

HYPOTHETICALITY, RESILIENCE AND OPTION
FORECLOSURE: SUMMARY NOTES OF A IIASA WORKSHOP

William C. Clark and Harry Swain

July 1975

WP-75-80

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HYPOTHETICALITY, RESILIENCE AND OPTION FORECLOSURE:
SUMMARY NOTES OF A IIASA WORKSHOP

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Introduction

An informal workshop on the themes of hypotheticality, resilience, and option foreclosure was held in Laxenburg on 7 July 1975.

This Working Paper is meant to serve as an informal record of the workshop. It includes the following material:

- PART I: Invitation and Outline for the Workshop
- PART II: Rapporteur's Notes - H. Swain
Rapporteur's Notes - Wm. Clark
- PART III: Notes on Certainty, Uncertainty, and
the Unknown (proposal of definitions for
the workshop)
- PART IV: A bibliography of relevant documents.

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PART I

MEMORANDUM

To: Afifi, Bykov, Clark, Dennis, Foell Date: 27 June 1975
Hilborn, Knop, Majone, Rabar, Raiffa,
Schmidt, Swain

From: Haefele, Holling, Walters

Subject: IIASA workshop on hypotheticality, resilience, and
option foreclosure

Gentlemen:

We would like to request your active participation in a short IIASA workshop to explore common themes and implications relating to the concepts of hypotheticality, resilience, and option foreclosure.

The workshop will be held on Monday, 7 July, from 9:00 am - 12:30, in Historical Room C, and will conclude with a luncheon to which all participants are invited.

The workshop goals and agenda are outlined below. We very much hope you will be able to attend.

Three related concepts relevant to systems design and evaluation have emerged from applied studies conducted at IIASA over the last two years.

Hypotheticality was initially posed as an engineering question: how do we best proceed with the development of new technologies or programs where traditional trial-and-error approaches to design and evaluation are not possible.

The concept of resilience, on the other hand, evolved from considerations of ecosystem behavior: persistent natural systems were found to exhibit a variety of mechanisms allowing them to absorb stress, adapt to changes in their environments, and generally survive in the face of the unexpected. Finally, the idea of policy option foreclosure emerged from studies of resource development programs: it was observed that existing approaches to planning and development systematically and predictably lock society into inflexible and nonadaptive situations to which the only response is too often the preservation of an undesired status quo.

With their very different histories and approaches, each of the three "core" concepts for this workshop has its own unique strength, weakness, and potential for application. But in our own discussions over the last year we have been more and more struck by their remarkable and fundamental similarities.

Each concept, for instance, is centrally concerned with understanding the nature and implications of the unknown (as distinct from the merely uncertain) in various aspects of applied systems analysis. Each breaks with trial-and-error as a sufficient paradigm for program development. Each seeks to provide practical tools and guidelines for the manager or engineer seeking to formulate better and more adaptive system designs.

Our own research on these ideas will continue through the summer and into the coming year in a loosely coordinated way. But we wish to take the opportunity while together here at IIASA, to explore the concepts jointly. And, as important, to take advantage of the particular blend of backgrounds and experience available here to obtain a critical and wide ranging review of the ideas as they now stand, and to generate suggestions as to where we should be headed with them next. This latter goal is the purpose of the present workshop.

The workshop is being kept small in order that it may truly function as a discussion group. Each of you has been invited because of relevant interest, criticism, commentary you have expressed to one or more of us in the past. We will be asking each of you, if you chose to participate, to carefully read the attached set of core documents and to be prepared to offer substantive criticism and commentary on them during the workshop. In addition, we will approach several of you asking for the preparation of some written remarks for circulation among the working participants.

On the morning of the workshop, each of us will present a brief review of those aspects of the core concepts most central to our own work, and then serve the rest of the morning as a panel responding to your questions and comments from the floor. (Un-attributed rapporteur's notes will be kept for post-workshop distribution to participants.)

We hope the discussion will focus on developing the common ground of the core concepts, rather than highlighting their differences. In particular, we wish to investigate their approaches towards the "unknown" (cf. "Notes on certainty, uncertainty, and the unknown," enclosed) and their potential relevance to the trial-and-error mode of program development. We will be particularly interested in comments, regarding the applicability -- or impracticality -- of variants of the core ideas to applied problems of system design and management.

(A separate workshop for the discussion of methodological aspects of resilience and option foreclosure quantification will be held on the morning of 11 July from 9:00 am - 12:30 in Historical Room C. Any participant in the present workshop who is interested in addressing these methodological issues should contact Dr. Bell (X249) for details.)

If you have any questions regarding the workshop or attached papers, please see one of us or Bill Clark (Ext. 200). Also, please let Maria Helm (Ext. 223) know whether you plan to attend the workshop and the following luncheon.

PART II

RAPPORTEUR'S NOTES FOR WORKSHOP ON HYPOTHETICALITY,
RESILIENCE, AND OPTION FORECLOSURE - Harry Swain

15 July, 1975.

In attendance:

Afifi
David Bell
Sandy Buckingham
Bill Clark
Robin Dennis
Raul Espejo
Wes Foell
Michel Grenon
Wolf Häfele
Buzz Holling
Nino Majone
Howard Raiffa
Jürgen Schmidt
Harry Swain
Carl Walters

Clark opened the meeting by saying that the common ground shared by the concepts of hypotheticality, resilience and option foreclosure is an active design

approach, but one which does not involve the trial and error of classical engineering. Second generation designers progressed beyond sheer redundancy and over-design into an approach that embedded uncertainty into the design process. Clark digressed momentarily to recall Fiering's (8)* and Raiffa's (15) definitions of types of uncertainty, and pressed on with the "third generation" question: how does one deal with the wholly unimaginable, or at least unimagined? These kinds of events, labelled "surprises," had an operational definition comparable to residual error. Consideration of these issues had led in two directions, according to Clark: a behavioural direction, which he identified with the later work of Holling, and a structural direction, which he discerned in the options foreclosure paper by Walters (5). Parts of Clark's introductory overview was summarized in a last-minute paper (7).

Häfele's prepared presentation followed Clark's general introduction. He began by reviewing recent engineering history. The first epoch, which ended late in the 1950's, was identified by its "design within limits" approach: the pre-identified "design-base accident" was engineered out of consideration by severely conservative construction or design standards. A second approach came to the fore early in the 1960's as serious (i.e. non-frivolous) workers in nuclear energy began to be worried about events without inherent limits: a worse accident

* Citations are keyed to numbers in the Bibliography (Part IV).

than the design-base accident could always be plausibly imagined. Thus there was always a category of residual risk, and the way to deal with it was to "embed" it through a comparison with rare but natural catastrophic events. Since these residual risks could always be engineered to be appreciably smaller than the risks associated with natural hazards against which societies and individuals take no special precautions, embedding could be said to represent a valid psychological coming-to-terms with risk. Thus the perception of risk becomes central to the issue, and techniques for decision-making under conditions of great uncertainty come to the forefront. The basic approach to dealing with hypotheticality, then, must be the setting of standards that deal squarely with the question, "how safe is safe enough?"

Häfele went on to speculate that there might be a third domain, beyond this but still short of the extreme case of utter ignorance, where one is designing for events inherently beyond anticipatory specification. The approach then becomes, "can one implicitly anticipate non-probabilistic events?" Two approaches suggested themselves: (a) don't put all your eggs in one basket -- which gave rise to a comment from the floor about the value of organizational slack; and (b), use policy analysis to discriminate more from less resilient approaches. In this latter case, if one has an explicit measure of resilience -- and one was

mentioned (10) -- then it would conceivably be possible to optimize for R, or at least to compare alternative strategies in terms of their inherent R-values. Bell, Winkler and Grümm had been working on just such procedures.

The floor passed to Holling, who began by specifying what he hoped to get out of this seminar and his brief stay at IIASA this trip. As a modest minimum, he wanted understanding, in dictionary form, of what each of the various actors meant when they used terms like hypotheticality, option foreclosure, resilience, risk, uncertainty, and probability both objective and sub. He also hoped to deepen his understanding of the potential roles of various methodological tools, especially catastrophe theory, control theory, and stability theory. His reason for so doing, in fact the fundamental goal toward which all his work was oriented, was to design "a world without hypotheticality:" not to design yet more coping strategies that dug us all in deeper, but to prescribe approaches which would make the consideration of hypotheticality irrelevant altogether. In this sense, he saw the work of many engineers, even (and perhaps especially) the most visionary, as antithetical to his own goals.

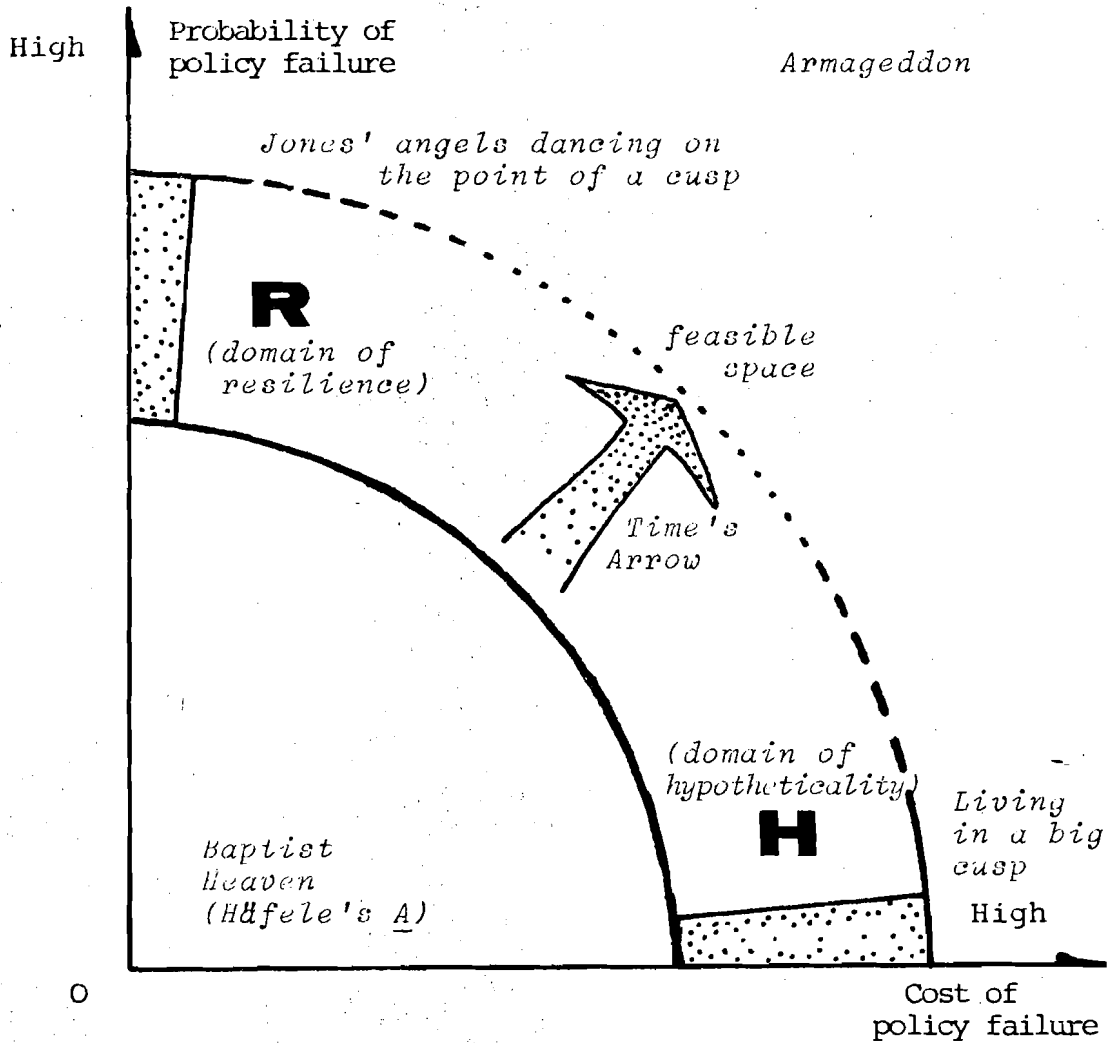
Holling then reviewed the "benchmark papers of 1975" in this area (see Part IV), which elicited complaints of fugitiveness even by IIASA's lax standards. Reviewing this literature against the background of Häfele's

three levels of dealing with uncertainty, he said that the first level implied perfect knowledge, perfect adaptive control in order to live in central or peri-optimal locations in phase space, and, in catastrophe theory terms, living right on the point of a shallow cusp. This management style, which he labelled "engineering for safety," was nice in theory but palpably unreal. Häfele's second level could be interpreted in the same terms, though not quite the way Beer and Casti (6) had done. The same huge burden of knowledge -- there is a stability domain, it's precisely mapped, the processes are indeed deterministically controllable -- and the same unrealistic perfection of adaptive control had to exist. What Beer and Casti missed, through a mistaken inclusion of time as a model parameter, was that engineering to broaden the stability domain carried with it the inescapable consequence of deepening the catastrophe manifold -- in other words, according to Holling, of moving the system into a domain of a smaller probability of a much larger disaster. Thus the Beer-Casti prescription favoured, unwittingly, a move away from resilience and toward hypotheticality!

Holling felt more comfortable on the third level. There, the knowledge requirements were considerably relaxed: the existence of equilibria could be assumed but their behaviour need only be topologically known. The locus of the system can be allowed to wander all over the domain,

but one tries to design in enough spatial friction in the phase space so that edges are approached sufficiently slowly for warnings to have effect. The system is made resilient by being forced to mimic unpleasant surprises: here Holling used the analogy of boat drill on a cruise ship. Lastly, there was a fourth level, that of the unknown and totally unknowable, which was where Walters' notion of tippy-toeing along separatrices came in.

After coffee, claiming that as a geographer he needed a map, Swain intervened to show the following diagram. If actions or strategies were arrayed in a plane whose axes were the cost of policy failure and its probability, then low values on both would represent a kind of heaven -- but so safe and risk-averse a heaven as to be without those little surprises that Holling says (shades of Toynbee's Golden Mean) are necessary for an interesting life. It would be, in other words, the sort of heaven invented by an unimaginative Baptist. The diagonal opposite, of course, is Armageddon. Real choices lie in a broad band in the middle, where the costs and probabilities can be traded off against each other, at least to some extent, but history in the form of increasing technological sophistication is pushing us (Time's Arrow on the map) ever outward. In fact, one can think of technologically determined isolines, or indifference curves in a very general sense. At one end of those isolines, where the probability of



policy failure is high but the cost low, is the region of resilient policies, exemplified in the extreme case by Jones' "angels dancing on the point of a cusp catastrophe;" at the other end is what Beer and Casti recommended -- living deep in a cusp -- which means living with a low probability of truly disastrous failure. This is the region of hypotheticality: fail-safe, in Clark's immortal words, rather than safe-fail.

Walters then repeated the main conclusions of his option foreclosure paper. We should try to think systematically about the decision consequences of decisions, not just the system consequences, he said, confusing Raiffa no end. Using education as an analogy, we should evaluate present decisions in terms of the size and attractiveness of the array of new decisions that are then opened in future time periods. Clark and Swain both noted the analogy with military history and tactics and suggested, sub rosa, that IIASA hire a General or two as consultants. Holling broke in to say that all these suggestions were retrograde -- essentially back in the "engineering for safety" paradigm. What about (he asked rhetorically) all those folk who value, indeed live off, a series of mini-disasters? Fishermen, entrepreneurs, and Howard Raiffa's hiring policies were all built around the deliberate planning of serendipity. He denounced us all, and decision theorists in particular, for wanting to take the fun out of life. Walters, regaining the floor with difficulty, said that he saw three broad strategies for dealing with uncertainty in a resilient way: better prediction (which was hopeless); engineering for surprise (Clark's Class II -- insurance games, etc.); and the deliberate invention of strategies for graceful retreat. Swain noted the usefulness of secrecy and ambiguity in such contexts, surmising that it accounted in no small measure for

the success of Harvard men in the world of diplomacy. As a last point before the discussion got entirely out of hand, Walters said we needed to consider what he called "certainty-equivalent policies," that is, those policies that would result if the underlying models were faithful to natural processes and the objective functions really represented what society wanted. We could then characterize a spectrum of policies as being more or less likely to be correct ones. Majone suggested the term "conditionally optimal policies," as the other term had a precise meaning in decision theory.

Raiffa was becoming impatient with ecologists reinventing the wheel. Every Harvard Business School graduate has been taught maxims like "when in doubt, diversify" for decades. There is a huge literature on diversification and optimal hedging known as portfolio analysis which is mother's milk to every businessman, though palpably not to every engineer or ecologist. He thought there were genuine problems here, but that we had collectively gotten sidetracked into banalities on the way to solutions. As for himself, he had happily used the classical risk and uncertainty definitions pioneered by Knight up to and through 1955, but during 1955-59 he had "got religion" and recognized that the real managerial problem lies in facing non-repetitive situations, where subjective and not objective probability was the key tool.

The problem might now be reformulated as decisions in trees which the analyst knows a priori to be incomplete. In short, the issues of hypotheticality, resilience and option foreclosure existed as real problems for him without resort to Clark's metaphysical Class IV surprises, for which only very elementary and well-known precautions could be taken. Formal analyses of uniqueness were clearly not possible: the only course here was the development of wisdom through examples and experience.

RAPPORTEUR'S NOTES FOR IIASA WORKSHOP ON HYPOTHE-

TICALITY, RESILIENCE AND OPTION FORECLOSURE - W.C. Clark
9 July 1975

A. INTRODUCTION*

- (1) Common ground of Hypotheticality, Resilience and Option Foreclosure as the theme and focus for the WS -- H originally posed as the engineer's dilemma of designing "that which can never be investigated through trial and error" -- R and OF first conceived as descriptive treatments of the way ecosystems and resource development programs (respectively) behave--
- (2) The shortcoming of trial and error as a common concern, but not the fundamental one of H,R and OF -- trials and errors viewed not as givens but as design variables (Walters) -- strengths and weaknesses of trial and error previously treated by Lindblom, Simon, Wildavsky -- .
- (3) The unknown: Explicit recognition of a class of wholly unknown or surprise contingencies, as distinct from the merely uncertain; (cf. WS paper "Notes on Certainty, Uncertainty and Surprise) -- the central challenge recast as "How to plan or design in the face of surprise?"--

*The following abbreviations are used in the notes:

WS = workshop
H = hypotheticality
R = resilience
OF = option foreclosure

(4) Casual Mechanisms vs. Behavioral Measures: two separate thrusts of research on R and OF, both directed to problems of dealing with "surprise" -- early work concentrates on measuring R, OF behavior of systems (cf. coming WS on Methodology of Resilience Estimation) and evaluating relative degree of R or OF is alternative models -- these behavioral approaches fail to give guidance on design problems: How do I build a R or non-OF system? -- recent work on casual mechanisms (i.e. underlying structure, organization) of R and OF addressing this problem (cf. WS paper "Notes towards a structural view of resilience" and Walters comments below) --

(5) Models of Resilient/Adaptive Design

Contrasting views of designing for comparative certainty (fail-safe) in designing for flexibility at the "cost" of frequent error (safe-failure) -- goals of maximizing distance to boundary (Häfele) as those of living on boundary (Walters); these to be explored through "cusp" paradigm of Beer/Casti -- relevant factors to be explored include degree of control and certainty, ability to monitor state space location re boundary, ability to learn from errors, etc. --

B. HYPOTHETICALITY (Häfele)

- (1) Designing in the face of unknowns was discussed in the context of figure 1, adapted from Häfele's WP-75-25 Objective Functions --"striving for resilience seen as presently consisting of little more than folk wisdoms; the problem is discovering a systematic (and therefore structural?) approach --.
- (2) Topology of Resilience discussion centered on the emergence of state-space behavioral regions in ecologic and socio/economic systems (figure 2) -- essential property of such topologies is that small changes in early state (or "initial") conditions can lead to large differences at later times -- where you wish to be in the state-space seen as properly a value judgement; this includes decision to keep options open by remaining on boundary (S_1) problems of measuring your location relative to boundaries in state-space to be discussed in methods workshop, but requires second value judgement regarding relative scaling of the state axes --.

C. Resilience (Holling)

- (1) Goals for workshop and the immediate future to include a concise common agreement on definitions of Hypotheticality, Option Foreclosure, Resilience and Unknown -- .
- (2) Later goals of own work to seek policy designs which render hypotheticality irrelevant; i.e., make systems which are safe for trial and error (safe-failure) -- also to

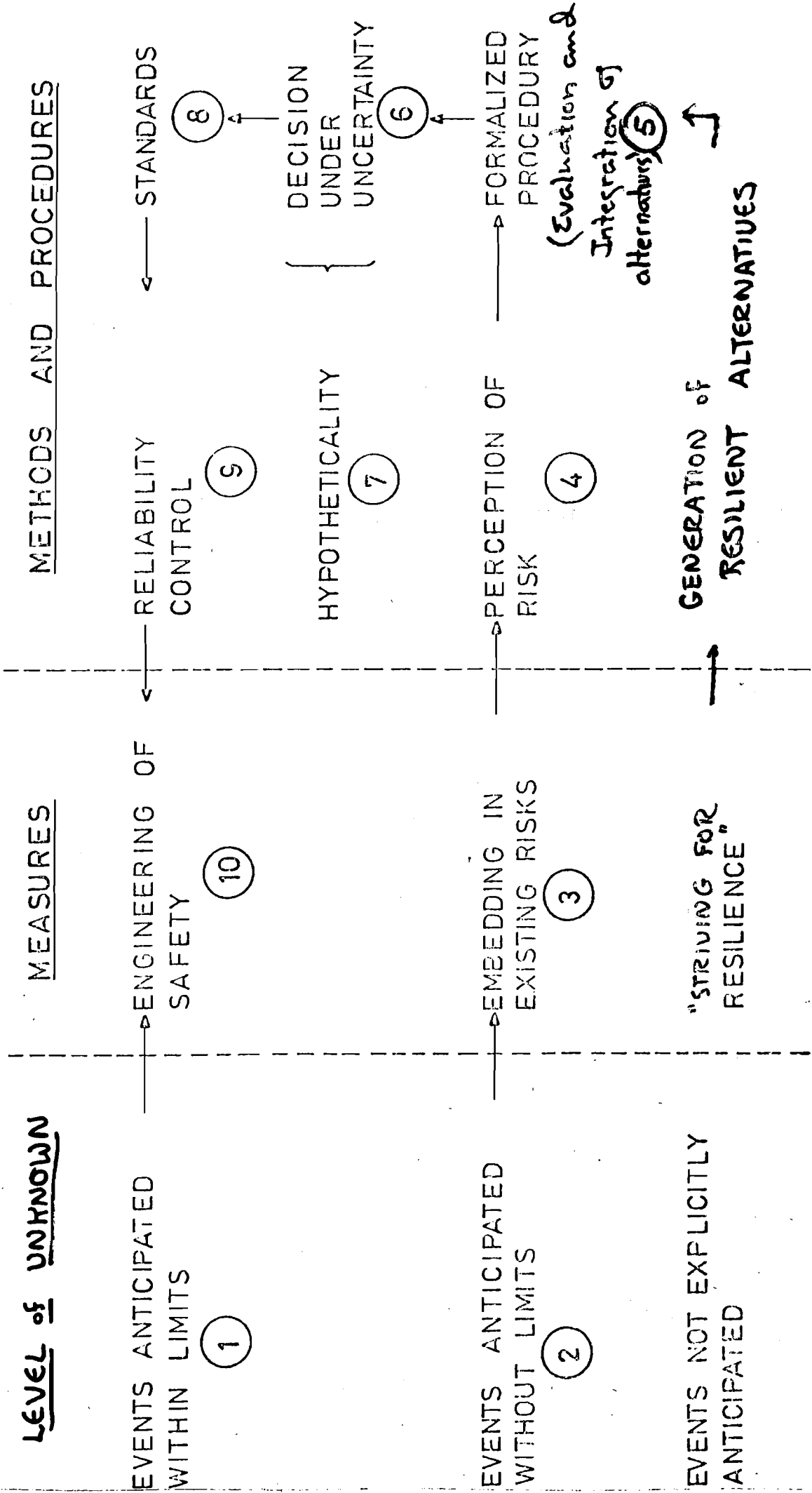


FIGURE 1: TREATMENT OF THE UNKNOWN (adapted from Haefele 1975)

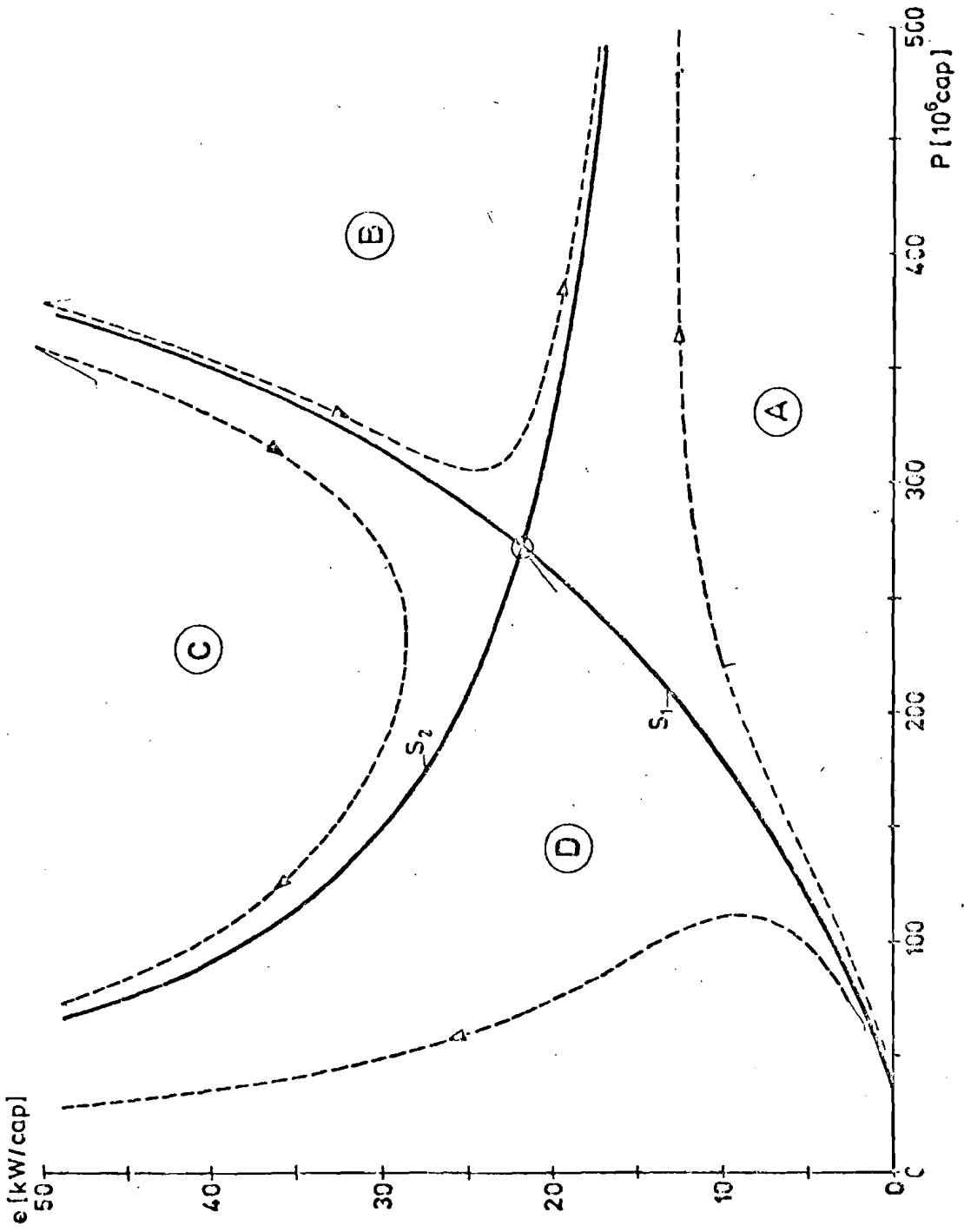


FIGURE 2: SOLUTIONS IN THE (e,P) - FIELD

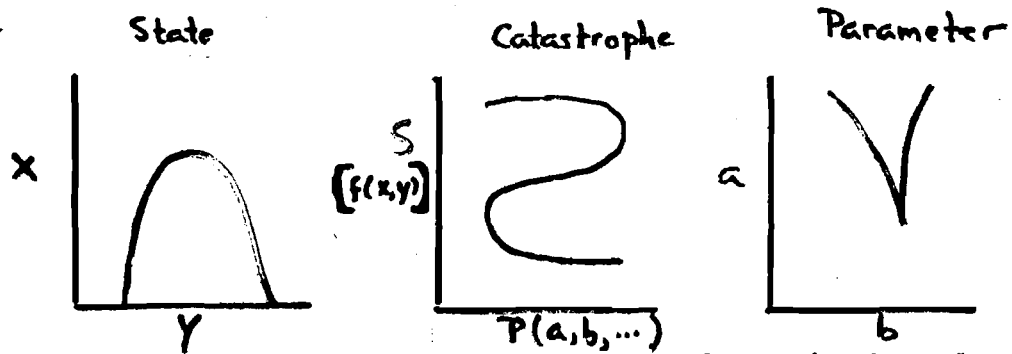
(Adapted from Hasfelle 1975)

explore relevance of various methodologies (catastrophe theory, control systems meths., stability theory) to this issue --.

(3) Benchmark Documents (See Annex 1)

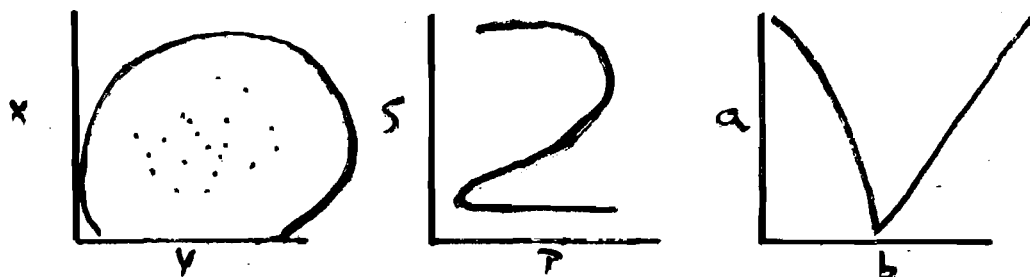
(4) Models and the Unknown dealt in overview with remarks to be presented at the Methods workshop --

(a) The certain world: here you know the state space configuration and your location in it --



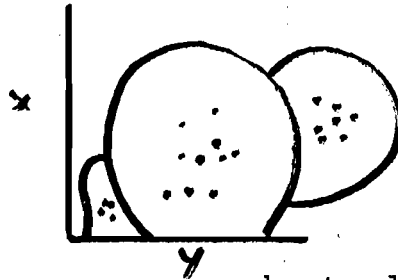
you choose to reside as far from the boundary as possible, as in present health and environmental standards --.

(b) The uncertain world: as above, but with stochastic noise on your state values only --



You engineer the biggest possible boundaries as in the Beer and Casti broadened cusp proposal; but the broader cusp forces a deeper fold in the catastrophe manifold, and thus a higher cost of failure --

- (c) The partially unknown world in which state-space stability boundaries may shift unaccountably, due to aspects of the real system which are unknown or left out of the model -- If (and only if), you assume that excursions in state space to the boundary (whenever it is) can force the boundary "out", or at least warn you of its location, then

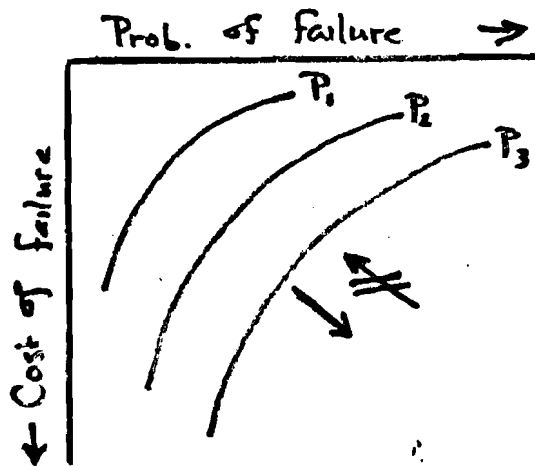


the proper response may be to design your system so as to get such excursions; this presumes, of course, that crossing of boundaries is not an irreversible act.

- (d) The totally unknown world is one in which, as the folk-wisdom would have it, you must be "fast on your feet" -- i.e. adaptable --. This parallels Walter's notion of trying to stay on the stability boundary --.
- (5) A catastrophe Footnote (Swain) was added relating costs and probabilities of failure to the topology cusp view of systems relevance of systems structure to its resilience was stressed -- (cf. Swain rapporteur notes) --

D. OPTION FORECLOSURE (Walters)

- (1) Option Foreclosure as the institutional implications of resilience --
- (2) Sequential nature of decisions as key -- focus on decision consequences of decisions, rather than the "system" consequences -- note that initial decisions lead to events, which include surprises, which are then reacted to with corrective decisions, and so on ...
- (3) Unidirectional nature of sequence is what leads to systematic option foreclosure -- return to Swain's figure:



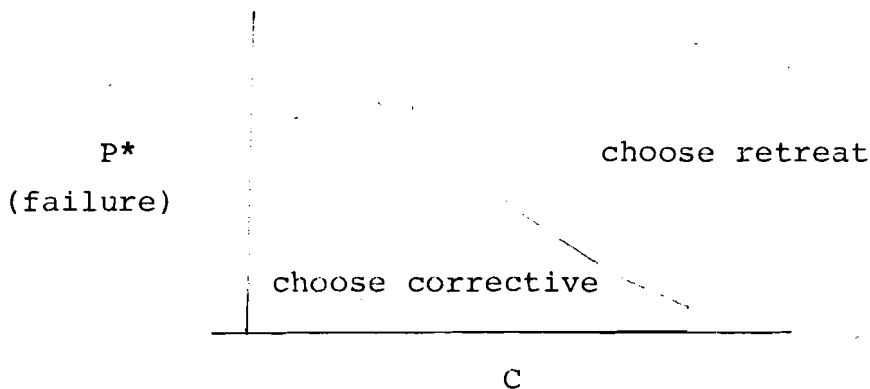
Imagine P_i 's to be "political acceptability" (Pareto) isoclines; easy to take decisions and correctives along an isocline or to a higher one (\searrow), but very difficult to go to a lower one than that now inhabited -- each step to a higher isocline effectively eliminates more of the option space --

(4) Mechanisms seen from a different perspective through following diagram:

		<u>Policy</u>	
		Retreat	Correction
<u>RESULT</u>	Correction fails	-L	-(L+C)
	Correction Succeeds	-L	0 (scaled)

[(-L) is loss on retreating with no corrective act, (C) is the cost of the corrective act; all values scaled to give zero as shown].

It is not implausible that this would yield a relation among cost of corrective action, prior probability of corrective action failure, and decision to correct or retreat as follows:

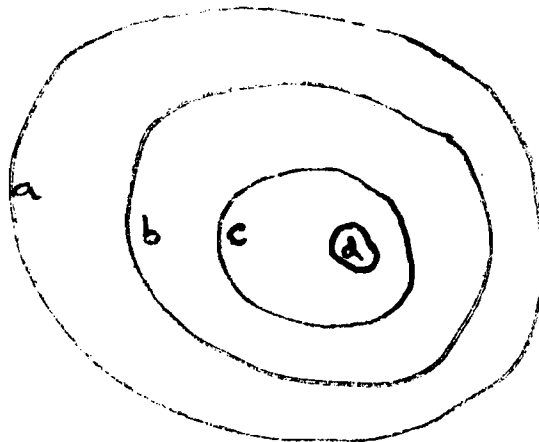


With moderate P* (failure) would always be willing to take moderately costly corrective, thus further closing off options as per above --.

(5) Approaches to better policy design have three aspects --

- (a) better prediction, which is nice but of limited practical significance;
- (b) engineering for surprise via resilient system structure, and
- (c) designing management systems for "graceful retreat" via institutional flexibility and adaptability --

(6) Taxonomy of policy models



- (a) "best" policies, under assumption that the model is true;
- (b) "efficient" policies best for some assumed distribution of models, objectives;
- (c) "resilient" policies best for dealing with partially unknown systems;
- (d) "graceful(??)" policies as (c), but providing explicitly for graceful institutional retreat.

E. DISCUSSION (unattributed by agreement and in no particular order).

- (1) Surprise is spoken of pejoratively; many people and institutions seek out surprise.
- (2) Discount implications of option foreclosure and adaptiveness -- valuable contradiction would seem to exist between those who say we foreclose options via too high a discount rate, and those who say organizations or beasts adaptive to surprise exhibit high discount rates.-- What goes on here??
- (3) Business management literature is full of resilience notions, almost to the point of gospel; when uncertain, diversify; when risk-adverse, diversify -- What is supposed to be new in this??
- (4) Uncertainty and surprise: not clear to some that there is a significant practical difference between the two -- decision literature copes effectively with the unknown (surprise) by asking how much a person would pay to remove the "uncomfortableness" he feels when confronted with an admittedly (and inevitably) incomplete decision tree -- But this is the decision approach to pricing surprise, not the engineering approach to designing it --.

- (5) Resilience and Decisions - integrated via the Häfele approach to policy analysis: design resilient policy alternatives from structural or behavioral optimization arguments, and then choose among these and more conventional alternatives via traditional decision theory -- distinguish between these two types of problems for dealing with the unknown; one is for resolution of specific cases, the other as a "constitutional" approach to the game.--
- (6) Irreversability - How should the irreversability of a possible outcome influence the foregoing concerns?

PART III

NOTES ON CERTAINTY, UNCERTAINTY, AND THE UNKNOWN

William C. Clark
5 July 1975

The notes which follow are derived from various published works, correspondence, and informal conversations of Messrs. Häfele, Fiering, Walters, and Holling. This summary is for the purposes of the IIASA workshop only and has not been reviewed by any of the "contributors."

All the contributors are concerned with approaches for dealing with the unknown in systems analysis and design. Each has taken the step, more or less independently, of "classifying" the various degrees of "unknown-ness" which may characterize given aspects of a problem. Out of these classifications exercises has emerged a concern that there exist types of "completely unknown" phenomena, relationships, and events which are not dealt with effectively by present analysis techniques or design philosophies. It is to this class of "completely unknowns" that much of the hypotheticality, resilience, and option foreclosure research has been addressed, and it is specifically this aspect of that research which the present workshop is being held to investigate. We are interested in establishing a "taxonomy of the unknown" primarily to clarify the specific set of considerations on which the workshop discussion will be focussed.

Although each of the contributors, as noted above, has formed his own version of an essentially common taxonomy of the unknown, they have used a variety of terminologies in identifying the component classes. Table 1 represents an attempt to match these terminologies with one another, to reference their fullest available documentation, and to propose a set of common terms for use at the present workshop.

The proposed common terms ("synthesis" column in Table 1) with their definitions are as follows (quoted definitions are from Luce & Raiffa, 1957, Games and Decisions):

Certainty: "...each action is known to lead invariably to a specific outcome..." Certainty is one term we all understand because it is what we never have. It is included here for the sake of completeness, and because so many managers and program designers act as though they were in a certainty situation.

Risk: "...each action is known to lead to one of a set of possible specific outcomes, each outcome occurring with a known probability..." Risk is something that maybe gamblers and decision theorists have, but it is generally as unlikely that we know probabilities as that we know outcomes for certain.

Uncertainty: Where an action "has as its consequence a set of possible specific outcomes, but where the probabilities of these outcomes are completely unknown or are not even meaningful." This is beginning to be a more realistic

description of the state of affairs encountered by real managers, analysts, and designers. But note the crucial inclusion of the phrase "possible specific (i.e., specified) outcomes." What is to be done when you cannot, or cannot be bothered to, explicitly specify the outcomes? This is the crux of the "surprise" category described next, and ignored by Luce, Raiffa, and almost everyone else.

Surprise: In general, we cannot specify all of the possible outcomes or events which may be relevant to a given problem. Social objectives change in unforeseeable ways, unprecedented changes of inputs occur, and so on. And if we cannot imagine such contingencies ahead of time, we cannot treat them as classical uncertainties where the only problem is to assign a (subjective) probability to a known possibility. Following Fiering, we will call these situations you cannot anticipate as situations of "surprise." Note that surprise is not an absolute category any more than the "error" or residual term in an analysis of variance. Both terms are operational in character, consisting of those things which you cannot, or cannot be bothered to, account for in the explicit analysis.

VERSION OF TAXONOMY

	SYNTHESIS	HAEFELE	FIERING	HOLLING	WATERS
Documentation	for use as workshop	W.Häfele. 1975 Objective Functions. IIASA - WP. 75-25	M.B. Fiering, 1974 A Formalism for the management of surprise. - IIASA WP-74-20	C.S.Holling. 1974 Towards a Science of ecological management. - IIASA WP-74-22	Personal comments
Level of unknown	Certainty	Events known	----	Totally known	----
Completely Known	Risk	Events anticipated within limits	Safety factor engineering	Partially known	Probabilizable
	Uncertainty	Events anticipated without limits	Probabilistic engineering		Recognizable
Completely Unknown	Surprise	Events not explicitly anticipated	Surprise engineering	Unknown	Unrecognizable

PART IV

A BIBLIOGRAPHY OF HYPOTHETICALITY - RESILIENCE
OPTION FORECLOSURE DOCUMENTS

(available as IIASA publications, from the authors,
or in the published literature)

Primary Publications

- (1) W. Häfele 1973. Hypotheticality and the new challenges: The pathfinder role of nuclear energy. IIASA RR-73-14.
- (2) W. Häfele 1975. Objective Functions. IIASA WP-75-25.
- (3) C.S. Holling 1973. Resilience and stability in ecological systems. IIASA RR-73-3.
- (4) C.S. Holling 1974. Notes towards a science of ecological management. IIASA WP-74-22.
- (5) C.J. Walters 1975. Foreclosure of options in sequential resource development decisions. IIASA RR-75-12.

Secondary Publications

- (6) S. Beer and J. Casti 1975. Investment against disaster in large organizations. IIASA RM-75-16.
- (7) W.C. Clark, C.S. Holling, and D.D. Jones 1975. Towards a structural view of resilience. IIASA WP-75-in press.
- (8) M.B. Fiering 1974. A formalism for the management of surprise. IIASA WP-74-20.
- (9) D.D. Jones 1975. The application of catastrophe theory to ecological systems. IIASA RR-75-15.
- (10) R. Avenhaus, et al. 1975. New societal equations. IIASA WP-75-67.

Unpublished Documents

- (11) W. Häfele 1975. Good morning, Buzz.
(transcript of a tape).
- (12) C.S. Holling 1975. Good afternoon, Wolf.
(transcript of a tape).
- (13) C.S. Holling, D.D. Jones and R.M. Peterman 1975.
Comments on "Investment against disaster in large
organizations" (letter).
- (14) D.D. Jones and C.S. Holling 1975. Fail-safe
versus safe-fail catastrophes (manuscript).

Other Documents Cited in Rapporteur's Notes

- (15) R.D. Luce and H. Raiffa 1957. Games and Decisions.
New York (Wiley).