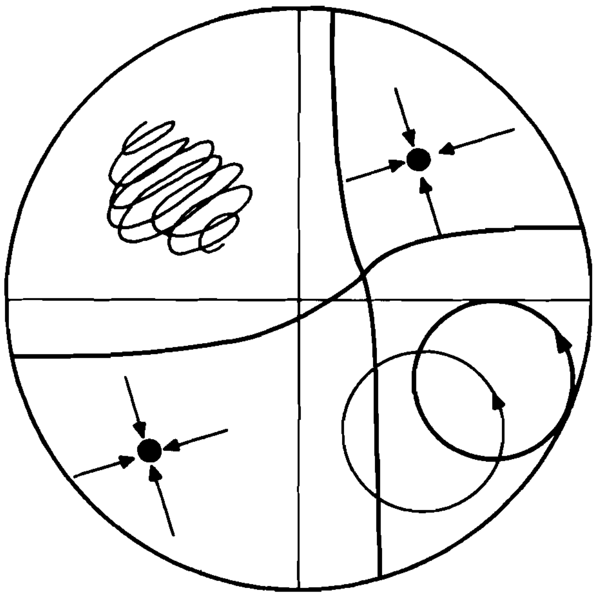


Figure 3. Resilience of state space (ROSP).

In the first case, basin boundaries can, so to speak, "jump" over the system point. For adiabatic changes, the system can "outrun" any motion of a basin boundary. By the time the parameters have changed significantly, the system will be almost on the attractor. Only the complete disappearance of a basin together with its attractor--or the appearance of new quasi-basins plus attractors--could be termed non-resilient behavior. Here the resilience concept is closely related to Thom's catastrophe theory: if all attractors of the system are stable equilibria, catastrophe theory quickly gives information on the surfaces in parameter space where attractors appear or disappear. Suddenly or adiabatically crossing these surfaces--which could be called parameter separatrices--will change the overall structure of the system.

For applications, we are interested in not only a qualitative concept of resilience, but also a quantitative measure of it. This presupposes certain information about the nature and size of the perturbations likely to occur, and various proposed measures are adapted in different degrees to the actual systems studied. A promising idea that is commonly pursued consists in looking at distances in state space to measure RISP: the minimum distance of a trajectory from the basin boundaries or from a suitably weighted average of distance to the boundaries can be taken (see Figure 2). This value can then be either treated as a function of the initial condition or averaged again over the basin. Of course, one encounters the familiar problem of balancing apples and oranges: the orders of magnitude of typical perturbations of different state variables--of different dimensions--have to be compared and combined, in a single distance notion, on the state space. Another possible resilience measure is the volume of the desired basin. This notion is mainly applied to ecological situations where there is an ensemble of similar systems; obviously it presupposes some information on the systems' distribution within the basin.

For calculating various resilience measures in an actual system, an algorithm for determining basin boundaries is needed. We have proved a general theorem on their location, which has been used for numerical evaluation. But approximations based on the Liapunov method are less time-consuming; although less accurate, they have been used by Gatto and Rinaldi in prey-predator models [2].

The second line of research focuses attention on one particular attractor and its changes, termed bifurcations, that result from parameter changes. Often a particular parameter--as for example, solar insolation in climatology, energy input to a food chain in ecology, the Reynolds number and other dimensionless numbers in hydrodynamics--can be viewed as a "driving force". That is, at low levels of this parameter, the attractors are stable fixed points; often there is only one attractor, as for example, laminar flow in hydrodynamics, or extinction in an ecological system. As the parameter increases, the fixed points bifurcate through various stages into more complicated structures: the strange attractors that describe the erratic behavior actually observed. As mentioned earlier, this approach in the case of hydrodynamics was pioneered by Ruelle; its use in food chain models was proposed by William Clark, formerly of the IIASA Ecology project, and myself.

A particular three-dimensional system of equations yields an attractor known as the Lorenz attractor, which is interesting for applications as well as for our understanding of the behavior to be expected from nonlinear systems. The actual form of the equations has an unexpected simplicity:

$$\dot{X} = \sigma(Y - X)$$

$$\dot{Y} = -XZ - Y + rX$$

$$\dot{Z} = XY - \beta Z \quad ,$$

where X, Y, Z are state variables, and σ, β, and r are parameters. The model was originally invented by Lorenz to solve a problem in aerodynamics [3]; it was later used for a semi-phenomenological description of the reversals of the Earth's magnetic field over geological times. For small values of r--the "driving parameter"--the system globally tends to a simple equilibrium; for larger values of r, there exist two stable equilibria, and as r increases further, a new mode of behavior is suddenly ignited. This mode of behavior first appears in one particular basin which, as r further increases, grows and swallows up the whole state space as all fixed points become unstable. The Lorenz attractor is characterized by the existence of two quasi-basins, corresponding to metastable regions; the system circulates in one of these basins for some time, then switches over to the other quasi-basin, circulates again and returns to the original quasi-basin. Figure 4 shows a projection of a sample trajectory on the attractor. This behavior characterizes the Earth's magnetic field, and also occurs in some ecological systems.

The most essential point here is that the sequence of times spent by the system in one of the quasi-basins is essentially random and uncorrelated, because the system is extremely dependent on initial conditions. In Figure 4, one can see two trajectories that start at nearby points indicated by Δ: one is still staying in the same quasi-basin, while the other is already in the other quasi-basin. Any two points arbitrarily close but on different trajectories will, given sufficient time, become uncorrelated in this sense. Actually, the sequence of "rotation numbers"--how many rotations the system makes in one-quasi-basin at a time--is a Markov sequence. But, although the motion on the attractor is erratic, we are still dealing with an attractor: all points in state space will, over long times, behave in this way. Strong ergodic theorems allow one to calculate time averages from the position of the attractor: this is obviously very interesting

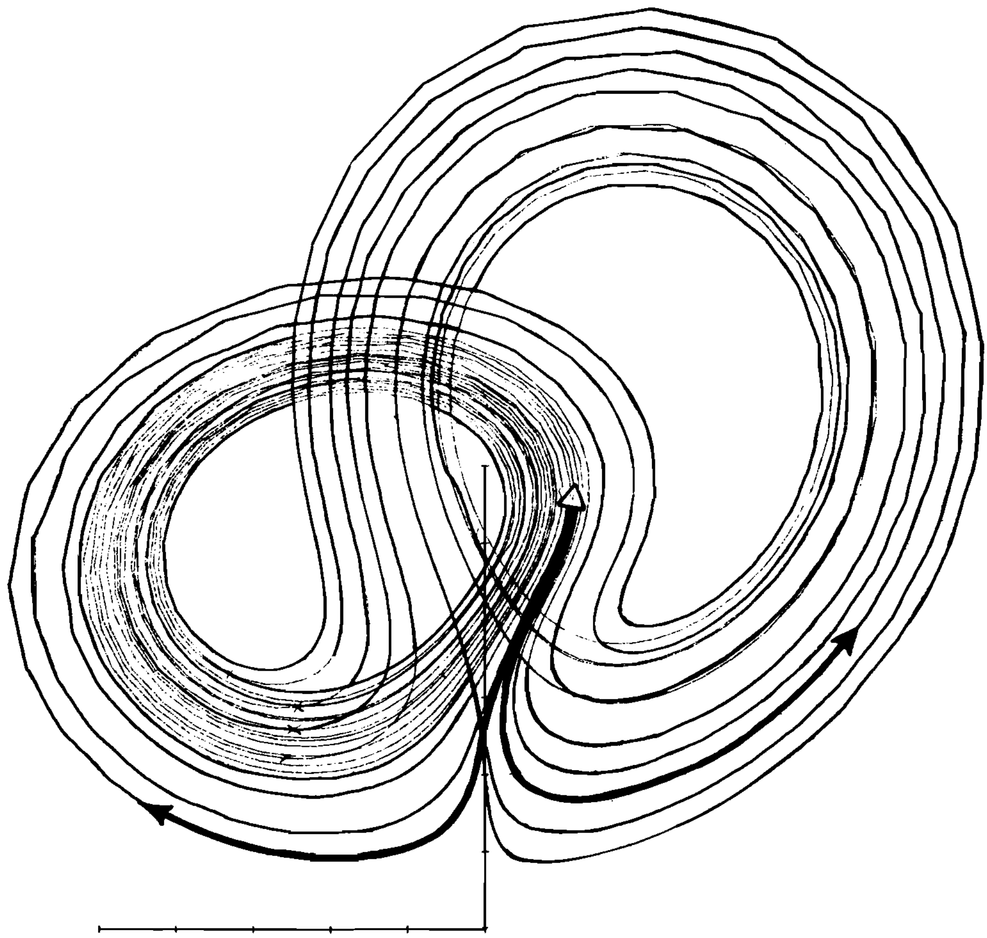


Figure 4. Lorenz attractor.

for climatology, since, for the essential features of a climatic change, this approach could possibly replace long simulations with a global circulation model (GCM).

Let me summarize the main points that can be learned from the Lorenz attractor, which are true for most strange attractors:

1. The *possibility of quasi-basins*: metastable regions between which the system fluctuates (without any stochastics in the dynamics);

2. *Extremely sensitive dependence on initial conditions, and erratic behavior.* This suggests the impossibility of predicting the "weather"--the actual point in state space--over longer times because of the lack of knowledge of all the details of the initial conditions. The accuracy of our measurements divides the state space into cells; we know only from which cell the system starts initially. The image of any cell under time evolution--if the time interval is large enough--will be spread over all the attractor;

3. In contrast to 2 above, the *possibility*, at least in principle, *of directly calculating the "climate"*-- i.e., long-term averages.

Let me add to 1 above that one could probably construct systems with any number of quasi-basins: an example of a system with four quasi-basins, called super-Lorenz, is being investigated; its other properties are the same as those given above for its progenitor.

After all this emphasis on the global structure of systems, let me add that by the use of this approach we do not intend to put numerical integrations out of business. But it can save a lot of time, for example, by pointing out the interesting regions of state space where one could calculate a few sample trajectories, or by obtaining time averages. For studying the impact of parameter changes, the global approach seems definitely superior.

To close, let me outline an interesting line of research being pursued at IIASA, where it is known as the "kit concept". The kit consists of a list of attractors relevant to a description of the behavior of actually occurring systems. This list, which is being drawn up, starts with the trivial cases of stable equilibrium and closed orbit, and then moves on to strange attractors. Depending on the observed--or desired--structure of the phase portrait, one would choose the corresponding attractor to model the real situation; for instance, a system oscillating at random between two regions would be modeled by the Lorenz attractor or by a variant of it. (Such systems abound in ecology.) For the whole state space of the system, the basins of the corresponding attractors will then be put together. Using this approach, one can obtain a model that shows the correct structure; thereafter one can start to adjust the parameters.

References

[1] Ruelle, D., and F. Takens, On the Nature of Turbulence, *Comm. Math. Phys.*, 20 (1971), 167ff.

[2] Gatto, M., and S. Rinaldi, *Stability Analysis of Predator-Prey Models via the Liapunov Method*, RM-75-52, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[3] Lorenz, E.N., The Mechanics of Vacillation, *J. Atm. Sci.*, 20 (1963), 448.

Computer Networks: Comment on a IIASA Research Activity

V.M. Glushkov

The System and Decision Sciences area focuses on problems of *developing* systems analysis rather than *applying* systems analysis. A reasonable policy for an institute like IIASA is to have well-balanced projects that deal with both aspects of the problem--i.e., developing the techniques and applications of systems analysis. The System and Decision Sciences area should include at least three important projects. Two projects are evident--the development of mathematical methods for modeling and optimization of large-scale systems, and the long-term development of IIASA's computer facilities including both hardware and software. A third project--problem-solving in the area of computer networking--is in my opinion a prerequisite for developing the techniques of system analysis.

There are several reasons why computer networks are an essential tool for applied systems analysis. The first is simple and pragmatic: for effective work in applied systems analysis, each scientist must have easy access to large-scale computer facilities. The most appropriate and economical way to achieve this is to create a computer network. The first step in establishing such a network is to install a terminal at the centers of each of the participants in the system. The second step involves the use of minicomputers with special communication equipment. The final step involves a large-scale computer system with telecommunication access.

In such a network, good organization ensures the effective use of a large-scale computer system and communication lines. The experience of the Ukranian Institute of Cybernetics in Kiev shows that through the combined use of a minicomputer (NJR-2) and a large-scale computer (BESN-6), the efficiency of the BESN-6 was enhanced almost sixfold. Expenditures for computations were reduced, while the servicing of users was noticeably improved (e.g., reduction of the system response time in the dialog mode, feasibility of rapid changes when constructing and debugging programs).

The second reason for IIASA to create a computer network and gain access to existing networks is related to the special features of its structure. Dr. Levien has already explained that collaborative research is an essential feature of IIASA's research activities. This involves the broad use of scientific capabilities and computer facilities, especially the complex software systems in collaborating institutes. In many cases, such software systems are being realized on non-compatible hardware that is not easily transferable to the computers in Vienna used by IIASA. Thus, both IIASA and the collaborating institutes would benefit greatly from the inclusion of the computer facilities at these institutes in the IIASA Computer Network.

Many institutions are currently collaborating with IIASA on the development of software systems for solving problems of systems analysis. For example, the man-machine interactive software system for forecasting the development of scientific technology and social processes has been effectively used at the Institute of Cybernetics in Kiev.

There is a third reason which is perhaps the most important one for having a computer networking project at IIASA. Again, I wish to refer to a previous statement by Dr. Levien in which he points out that IIASA's work should contribute to the development of decision-making techniques at both the international and national levels. Any such technique must take into account the three elements of a decision-making system: the decision maker(s), the computers (with special software), and the necessary data base.

The techniques used in the 1960s involved assembling all three elements together in one place, or supplying decision makers with the results of preliminary computations for making decisions. This approach, however, can be used effectively only on comparatively simple problems. Current problems are more complex and therefore require more advanced techniques for decision-making. First, they involve a sophisticated data base that, by means of many computer centers, is distributed over large territories. (It is almost impossible to transfer all preliminary data to one place.) Since the data are distributed in local data banks, they are easily processed on local computer facilities. In some cases, the situation may be aggravated by the fact that data are constantly changing and many complex decision-making procedures are multi-level. Decision makers using local data banks and computer facilities contact decision makers at higher levels to obtain some initial information. For example, this information may result from data processed on the lower level and transferred not only to the decision makers at the next level but also to their computer facilities for the second phase of data processing. Simultaneously, information is flowing vertically and horizontally in the system.

To develop such complex and partly automated decision-making techniques involves creating a temporary configuration of participating computer centers (with corresponding local software and data bases), and centers for decision makers at different levels. Thus, a system would be created that would control all the data processing, information retrieval, data transfer, dialogues between decision makers responsible for setting up the links in a communication network, the necessary protocols, etc. The techniques for controlling such networks can be more complicated than the techniques currently used in existing commercial networks.

Many countries are now--or will be in the near future--in great need of research on solving the type of problems mentioned above. The complexity of such work greatly exceeds that of any work previously done on creating complex software systems implemented in one computer system.

Multi-level and multi-computer decision-making systems should be considered from two different aspects. First, they are an interesting and promising subject for applied systems analysis. Secondly, they can be designed and constructed so as to be a powerful tool of systems analysis. In this case, decision makers must be replaced by corresponding researchers--i.e., systems analysts and experts on different topics.

Because the computer network is the base of such a system, the theoretical and applied research in computer networking will be of great importance at both the international and national levels. In the future, we hope to be able to consider IIASA's Computer Network project not only as a methodological but also as a universal or even a global project.

Discussion

(H.P. Young and F. Toueg, Rapporteurs)

Reference was made to a comment in the introductory presentation regarding the implied lack of continuity in the System and Decision Sciences area as a result of the personnel policy at IIASA. Further clarification of the author's opinion was requested. The latter replied that he thought his opinion was at least implicit in his remarks. Various people have brought particular interests with them when they came to IIASA, and these have flourished as research projects here. Naturally when they leave they take these projects away and new interests develop. Therefore he did not feel that the personnel policy needed to be changed for significant research to be done at IIASA. The policy as it exists now can be lived with.

Several statements were made relative to the presentation of a mathematical programming energy model. Are elasticities included in this model? Would the coefficients change drastically in the model with basic changes in the structure of the economy? The author pointed out that elasticity coefficients were not used because of a lack of confidence in the economic data available. Those involved with the model's development felt more comfortable with the approach that first estimated (with the help of industry experts and economists) the production changes that occur when there is a major realignment of prices, and then entered these changes as a new column in the model. The present plan is to incorporate certain satellite models of industries related to energy as, for example, those now being used at the Wharton School. These satellite models contain a variety of substitution possibilities that would make the model more realistic. This is a refinement that is reserved for the future, and is therefore not incorporated in the model at present.

One discussant expressed doubt that the u's in the model realistically represented the number of people in different income brackets, since an optimal solution might have only one or two of the u's different from zero. Could one assume a particular distribution of the u's, and would this change the structure of the model? In the author's opinion, historically distributions have shifted to the right, which tends to favor the poor rather than the rich. A report on the effects of different assumptions on the distribution of the u's has been prepared at Stanford University.

The view was expressed that to extend this model to include the remainder of the world, it was necessary to introduce the additional variable of trade among the various parts of the world.

Also, the balance of payments would have to be addressed. The author noted that the whole issue of dealing with the financial flows is a very complicated one. As to whether software systems were used in the model, he stated that all the codes used are based on some variant of the simplex method, and contain several hundred thousand instructions that make it easy for the user to change the data or correct errors in the model. He suggested that those interested consult with Dr. Orchard-Hays, a leading international expert on software systems who was present at the Conference as a IIASA scientist. The systems used in the model are the MPS-3, and a nonlinear programming system developed by Michael Saunders. When asked to comment on the relationship of this model to that being developed by the Environmental Protection Agency in Washington, D.C., he replied that he was not familiar with the latter model, adding that his model uses the SEAS in its environmental coefficients.

Two sources of data for the input/output coefficients of the energy flows in the PILOT model were used: historical figures in the amount of different energy types used in different basic industries, and a breakdown of consumer demand categories such as quantity of energy used for space heat. As to what drives the model, it was pointed out that the goal was to move as many people as possible into higher income brackets. The gross national consumption per capita is the key indicator for estimating the effects of different policy changes.

A number of comments were made about the presentation on multiple objective evaluation. Has the quest for the quality of life been incorporated realistically into the utility functions? Can one learn from experience how to readjust utility functions and increase their accuracy? It was the author's expressed belief that the quality of life considerations can be incorporated into utility functions. This is explained in a book that he co-authored with Howard Raiffa.* He also believed that preference structures over time can be adjusted.

Discussion then centered on the presentation on resilience and related mathematical concepts. The question was asked whether the theory of difference equations also yielded the same type of complexity of stable solutions mentioned in connection with the continuous case. According to the author, this type of behavior is obtained in *difference* equations; in fact, in the case of certain difference equations you can get behavior analogous to the Lorenz attractor in two dimensions. On the other hand, in the case of *differential* equations, one needs three dimensions.

Several discussants made some general comments. In ecological investigations, an interesting question is whether a parameter

---

*R.L. Keeney and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York (forthcoming).

shift can lead to shrinkage of a particular stable basin even though the equilibrium point may remain fixed. In particular, certain parameter shifts may eventually lead to the disappearance of a basin altogether; however, this would not be perceptible if one were already at the equilibrium point--that is, it would not be perceptible until the crisis itself occurred.

Methodology plays an increasingly important role at IIASA. One interesting theme being pursued by the Methodology project is the description of qualitative aspects of complex systems. This is illustrated by the resilience concept. The problem of describing the qualitative features of complex systems has existed for some time, and has been studied by various researchers in different countries. Origin and motivation for making a qualitative systems approach lies in the fact that traditional methods for mathematical description may encounter insuperable difficulties simply because of the physical impossibility of encompassing the whole system by one set of equations.

There are different approaches to qualitative modeling of systems, but their character is usually linked with a visual or topological type of presentation. For example, a mathematical description of the qualitative level of complexity has been studied by Academician Kolmogorov and his colleagues for nearly ten years. The essence of Kolmogorov's approach is to describe qualitative complexity with the help of topological methods, settery, and various other mathematical concepts. Another example is the theory of fuzzy sets. Mathematical linguistics has also been used in this context, in particular by Professor L. Zadé and his staff in the USA. Still another example is the von Neumann-Morgenstern theory of ordinal utility that describes qualitative aspects of complex social behavior.

We are thus brought to the conclusion that the problem of qualitatively describing complex phenomena has been of interest for some time to many researchers in a variety of fields. For this reason it is essential that the work conducted at IIASA, including the work on resilience, must not be conducted in isolation from the international experience that has already been gained. It was suggested that IIASA stimulate the creation of a "bank" of methods, computational procedures, and descriptive tools for solving the various complex interdisciplinary problems that arise on the national and international levels.

APPENDIXES

Appendix 1: About the Authors

Professor Michel Balinski, United States, came to IIASA in September 1975 to lead its methodological research. He is Professor of Mathematics at City University of New York, and founding Editor-in-Chief of "Mathematical Programming".

Dr. Edward Blum, United States, came to IIASA in September 1974 from the New York City Rand Institute. His research at IIASA focuses on modern service management, particularly urban services.

Dr. Alexandre Butrimenko, Soviet Union, joined IIASA in January 1974 as leader of the Computer Sciences group. He is on leave from the Institute for Problems of Information Transmission of the USSR Academy of Sciences.

Professor George B. Dantzig, United States, of Stanford University, is a former leader of the IIASA Methodology group, and a current member of its Advisory Committee. Professor Dantzig has received the 1976 President's Medal for Science, and is a member of the US National Academy of Sciences.

Dr. Laszlo Dâvid, Hungary, is head of the Water Resources Development Department of the National Water Authority in Budapest, and a member of the Hungarian Advisory Committee to IIASA. He has collaborated with the IIASA Water Resources group on research on the Tisza River basin.

Mr. Cyril Davies, United Kingdom, joined IIASA in November 1975 to participate in research on the planning, management, and organization of large-scale regional development programs. Mr. Davies is from the National Coal Board, UK.

Dr. Ada Demb, United States, came to IIASA in September 1975 from the Sloan School of Management of the Massachusetts Institute of Technology. Dr. Demb's research at IIASA focuses on interorganization behavior in integrated regional development.

Mr. Raul Espejo, Bolivia, came to IIASA in June 1975 from the University of Manchester, UK. Mr. Espejo's research at IIASA is a cross-cultural comparison of organizational forms for regional development.

Academician V.M. Glushkov, Soviet Union, is the Director of the Institute for Cybernetics in Kiev, and a member of the IIASA Advisory Committee for the Computer Sciences group. Academician Glushkov is the recipient of a number of awards including the Lenin Prize, the State Prize, and the Order of Lenin.

Dr. Hans Richard Grümm, Austria, came to IIASA in 1975 from the University of Vienna. His research focuses on the qualitative theory of differentiable dynamic systems in applications to the resilience concept.

Professor Niles Hansen, United States, joined IIASA as leader of the research on urban and regional systems. He was formerly Director of the Center for Economic Development of the University of Texas at Austin.

Professor Zdzislaw Kaczmarek, Poland, joined IIASA in 1974 as leader of its water resources activites. Before coming to the Institute, Professor Kaczmarek was Deputy Minister of Sciences, Higher Education and Technology in the Government of Poland, and head of the Environmental Engineering Department of the Technical University, Warsaw.

Dr. Ralph Keeney, United States, came to IIASA in 1974 to work on implementing concepts and techniques of multiattribute utility theory in applied research. Dr. Keeney was formerly Associate Professor of Operations Research and Management at the Sloan School of Mangement, Massachusetts Institute of Technology.

Professor Hans Knop, German Democratic Republic, came to IIASA in 1974 to lead its research in the design and management of large organizations. He is from the University of Economic Sciences, Berlin.

Professor Irving Lefkowitz, United States, was former joint leader of the IIASA Industrial Systems project. He is Professor of Engineering at Case Western Reserve University in Cleveland.

Dr. John Miron, Canada, joined IIASA in September 1975 to work on economic theory and models of urban growth and land use. Dr. Miron is from the Department of geography at Queen's University, Kingston, where he was Assistant Professor.

Mr. Jan Owsinski, Poland, came to IIASA in November 1975 from the Institute for Organization, Management and Control Sciences of the Polish Academy of Sciences. At IIASA, Mr. Owsinski is concerned with the use of mathematical models and computer applications in planning and decision-making in large organizations.

Dr. Roman Ostrowski, Poland, joined IIASA in 1975 to work on the management and organization of large-scale regional development programs. He is from the Institute for Organization, Management, and Control Sciences of the Polish Academy of Sciences.

Professor Andrei Rogers, United States, joined IIASA in 1975 to work with the Urban group on studies of migration and human settlement systems. He was formerly Professor of Civil Engineering and Urban Affiars at Northwestern University.

Professor Horst Strobel, German Democratic Republic, has been at IIASA for short periods during 1974, 1975 and 1976 as a member of the Urban group. Professor Strobel is currently leader of the Scientific Department for Automation at the University for Transportation and Communication, Dresden.

Dr. Harry Swain, Canada, formerly led the IIASA project on the management of urban systems. Before coming to IIASA, Dr. Swain was the Director of External Research for the Canadian Urban Ministry, and is currently a policy analyst with the Treasury Board Secretariat of the Canadian Government.

Dr. Andras Szöllösi-Nagy, Hungary, came to IIASA in 1974 to work with the Water Resources group. He was formerly with the Research Institute for Water Resources Development, Budapest.

Professor Dimitri D. Venedictov, Soviet Union, was appointed in 1974 to lead IIASA's research in biomedical systems. He is currently a member of the Executive Committee of the World Health Organization (WHO), and Deputy Minister of Health in the USSR.

Professor William Welsh, United States, from the University of Iowa, joined IIASA in January 1976. His research with the Biomedical and Urban groups focuses on interregional variations in the provision of basic public goods and services.

Mr. Detlof von Winterfeldt, Federal Republic of Germany, came to IIASA in November 1975 from the Social Science Research Institute of the University of Southern California, to work with the Large Organizations group on decision analysis in integrated regional development programs and decision processes in large organizations.

Dr. Eric Wood, Canada, came to IIASA in 1974 to work with the Water Resources group on analysis of river systems through the application of hydrological modeling and system techniques. Dr. Wood was formerly a research assistant in the area of water resources at the Massachusetts Institute of Technology.

Appendix 2: Table of Contents of Volume 1

Dr. Bruno Kreisky
Welcoming Address

Message from the Council of Ministers of the USSR

Message from the US Secretary of State

INTRODUCTION TO THE INSTITUTE

J. Gvishiani
The Concept of IIASA

H. Raiffa
Creating an International Research Institute

R.E. Levien
Applying Systems Analysis in an International Setting

McGeorge Bundy
Dinner Address

GLOBAL PERSPECTIVES

R.E. Levien
Introduction

W. Häfele
Energy Systems: Global Options and Strategies

F. Rabar
Food and Agriculture: Global Aspects of Supply and Demand

Panel Discussion

GLOBAL ENERGY SYSTEMS

G.B. Dantzig
M. Styrikovich
Discussion (*W. Sassin, Rapporteur*)

GLOBAL RESOURCES

Z. Kaczmarek
H. Mottek
Discussion (*E.F. Wood, Rapporteur*)

Panel Discussion (cont'd.)

GLOBAL DEVELOPMENT

G. Bruckmann
E. Pestel

GENERAL DISCUSSION
(*K. Parikh and W. Sassin, Rapporteurs*)

P. Handler
Invited Comment

UNIVERSAL PERSPECTIVES

H. Raiffa
Introduction

C.S. Holling, D.D. Jones, and W.C. Clark
Ecological Policy Design: A Case Study of Forest and Pest Management

W.K. Foell
Management of Regional Energy/Environment Systems

H. Knop
Large-Scale Planning Projects: the Tennessee Valley Authority and the Bratsk-Ilimsk Complex

A. Aganbegyan
Future Research Directions

Discussion
(*W.A. Buehring and A.B. Demb, Rapporteurs*)

SYSTEMS ANALYSIS AND POLICY-MAKING

T.C. Koopmans
Analytical Aspects of Policy Studies

L. Kantorvich
Theoretical Aspects of Policy Studies

H. Koziolek
The Systems Approach to Solving National Economic Problems

J. Lesourne
Systems Analysis and International Organizations

CLOSING SESSION

Invited Comments of the
National Member Organizations

The Polish Academy of Sciences

The Max Planck Society for the Advancement of Sciences, Federal Republic of Germany

The Hungarian Committee for Applied Systems Analysis

The National Academy of Sciences, United States of America

The Academy of Sciences of the Union of Soviet Socialist Republics

The Austrian Academy of Sciences

The Academy of Sciences of the German Democratic Republic

The Japan Committee for the International Institute for Applied Systems Analysis

The National Centre for Cybernetics and Computer Techniques, People's Republic of Bulgaria

The Royal Society, United Kingdom

J. Gvishiani
Closing Remarks

APPENDIXES

Appendix 1: About the Authors

Appendix 2: Conference Participants

Appendix 3: Table of Contents of Volume 2

NATIONAL MEMBER ORGANIZATIONS

The International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria