A SYSTEMS ANALYSIS STUDY TO COMPARE THE LONGTERM CONSEQUENCES OF INNOVATION POLICIES WITH REGARD TO UNDERGROUND COAL MINING

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PREFACE

This paper was prepared on the basis of a research study on future underground coal-mining technologies carried out by the author. Its main aim is to promote a closer consensus in the discussion about future possibilities of coal mining from the underground deposits as surface deposits are very quickly exhausted.

In spite of that, investment in the developmet of new technologies seems to be very high, from the point-of-view of future gains, especially with a decrease in the amount of underground labor, it is justified.

It is now widely accepted that innovation is a powerful tool for social and economic growth, but for coal industry managers it is not easy to make use of the situation because the problem is connected with underground human activity in general - see IIASA's PP-80-10 on "On Future Coal Mining and Human Underground Activities". Therefore information exchange and collaboration in the coalfield on the international level will be still more desirable.

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INTRODUCTION

An increase in exploration of oil and gas can hardly be expected in the future. On the contrary, the following titles are very well known today: The strategic role of coal in future energy systems; A global return to coal; Coal over the next twenty years; (Häfele 1980) etc.

Therefore, it was necessary to bring together specialists, both managers and analysts to identify the main issues which the coal industry faces over the next 20-30 years, to identify the way and approach in which systems analysis can assist in major policies and decisions.

The open cast mining technologies have no special future problems but different underground coal mining technologies need careful analysis in order to gain an insight into their comparative economies because their investment costs are continuously increasing with depth of mining and human underground labor is going to be very unattractive due to its physical nature and high degree of hazard. Moreover, the underground coal mining industry has developed over a long period of time under a variety of conditions and, therefore, coal industry managers need a suitable tool which would form part of their decision support system.

The systems analysis approach presented--analysis of underground mining technologies--gives us the possibility of seeing the advantages of the evolution potential of a new mining technology and to managers the possibility of seeing long term results of their decisions.

The underground coal mining method-"room and pillar"--was not taken into account because, from the point of view of raw material and energy conservation its lower recovery factor seems to be more and more problematic especially for the excellent deposits on which this method is being used today. Also, it is not suitable for coal mining under the depth of 300 meters (see Fettweis 1979 p. 266). Hydraulic coal mining used in the USSR is more interesting, but the growth of its productivity during recent years has been marked by the low increments. (The results are approximately the same as the productivity of the long wall mining method.)

This does not mean that these coal mining methods are unable to develop, rather it seems necessary to compare their future possibilities with other mining methods. However, until clear "discussion rules" about the future underground coal mining are prepared it is not possible to effectively discuss them, therefore, this systems analysis study has been prepared to explore the direction of innovation and identify the impacts, long term consequences, stimulants, and barriers of this technological change.

RESULTS OF PARTIAL ANALYSIS

The results of partial analysis of the future possibilities of underground coal mining can be simply summed up: in spite of a great number of patents (even if overall patent activity is declining--Thompson 1979) in the field of mining technology, methods, equipment, etc., there is, as yet, no deep mining method worked out that would comply with "a feasibility analysis" which would at the same time comply with criteria for future mining methods (see "Who Will Mine Coal and How Will Coal be Mined in the Year 2000?", Petras 1980).

It is quite possible that if there were another group of mining and systems specialists (i.e., coming from a country other than Czechoslovakia) who were to perform partial analysis, they would come to different conclusions. But it is difficult to alter the fact that the majority of today's technical efforts are directed towards reducing production costs of underground coal mining mostly aiming at improving partial mining activities (cutting, loading, transporting, etc.) and not towards improving mining methods as a whole (mining methods are a different set of activities). This means (after partial analysis) that essential concentration of the research effort is given to discovering a new mining method. This method should comply with the basic conditions of "the feasibility analysis" and at the same time with the above mentioned future criteria.

A team of specialists, whose leader is the author of this paper, did a study during 1978-79, and partly in 1980 an introductory study and a description of the main principles of underground coal mining future technologies were completed (see "PEEM", 1980). All this scientific and research work was complicated by our former analyses of major imperfections in underground work (Petras 1980) and by past research work (especially Petras 1976). The following demands have arisen; because of their importance they had to be included in the final mining method proposal:

-- to use (i.e., to mine) freely escaping CH_4 (methane) which is released from coal during a mining operation (on average 10 m^3/t);

-- to remove today's very complicated underground mining information system by means of concentrating the mining activity in time and space (today's considerable number of different work-places in a mine lead not only to information breakdowns but also to safety defects); this requirement also includes another one--to minimize the number of workers underground, since people are more and more becoming less willing to work underground--illness, hazard, etc.;

-- to minimize the mining of stone near the surface and thus prevent environmental hazards (waste tips, land in the area of the mine, water sources, pollution, etc.).

The "PEEM" method could comply with these requirements because its main principle relies on remote control of a robot mining device from manned underground bases and also partly from the surface (Evans 1977). From the standpoint of feasibility (not reliability) analysis so far, we have come to these partial conclusions:

-- for a mine with an average capacity (10,000 t/day) two work places should be sufficient, i.e., two mining modules (in cases of seam thickness 2 m and higher), because even today's mining unit (cutter loader) and transportation equipment can produce 150,000 t of coal per month or more (see USSR--Karaganda 1976); this means that cutting and transportation of coal are not limiting factors;

-- experience from other industrial branches (burnt-up fuel storage in an atomic power station, etc.) show that remote control and manipulation are not serious problems, especially in cases where in the future we can help people by a computer process;

-- predictions of geological structure (entirety, structure, tectonics) of coal are at the present time of a high standard and are still improving (see Czechoslovakian patent--in the USA, the patent has the number 3,858,167).

This coal mining process option allows us a regular maintenance so that problems connected with operation reliability, especially with cutting, transporting and monitoring equipment should not be insolvable. This problem should be seen in relationship to the initial costs of the latter whole mining module (device) within the framework of a "reliability analysis" (the reliability is, above all, a question of machinery investment level).

Thus, the goal which was and continues to be set by "mining research of future possibilities for human activities underground", has not yet been fulfilled. The proposal for new coal mining methods only enables us to consider this method as a basis for creating other modification alternatives; it is necessary to analyze them in order to see if they allow for the desired reduction of underground coal mining costs possible in the future. Studying future mining methods reveals great challenges.

PROBLEM FORMULATION

The working out of a proposal for a new method of underground coal mining ("PEEM") and the definition of its main technico-economic advantages has presented a new problem for the decision maker: to discover his "best" course of action given future developments in electronic and mechanical equipment for underground coal mining. For a systems analyst it answers the first question: "What are the decision maker's objectives in the coal fields?".

From the above it is evident that the decision maker would want to make such decisions that would result in the continuation of coal mining along with reduced total production costs, and further positive impacts. At this stage of systems analysis formulation it is possible to make a preliminary definition of the objectives and the means of measuring their effectiveness:

-- reduced production costs of coal mining;

-- except for these costs, it is necessary to measure: the production of stone (environment), increased work safety (miner's illness, hazard, etc.), WELMM's factors (Grenon 1976), the amount of CH_4 (as a secondary output).

Production costs of coal mining represent all the expenses for labor, materials, energy, and water, including costs (depreciation) of machine equipment of all kinds (except vertical transportation) and including surface costs (except machine equipment for investment construction). This means that production costs are, in fact, all direct costs connected with the coal mining activity except those costs of a main construction investment character, i.e., sinking of pits and driving of main roads (crosscuts), construction of essential objects on the surface (mining machine, service shops, storehouses, etc.) which vary for different mining methods. The investment, of course, creates a common comparable base: total production costs = production costs and investment costs.

There is another significant decision-making question for which an analyst must look for an answer--"What are his alternatives for attaining these objectives?". Some likely courses of action have already been indicated in a previous section and the two mining methods referred to will take into account the starting point of the first step of systems analysis. Other steps of the analysis from various standpoints (flexibility, reliability, etc.) of the two basic alternatives will have a considerable advantage as well (they will be easier to compare); therefore, only those two basic technological alternatives will be considered:

-- the "PEEM" method,

-- today's most widely used mining method "long-wall" mining in a modern arrangement.

For a more detailed systems analysis of other possibilities of reducing coal mining costs in the future, we can add to these *basic* technological alternatives other independent ones, or we can break them up into parts; this means modifying the alternatives (generating and selecting alternatives). For this present level of systems analysis the two basic alternatives are sufficient, since the main target of the first stage is to find a suitable method of comparing these technological alternatives of coal mining, taking into account their constraints, impacts on the environment, etc., instead of analyzing a real situation (this is in itself suitable as a case study with the goal of finding a recommendation for a decision). For this reason the analysis stage can be considered as studying the mechanism of technological substitution in deep coal mining.

METHODOLOGY

The innovation process in deep coal mining (defined here to incorporate the full cycle from invention to full commercialization) is slower than in other sectors. It cannot be encompassed with time horizons of less than approximately 30 years and some of them require more years to reach commercial maturity. This fact makes the process difficult for economists or policy makers to understand or control. Typically, they consider 10-15 years a long-term plan. And we know how often it happens that 10-15 years is not enough for, e.g., remote control of mining equipment to show a respectable profit. Who then will invest? And this is just the problem of these two basic coal mining technological alternatives: *Old and new technology and the time factor.*

Perhaps for this reason, a system dynamics modeling technique may be chosen as the best, because state variables are relatively slow changing over a given interval and the rates at which these variables change are determined by their values at the start of that interval. Basically, this means that the system being modeled is a set of system state variables, rates of change which are regulated by nonlinear information flows (Forrester's methodology 1973).

Most important is the fact that this type of modeling puts more emphasis on structure and on the relationships between structure and behavior than on parametric precision. It is suitable for an introductory view of the development of two coal mining alternatives in a given interval, e.g., 1980-2000 (or 2030), taking into account at least these factors (parameters), which are common for both technological alternatives (see Table 1). For these reasons the dynamic simulation model (so called the "COMTEM"--COal Mining TEchnology Model, see Figure 2 for its basic scheme) has been designed and it is still being developed (Petras, Janeck 1980) because it will serve for modeling new synfuel technology as well. The first part of the investigations have had the following purposes:

- to enable the decision maker a simple dialogue (gaming) with a computer for the substitution process of "old" technology (long wall) and new technology (PEEM);
- to take into account specific conditions in deep coal mining:
  - increasing production costs with the depth of mining (especially greater than 700 m) as it is a relation between capacity and time; therefore, the exponential rate (PDR) must be used for model calculations (see Appendix 1, position 107);

-- different rates of exponential growth for:

i) wages of miners (WUR--see Appendix 1, position 118; the level of corresponding wages--see Appendix 2, column WUL);

ii) wages of surface workers (similarly, WSR, position 123 and WSL);

-- the fact that the old mining technology (long wall) in a logistic curve is before its technological limits (OTMN = 0,9--see Appendix 1, position 96), and that the PEEM technology is just starting (with a possibility of being improved twice--NTMN = 0,5--see position 102);

-- for different coal demand in both basic technological alternatives construction investments are on the same level, because mines always have been constructed for a certain given daily production (due to problems of ventilation, vertical transportation, etc.); therefore the model has been tested under constant output, see Appendix 1, simple regulator, position 143-147);

o by using the methodology improve the existing empirical descriptive "models" which appear to estimate possibilities of these mining technologies for a given time horizon and to explain that through the dynamics simulation model various discussions and following decisions are made easier (it is the work on a software tool which would form part of the decision support system for coal mining industry managers);

o to find variants in the framework of each new alternative for different parameters MI of the new PEEM mining technology and for different concrete mine conditions (PDR--see above) for research purposes in other sectors (which produce mining equipment, i.e., electronic, machinery, chemistry, etc.).

The COMTEM model is a dynamics model, and because of this it was necessary to translate mathematical expressions into DYNAMO statements, which is the computer language (Pugh 1970,1977) of systems dynamics models (see Appendix 1) and which enables the user to solve initial value problems numerically by using either EULER, RUNGE KUTTA or ADAMS-BASHFORTH methods as determined by an integration option. The Euler integration method has been used for the COMTEM model with time steps for each month, for the examples of output results for each two years and a time horizon of 50 years.

The main principle of the model is shown in Table 1 (or for a concrete illustrative case see Table 2). This table (cost parameters) has been transformed into a matrix (for the old technology, see Appendix 1, positions 28-51, and for PEEM, positions 52-75). We can see that the old technology always has the coefficient k = 1 for parameters ML...TI, GL, etc., and for the new technology the coefficient k_n = 0-100 (e.g., estimated by

Table 1 Basic table of input data for the "COMTEM" dynamics model**

ACTIVITIES	LABOR	MATERIAL & OTHER COSTS	WATER AND ENERGY	MACHINERY EQUIPMENT INVESTMENTS	"ELEC-TRONIC COSTS***	* UCOST	REMARKS
mining	ML	MM	ME	MI	-		
development (driving)	DL	DM	DE	DI	-		
transport	TL	TM	TE	TI	-		
service	OL	OM	OE	OI	-		
Σ underground					-		
surface	SL	SM	SE	SI	-		without stone impact
extraction CH_4	GL	GM	GE	GI	-		only for PEEM technology
TOTAL UNIT COSTS *							without construction investment
rate	surface % underground %	%	%	%			per year

* Total unit production costs of coal and "UCOST": monetary units/ton coal

** See text

*** The factor will be taken into account later.

experts). Accordingly, there is a difference in the new and the old mining technologies.

If the matrix (cost table) for the old technology always has the coefficient k = 1 it means that it is a reference technology (the data of Table 2 are in position 4-27 in Appendix 1 and as reference data in position 28-51) = *New PEEM mining technology has been related to this reference technology by a matrix (cost table) of relative costs.* In other words, we have the technology descriptions (by matrix) and for further investigation we need a decomposition of the basic scheme (see Figure 2) accordingly:

1. Technical characteristics (mining depth, geological conditions, etc.),

2. Economic characteristics (external prices of material, energy, wages and machinery investments, etc.),

3. Other characteristics (logistic curves, time period of the innovation cycle, etc.).

Items 1-3 actually create several interconnected submodels which are important for the COMTEM model and is best shown in an illustrative case.

ILLUSTRATIVE EXAMPLE

In order to answer the question "How difficult and expensive is it for the new PEEM mining technology to get through the debugging and scaling up stages, as well as understanding the model better?", it is suitable to use an illustrative example of present mining practice.

It is a well established practice that the experimental test of some new technology is performed, as far as is possible, under natural conditions (geological and tectonic) which would be easily comparable and measurable and which would be closely related to the most widespread as well as to the most convenient type of coal seams. This means that steep seams, seams with tectonic zoning or very thin ones--under 1 m, or very thick ones--above 5 m would not be considered. For these reasons such a mining unit is suitable for the needs of modeling, having the following technical and economic characteristics:

(a) Technical Characteristics (for the productivity submodel)

1. Mine life time is approximately 150 years, these days, the mine is in the middle of its life time and it has not yet reached the critical mining depths (above 700 m) therefore PDR can be, e.g., 1%/year.

2. Its capacity has been planned for 10,000 t (see Appendix 1, position 78) of mining output per day using a mining field area of approximately 700 hectares; 10% of this amount is reserved for waste

* OTA.k = INTGRL (OIN.JK-ODP.JK)
see the position -0076 in app. 1

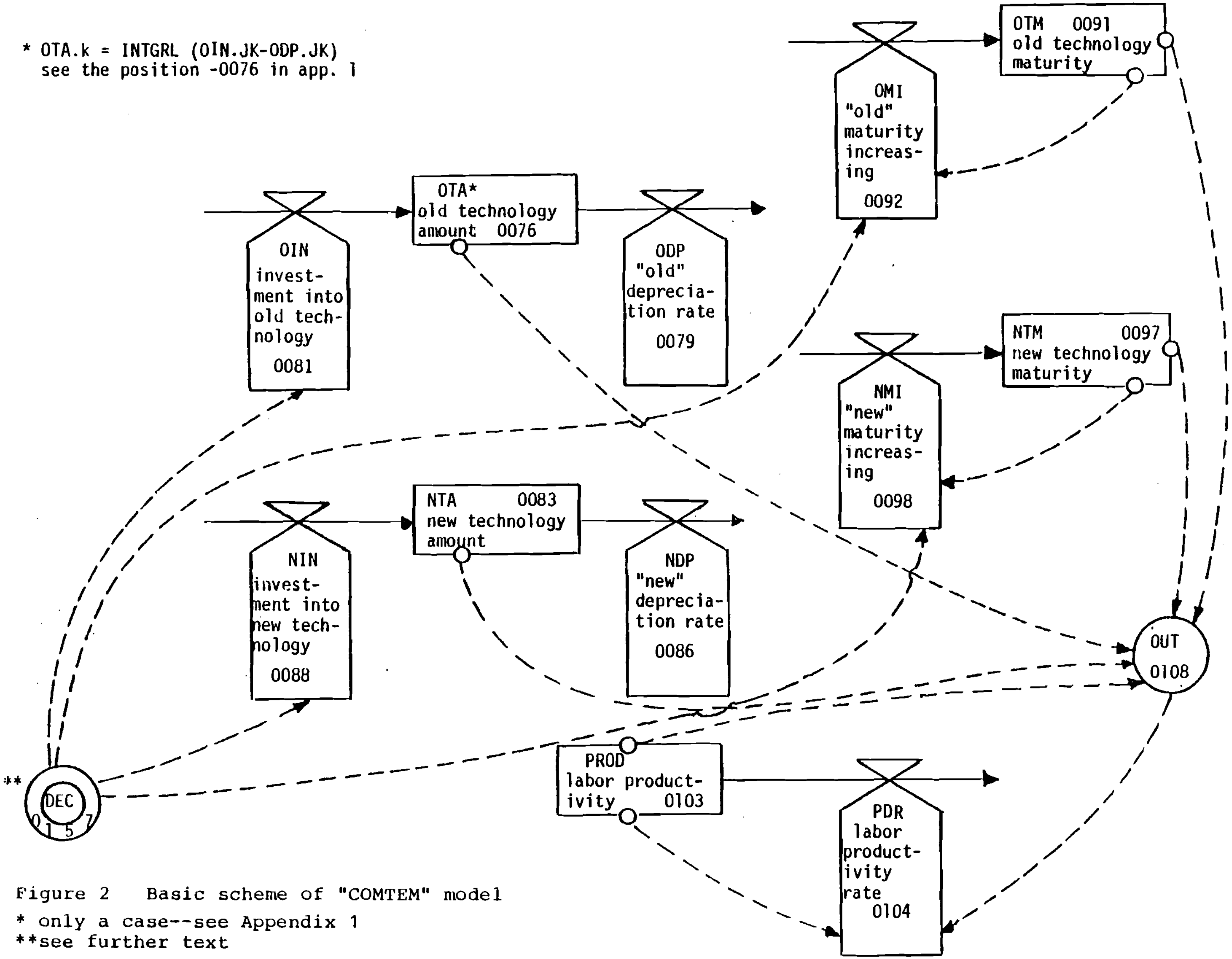

Figure 2 Basic scheme of "COMTEM" model
* only a case--see Appendix 1
**see further text

tips (waste disposal); annual capacity of a mine is derived from a 5-day working week. In the case of PEEM technology, a continuous operation must be taken into account (except maintenance of vertical mining equipment)--especially in parameters ML, DL, MI, DI.

3. Gas content of mining coal accounts for 10 m^3 per ton and per 24 hours on average, water consumption for 2 m^3/t; investment costs for approximately 30 monetary units per extracted ton of coal and costs for reclamation and rehabilitation operations of land disturbances will always be included in SL, SM, SE and SI (see Table 1).

4. For this example seams of 2 m average thickness are taken into account; this means that for the purpose of mining 10,000 t of coal, it is necessary to drive out approximately 70 m of entries (drifts)--parameters DL, DM, DE, DI.

5. All these technical characteristics (or factors, parameters) influence the productivity of both technologies, it is the actual amount of coal because the productivity reduces the amount of coal extracted due to the worsening of mining conditions over time. In other words the rate for PDR (e.g., 1%/year--see above) respects only higher temperature and pressure, therefore, we are going to complete the productive model on influencing the structure of resources of a given mine (for micro-economic purposes).

6. Mine development by means of investment cost (crosscuts, raises, pits, etc.) is supposed to be the same for both mining technologies.

(b) Economic Characteristics (for the costs submodel)

1. In this phase of systems analysis the same economic approach to the selective mining and recovery factor is considered. Work underground is classified in its risks and health dangers from the standpoint of long-term investigation to the same category as qualified work.

2. It follows from the technical characteristics that investments are supposed to be at the same level, so that the investment output ratio of one ton of coal will be assumed to be at the same level.

3. Except rates of wages underground (WUR) and on the surface (WSR) there is, respectively, a rate of the non-wage costs (changes in material, energy and machinery investment costs) as well (see MCR in Appendix 1, position 113, and Appendix 2, column MCL).

4. It is easy to identify labor productivity according to individual principal activities (extraction,

transport, etc.), from the number of workers recorded in Table 2 in column "Labor Costs" wage unit costs and other parameters for the illustrative example as well (all concerning 10,000 t output per day).

5. Very simple models of exponential growth have been used to approximate the increase of external prices (see Appendix 1, positions 109, 114, 119). Separate models can be defined for other decomposed unit costs--e.g., from the machinery equipment investment it is possible to take out the "electronic costs", see Table 2, for the purposes of micro-economic investigations.

(c) Other Characteristics (for the maturity submodel)

1. The maturity of the technology is hypothesized to be increasing due to experience in theory and production. For construction of logistic curves, which illustrate development of technology in time, a current mining technology of long wall face with an innovation cycle period of 50 years must be considered (see Appendix 1, positions 95, 101), and at the same time the fact that the development of this technology is in a stage of saturation (since further automation of works in a face--increasing MI brings only very low savings of labor--ML, and the rest of underground activity will remain unchanged in spite of the automation of mining works).

2. From the equations (see Appendix 1, positions 93 and 99) it is clear that the submodel largely respects experience in production but the increase in general knowledge has not been taken into account. Both technologies in the submodel have been used for the same maturity model with different OTMN and NTMN (see above).

Coal is currently mined by the best and most widespread method "long wall" and in this illustrative case it is only for caving, using 10 progressive faces; in the case of the PEEM mining method it corresponds, e.g., to two mining units. For calculations by the COMTEM model the amount of technology (OTA or NTA) is measured in units of potential output production, e.g., production related to the contemporary mining productivity. Actually it is the relation between the investment into technology (investment rate OIN for the "old" and NIN for the "new"--see Figure 2) and the amount of technology retired (ODP or NDP--see Figure 2, which depends on the average life time of technology OAL or NAL--see Appendix 1, positions 80 and 87, for the case it is 5 years).

One existing level (they are different for individual mines) of production costs for various activities of the old technology in present concrete mine enterprise is demonstrated in Table 2--they reflect the above mentioned technical, economic and other characteristics (it is the reference matrix, therefore, for the purpose of comparison costs for coal preparation through washing

Table 2 Unit costs (ucost) for present deep coal mine (capacity 10,000 tons/day)

Activity	Labor cost		Material & other costs	Water and Energy	Machinery equipment investment	"electronic" costs	UCOST	Remarks
	Number	Money						
Mining	(700)	18	9	2	25	-	54	only long-wall faces
Development (driving)	(500)	11	17	2	2	-	32	
Transport	(500)	9	2	1,5	2	-	14,5	
Service	(1000)	39	26	6	34	-	105	
Σ Underground	(2700)	77	54	11,5	63	-	205,5	
Surface	(1300)	18	22	11	82	-	133	
CH_4	-	-	-	-	-	-	-	
Total	(4000)	95	76	22,5	145		338,5	monetary units/ton
Rate (e.g.)		WUR=4% WSR=3%	2%[+]	2%[+]	2%[+]	-		per year

+ = so called "nonwage" costs--MCR

coal in a heavy liquid, washing plants on the surface are not included in the cost matrix--except costs of separating coal from stone).

It is not difficult to evolve an illustrative example in the case of the old mining technology. It is more difficult to find appropriate technical, economic and other characteristics and data, which would be sufficient even for the following phase--this means an expert's estimation of reducing coefficients of the cost matrix for the new PEEM mining technlogy.

GENERATING ALTERNATIVES AND VARIANTS

Before everthing else, it is necessary to realise the fact that the COMTEM model has been designed for improving the decision support system of coal industry managers and for management gaming. For the second purpose, it is suitable to always obtain the same coal production from various technological alternatives. Therefore, the model has been tested under a constant output (OUT) scenario. The control function of the manager has been substituted by a simple regulator structure (see Appendix 1, positions 143-147). The requirements of the constant coal output is realizable (see Appendix 2,3,4, OUT = 99,9 or 100%) and enable a comparison of technological alternatives, especially following the results of the main objective functions (see Appendix 1, positions 124-142):

-- UCOST = the unit cost of the coal produced

-- LAUG = the sum of the underground labor

-- LASF = the sum of the labor on the surface

-- LAUG + LASF= LAALL (other acronyms, see Appendix 5)

For the overall structure of the model description it is necessary to explain how the manager can create various strategies for engaging eligible new PEEM technology; this is possible by DEC (see Figure 2). In actual fact, it is the proportion (sharing ratio) between the amount of the old (OTA) and the new (NTA) working mining technology. If DEC = 0,0 it means that only the old technology is working; if DEC = 1,0 it means that 100% of the depreciation of old technology is substituted by the new one.

In Table 3 (or see Appendix 1, position 52-75) we have coefficients of the new PEEM mining technology--it is the actual matrix of relative costs which have been related to the reference matrix for the old technology (see above). The difference between both technologies (for each activity: mining, transport, etc.) can be estimated by experts or in a different way--it depends on the practice of the coal area of the country.

Filling up the table with coefficients (k_n) means creating one so called *fundamental* alternative (FA) for new PEEM technology development--a possibility (by Czechoslovakian experts) is shown in Table 3 (FA_1).

Table 3 Expert assessment of coefficients k_n for "n" *fundamental* alternative of PEEM mining technology (for calculation by COMTEM model it is more suitable to take into account the median of those spans of different experts) - the table is for FA_1

Activity	Labor	Material & other costs	Water and Energy	Machinery equipment investment	"electronic" costs	UCOST	Remarks
Mining	0,1 - 0,2	1,0 - 2,0	1,0-2,0	5,0 - 10,0	-		
Development (driving)	0,2 - 0,5	0,2 - 0,5	0,5-0,6	0,5 - 0,6	-		amount of stone is decreasing
Transport	0,2 - 0,3	0,4 - 0,5	0,4-0,5	0,4 - 0,5	-		
Service	0,1 - 0,3	0,4 - 0,5	0,4-0,5	0,4 - 0,5	-		
Σ Underground							sum total is only important for wages
Surface	0,3 - 0,4	0,4 - 0,6	0,7-0,8	0,7 - 0,8	-		
CH_4	-	-	-	-	-		
Total							monetary units/ton
Rate (e.g.)	underground 4% surface 3%	2%	2%	2%	-		per year

From the theoretical point of view, we can say that if the table is changed by only one coefficient--then it is quite a new fundamental alternative. If we change:

-- labor rates (WUR or WSR for different rates /%/year) of increasing labor cost;

-- material rates (MCR for different rates of increasing material costs including water, energy and other costs);

-- OAL or NAL for different service life of mining machinery equipment (e.g., 3, 5, 7, 10 years, etc.);

-- PDR--different influences on lower depths of mining for labor productivity (1%, 2%, etc., per year),

we receive various *generating alternatives* of new PEEM technology development in, e.g., 50 years time horizon. Depending on the decision maker's objectives, the COMTEM model can give generated alternatives with various logistic curves (OMP, NMP or OTMN, NTMN, etc.) and with various DEC also.

In predicting the impacts associated with the generating alternatives, the decision maker has to take into account especially a price (in investment costs) of machine mining equipment (device) for the new PEEM technology, i.e., coefficient (parameter) MI (NMI), because it is a core of the new innovation. For this reason it is useful for each generated alternative to arrange through the model, several *variants* for different levels MI - 2,5-(5,0) - (7,5) or (10,0), etc.

Generating these alternatives and variants by the COMTEM model is possible very quickly and decision maker-computer dialogue is possible as well. This means one can stop the model at a certain time and change the input data, etc., and identification of some innovation technology problems in the future of coal mining is possible (or to minimize objective functions). The model would form the core of the game, the interface between the player and the model would be constructed as a further step. It is however not our purpose to pursue these aspects of the COMTEM model in great detail (there will be very many obstacles because the software used (DYNAMO) is a very poor and closed programming language which has no means of per-parts simulation, etc.).

Instead, as we have said, this paper concentrates on an introductory description of "how well the COMTEM model can help, for following the stages of systems analysis of this problem". Only simple computed examples can be a source for several scenarios (see Figure 3) creating alternatives and variants for the new PEEM technology as shown in Figure 3 (this does not mean that one variant can be a source for only one scenario and vice versa conversely).

Obviously, many different alternatives, variants and scenarios can be envisaged by such a model, but again we intentionally choose the most cautious approach by assuming that the decision makers and analysts should make the greatest possible

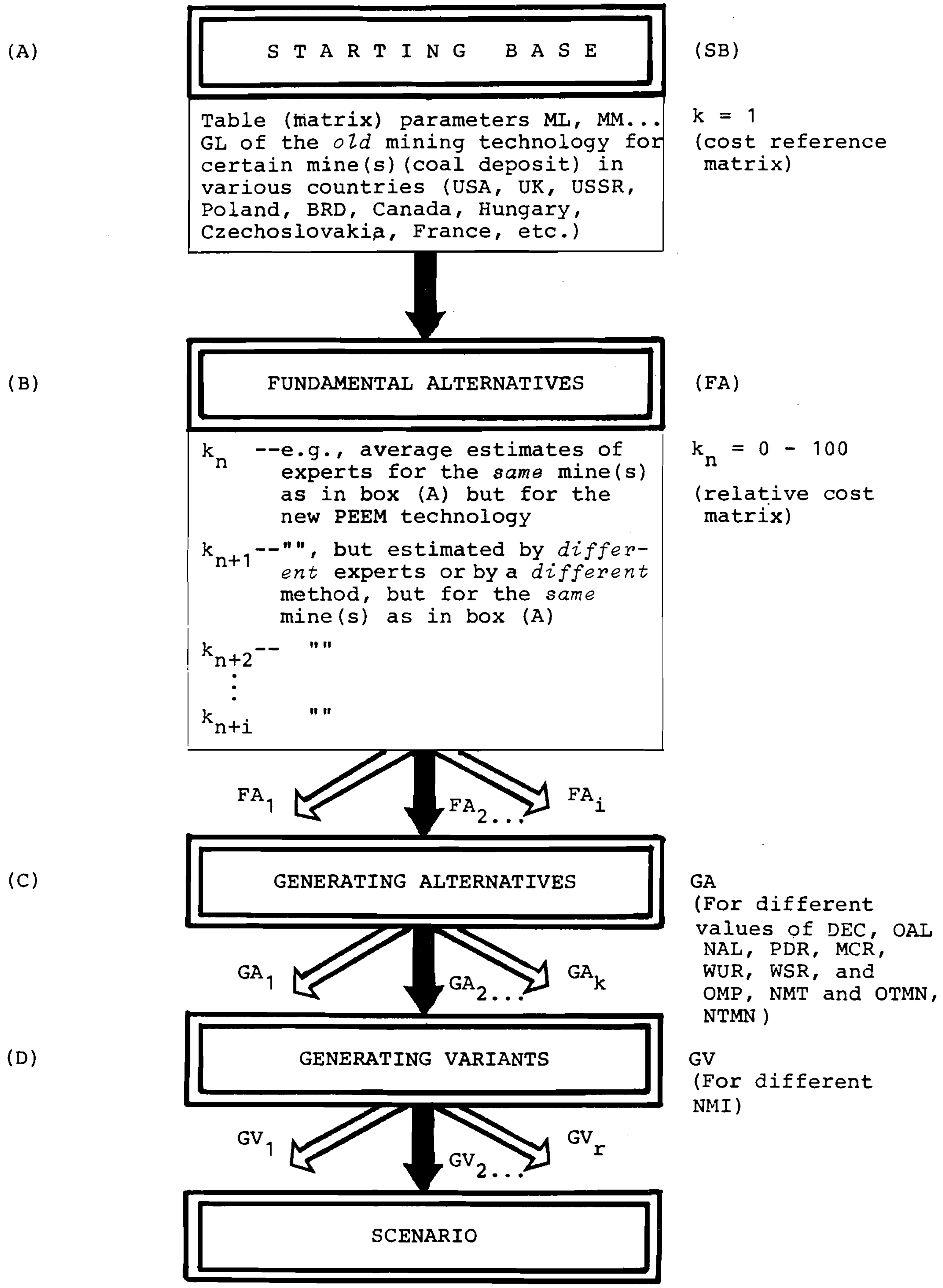

Figure 3 Progression Scheme of Creating Alternatives and Variants of the New PEEM Mining Technology

use of this part of their decision support system (because the model IS this part) which would include not only the innovation process but also other future problems of human underground activity (Petras 1980). Such a scenario or an alternative, may not be always realistic, but it will help us to understand what the approach would look like through new mining technologies to decision making in the coal industry.

INTRODUCTION TO RANKING VARIANTS AND THEIR CONSEQUENCES

Generating alternatives and variants by the COMTEM model or their selecting (or tuning) can be explicitly managed by the decision maker, i.e., they are defined by a more or less detailed enumeration of their specific characteristics. For our purpose, it is clear that the many alternatives or variants cannot all be investigated in detail (that is a job for a group of specialists!). For this reason only some of them have been calculated--like a case before a more detailed analysis.

With the easy ranking of alternatives (GA) and variants (GV) in mind, the following outputs of computer calculations for the illustrative case (i.e., in Table 2 = SB_1 and in Table 3 = FA_1) have been received:

GA_1 for:	DEC = 0,0	OAL (NAL)	= 10,0
	MCR = 2,0	PDR	= 2,0
	WUR = 4,0	NMI	= 7,5
	WSR = 3,0	OMP (NMP)	= 50,0

Because DEC = 0,0 it is possible to consider this GA_1 as an extreme generated variant (actually it is only a development of the old mining technology)--therefore it is useful to show its development in a time period (see Tables 4 and 5). These two tables show a 50-year simulation run of the COMTEM model for some computer outputs which always conform to other alternatives and variants:

- -- OCOST = see Table 1 (Σ MM, DM, TM, OM, SM, GM, ME, DE, TE, OE, SE, GE, MI, DI, TI, OI, SI, GI) and NCOST for the new PEEM technology;
- -- COSTS = OCOST + NCOST
- -- OLABOR = see Table 1 (Σ ML, DL, TL, OL, SL, GL) and NLABOR for the new PEEM technology;
- -- LABOR = OLABOR + NLABOR
- -- UCOST = LABOR + COSTS

In Table 5 it may be observed that unit costs (UCOST) of coal in the case of old mining technology are increasing over the 10-year horizon: 10 years + 48%, 20 years + 225%, 30 years + 360%, and 50 years + 950%!!

Table 4 Values of outputs for the old mining technology (generated alternative GA_1)

TIME E+00	OTA E+03	NTA E+00	OTM E+00	NTM E-03	PROD E+00	OUT E+03
0.000	100.00	0.0000	0.9000	500.00	1.0000	100.00
2.000	101.78	0.0000	0.9186	500.00	0.9609	99.82
4.000	104.16	0.0000	0.9349	500.00	0.9232	99.90
6.000	106.86	0.0000	0.9485	500.00	0.8870	99.89
8.000	109.89	0.0000	0.9598	500.00	0.8522	99.88
10.000	113.27	0.0000	0.9691	500.00	0.8188	99.87
12.000	116.99	0.0000	0.9766	500.00	0.7867	99.87
14.000	121.02	0.0000	0.9825	500.00	0.7559	99.86
16.000	125.36	0.0000	0.9871	500.00	0.7263	99.85
18.000	130.00	0.0000	0.9906	500.00	0.6978	99.85
20.000	134.93	0.0000	0.9933	500.00	0.6705	99.84
22.000	140.14	0.0000	0.9952	500.00	0.6442	99.83
24.000	145.63	0.0000	0.9967	500.00	0.6190	99.83
26.000	151.40	0.0000	0.9977	500.00	0.5947	99.82
28.000	157.45	0.0000	0.9985	500.00	0.5714	99.81
30.000	163.77	0.0000	0.9990	500.00	0.5490	99.81
32.000	170.37	0.0000	0.9993	500.00	0.5275	99.80
34.000	177.26	0.0000	0.9996	500.00	0.5069	99.79
36.000	184.44	0.0000	0.9997	500.00	0.4870	99.78
38.000	191.92	0.0000	0.9998	500.00	0.4680	99.77
40.000	199.71	0.0000	0.9999	500.00	0.4496	99.77
42.000	207.82	0.0000	0.9999	500.00	0.4320	99.76
44.000	216.26	0.0000	1.0000	500.00	0.4151	99.75
46.000	225.05	0.0000	1.0000	500.00	0.3989	99.74
48.000	234.19	0.0000	1.0000	500.00	0.3833	99.73
50.000	243.70	0.0000	1.0000	500.00	0.3683	99.71

Table 5 Values of outputs for GA_1

TIME E+03	OCOSTS E+06	NCOSTS E+00	COSTS E+06	OLABOR E+06	NLABOR E+00	LABOR E+06	UCOST E+03
0.000	24.35	0.0000	24.35	9.50	0.0000	9.50	0.3385
2.000	25.79	0.0000	25.79	10.43	0.0000	10.43	0.3629
4.000	27.48	0.0000	27.48	11.53	0.0000	11.53	0.3904
6.000	29.33	0.0000	29.33	12.76	0.0000	12.76	0.4214
8.000	31.40	0.0000	31.40	14.16	0.0000	14.16	0.4561
10.000	33.68	0.0000	33.68	15.75	0.0000	15.75	0.4950
12.000	36.21	0.0000	36.21	17.56	0.0000	17.56	0.5384
14.000	38.98	0.0000	38.98	19.61	0.0000	19.61	0.5867
16.000	42.03	0.0000	42.03	21.93	0.0000	21.93	0.6405
18.000	45.36	0.0000	45.36	24.55	0.0000	24.55	0.7002
20.000	49.00	0.0000	49.00	27.51	0.0000	27.51	0.7663
22.000	52.97	0.0000	52.97	30.85	0.0000	30.85	0.8396
24.000	57.29	0.0000	57.29	34.62	0.0000	34.62	0.9207
26.000	61.98	0.0000	61.98	38.87	0.0000	38.87	1.0103
28.000	67.09	0.0000	67.09	43.65	0.0000	43.65	1.1094
30.000	72.63	0.0000	72.63	49.03	0.0000	49.03	1.2189
32.000	78.64	0.0000	78.64	55.08	0.0000	55.08	1.3399
34.000	85.15	0.0000	85.15	61.90	0.0000	61.90	1.4735
36.000	92.21	0.0000	92.21	69.56	0.0000	69.56	1.6213
38.000	99.87	0.0000	99.87	78.18	0.0000	78.18	1.7845
40.000	108.16	0.0000	108.16	87.88	0.0000	87.88	1.9650
42.000	117.14	0.0000	117.14	98.79	0.0000	98.79	2.1645
44.000	126.87	0.0000	126.87	111.06	0.0000	111.06	2.3852
46.000	137.40	0.0000	137.40	124.35	0.0000	124.85	2.6295
48.000	148.81	0.0000	148.81	140.37	0.0000	140.37	2.8997
50.000	161.17	0.0000	161.17	157.82	0.0000	157.82	3.1990

| GA_2 | for: DEC = 0,5 and other inputs as in GA_1;

Behaviors of key variables (OTA, NTA, OTM and NTM) of the generated alternative GA_1 are observed in Figure 4. It is interesting that for DEC = 0,5 old technology capacities are increasing again after 25 years (because the engagement of eligible new PEEM technology is not able to cover other negative influences--even for the same output level).

The UCOST are for important time horizons, as follows:

0,0 - 338,5 = 100%	30,0 - 930,9
10,0 - 479,8	40,0 - 1368,5
20,0 - 659,60	50,0 - 2090,4

What is far more significant than the curves, is the fact that these UCOST are <u>much</u> lower than for GA_1 in spite of the fact that investment costs for machine equipment of the new mining technology are 7,5 times higher (see Table 3--the median of parameter MI is 7,5).

| GA_3 | for: DEC = 1,0 and other inputs as in GA_1 and GA_2;

Table 6 shows outputs in different time horizons which are important. The table also reveals that the system tends to manifest improvement if the proportion of new technology is increasing maximally. UCOST for GA_3 is better than the former alternatives and in spite of this the UCOST is higher in the first five years than the UCOST for the old mining technology (GA_1). For the behaviors of key variables of GA_3 see curves in Figure 5.

The results of GA_2 and GA_3 are very surprising, especially if we realize that the coefficient for parameter MI is 7,5, decreasing labor productivity (PDR) by worse mining conditions--2% per year is too much for present mines and for the life time of machine equipment--10 years (for OAL and NAL as well) is also unrealistic (but only from today's point of view).

Table 6 Outputs for GA_3

TIME	OTA	NTA	OCOST	NCOST	OLABOR	NLABOR	UCOST
0,0	100,0	0,0	24,3	0,0	9,5	0,0	338,5
10,0	36,6	61,7	10,9	24,5	5,1	2,0	425,3
20,0	13,4	80,4	4,9	38,9	2,7	3,9	505,0
30,0	4,9	94,4	2,2	55,9	1,5	6,6	662,4
40,0	1,8	112,3	0,9	81,2	0,8	11,5	946,1
50,0	0,7	135,9	0,4	119,9	0,4	20,4	1415,3

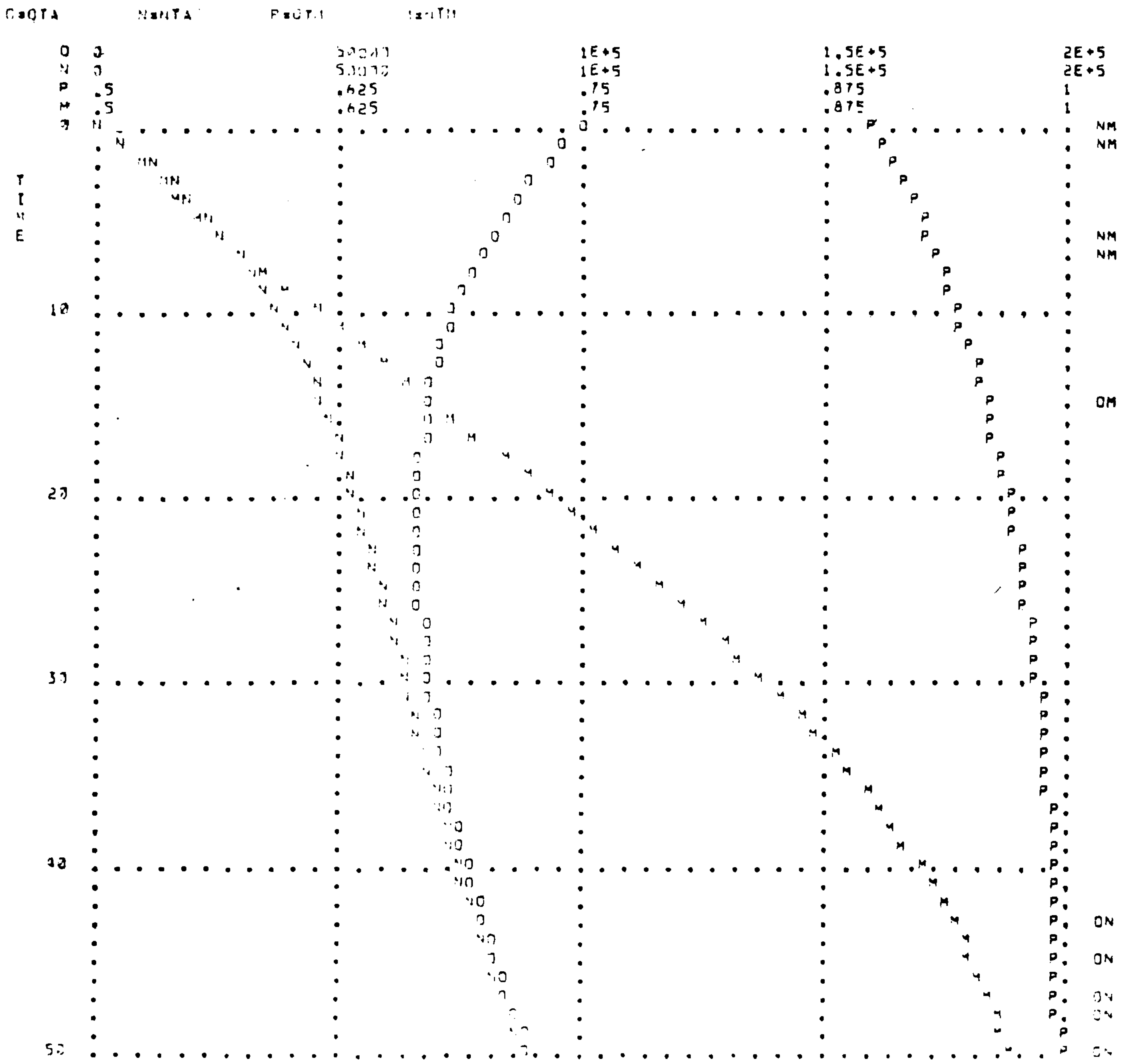

Figure 4. Behaviors of key variables of GA_2

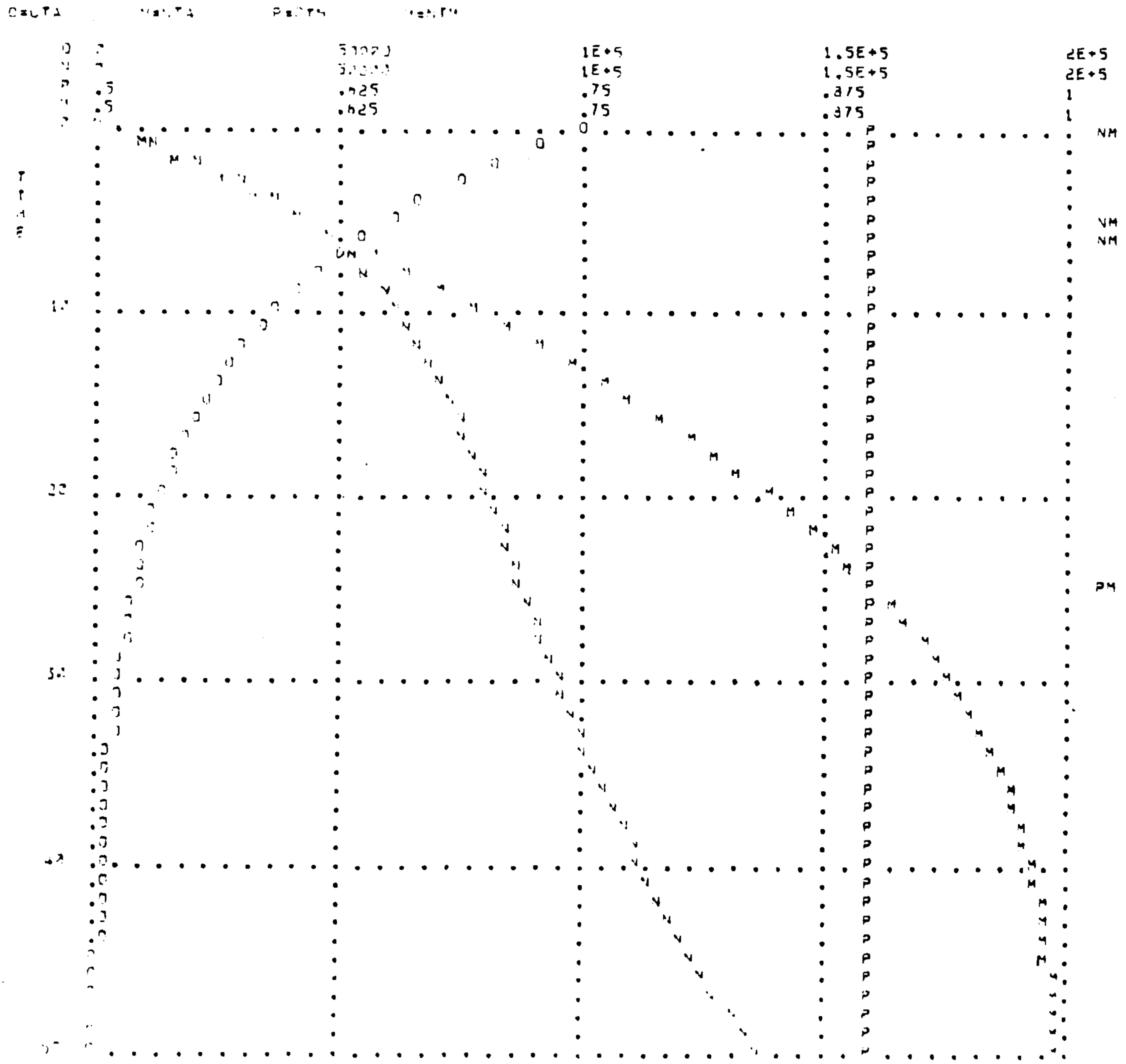

Figure 5 Behaviors of key variables of GA_3

Other generated alternatives in the framework FA_1 have been worked out therefore, with different values of inputs:

GA_4 for:	DEC = 0,0	OAL (NAL)	= 5,0
	MCR = 2,0	PDR	= 1,0
	WUR = 4,0	NMI	= 2,5(5,0),(7,5),(10,0)
	WSR = 3,0	OMP (NMP)	= 50,0

Again we start with DEC = 0,0, i.e., GA_4 is an extreme alternative (only the old technology is developing); the results are in Tables 7 and 8.

Consequences of each input that is being changed (OAL, NAL and PDR) are distinct, because UCOST of GA4 are much better (positive) than those of GA_1 (for the old technology as well). For example we can see from Tables 7 and 8 that a difference for the time horizon of 20 years is:

$$\Delta\ UCOST_{20} = 766,3 = 630,6 \doteq 136 \text{ monetary unit/ton}$$

and for the time horizon of 50 years it is:

$$\Delta\ UCOST_{50} = 3119,0 - 1941,9 \doteq 1257 \text{ monetary unit/ton.}$$

This means that the impact PDR (increasing 1%) is much stronger than impact OAL (decreasing from a 10 year life time to 5 years). It is possible to consider this alternative as a suitable base for comparison with similar alternatives for the new PEEM technology.

GA_5 for: DEC = 0,5 and other inputs as in GA_4
has: 4 generated variants

GV_1 for NMI = 2,5

The generated variant (GV_1)--for the lowest level of machine equipment investment costs has the following curves for the variables as shown in Figure 6.

It is interesting that as in GA_1 the amount of old technology is increasing (beginning at year 34), because the influence of PDR is still strong. The UCOST for some time horizons is: 10 years = 340,0; 20 years = 367,1; 30 years = 415,3; 40 years = 599,0; 50 years = 1124,8.

GV_2 for NMI = 5,0

The curves of variables OTA, NTA, OTM, NTM are identical as those for GV_1 (see Figure 6) because it is in the same frame of alternative (GA5). We can again see that there is favorable

Table 7 Computer results for GA_4

TIME E+00	INV E+03	OTA E+03	NTA E+00	OTM E-03	NTM E-03	PROD E+00	OUT E+03
0.000	20.000	100.00	0.0000	900.00	500.00	1.0000	100.00
2.000	20.134	100.37	0.0000	917.17	500.00	0.9802	99.96
4.000	20.368	100.47	0.0000	931.84	500.00	0.9608	99.94
6.000	20.627	101.14	0.0000	944.27	500.00	0.9418	99.94
8.000	20.918	102.05	0.0000	954.71	500.00	0.9231	99.93
10.000	21.238	103.16	0.0000	963.42	500.00	0.9048	99.92
12.000	21.582	104.45	0.0000	970.62	500.00	0.8869	99.91
14.000	21.950	105.91	0.0000	976.54	500.00	0.8694	99.91
16.000	22.338	107.51	0.0000	981.37	500.00	0.8522	99.90
18.000	22.744	109.24	0.0000	985.29	500.00	0.8353	99.90
20.000	23.168	111.09	0.0000	988.45	500.00	0.8188	99.89
22.000	23.607	113.04	0.0000	990.98	500.00	0.8026	99.89
24.000	24.061	115.08	0.0000	992.99	500.00	0.7867	99.89
26.000	24.529	117.21	0.0000	994.59	500.00	0.7711	99.88
28.000	25.010	119.42	0.0000	995.84	500.00	0.7559	99.88
30.000	25.504	121.71	0.0000	996.82	500.00	0.7409	99.88
32.000	26.010	124.06	0.0000	997.59	500.00	0.7263	99.87
34.000	26.528	126.49	0.0000	998.18	500.00	0.7119	99.87
36.000	27.058	128.98	0.0000	998.63	500.00	0.6978	99.87
38.000	27.600	131.53	0.0000	998.98	500.00	0.6840	99.86
40.000	28.153	134.15	0.0000	999.24	500.00	0.6705	99.86
42.000	28.719	136.83	0.0000	999.44	500.00	0.6572	99.86
44.000	29.296	139.56	0.0000	999.59	500.00	0.6442	99.86
46.000	29.885	142.36	0.0000	999.70	500.00	0.6315	99.85
48.000	30.487	145.21	0.0000	999.78	500.00	0.6190	99.85
50.000	31.100	148.13	0.0000	999.85	500.00	0.6067	99.85

Table 8 Computer results for GA_4

TIME E+00	OCOSTS E+06	NCOSTS E+00	COSTS E+06	OLABOR E+06	NLABOR E+00	LABOR E+06	UCOST E+03
0.000	24.350	0.0000	24.350	9.500	0.0000	9.500	0.3385
2.000	25.361	0.0000	25.361	10.259	0.0000	10.259	0.3563
4.000	26.500	0.0000	26.500	11.115	0.0000	11.115	0.3764
6.000	27.765	0.0000	27.765	12.075	0.0000	12.075	0.3987
8.000	29.156	0.0000	29.156	13.149	0.0000	13.149	0.4234
10.000	30.675	0.0000	30.675	14.348	0.0000	14.348	0.4506
12.000	32.327	0.0000	32.327	15.681	0.0000	15.681	0.4805
14.000	34.115	0.0000	34.115	17.164	0.0000	17.164	0.5133
16.000	36.043	0.0000	36.043	18.809	0.0000	18.809	0.5490
18.000	38.116	0.0000	38.116	20.632	0.0000	20.632	0.5881
20.000	40.340	0.0000	40.340	22.652	0.0000	22.652	0.6306
22.000	42.721	0.0000	42.721	24.886	0.0000	24.886	0.6768
24.000	45.267	0.0000	45.267	27.357	0.0000	27.357	0.7271
26.000	47.985	0.0000	47.985	30.088	0.0000	30.088	0.7816
28.000	50.884	0.0000	50.884	33.104	0.0000	33.104	0.8409
30.000	53.973	0.0000	53.973	36.435	0.0000	36.435	0.9052
32.000	57.262	0.0000	57.262	40.111	0.0000	40.111	0.9750
34.000	60.762	0.0000	60.762	44.168	0.0000	44.168	1.0507
36.000	64.484	0.0000	64.484	48.645	0.0000	48.645	1.1328
38.000	68.443	0.0000	68.443	53.584	0.0000	53.584	1.2219
40.000	72.650	0.0000	72.650	59.031	0.0000	59.031	1.3186
42.000	77.120	0.0000	77.120	65.040	0.0000	65.040	1.4236
44.000	81.870	0.0000	81.870	71.668	0.0000	71.668	1.5376
46.000	86.916	0.0000	86.916	78.977	0.0000	78.977	1.6614
48.000	92.275	0.0000	92.275	87.038	0.0000	87.038	1.7958
50.000	97.967	0.0000	97.967	95.928	0.0000	95.928	1.9419

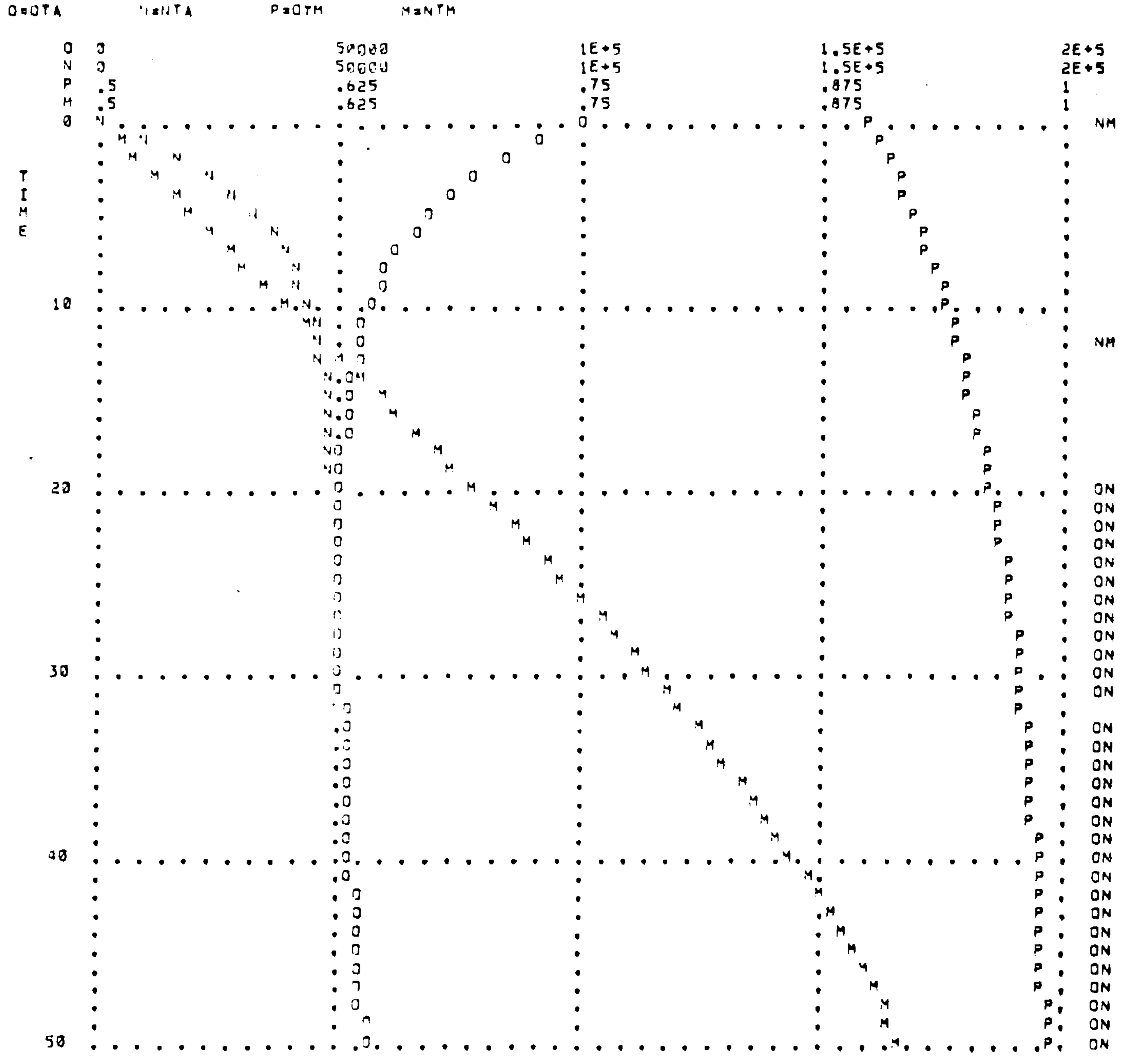

Figure 6 Behaviors of key variables of GA_5

development until 20 years has passed because the amount of units of old technology (OTA) is decreasing and NTA is increasing (the capacity is always constant, i.e., OUT = 100% ± 1%). See Table 9 for the UCOST.

| GV_3 | for NMI = 7,5

This variant better facilitates comparing more variants and alternatives among them because for GA_2 and GA_3 NMI = 7,5 too, therefore some values of outputs for several time horizons are shown in Table 9.

| GV_4 | for NMI = 10,0

It is logical that the variant is the most expensive because technology investment costs have been estimated at ten times higher than for the old technology, in spite of the fact that the UCOST is under the level of UCOST for the old technology alternative (GA_4). For the time horizon these are: 10 years = 466,2; 20 years = 594,1; 30 years = 772,2; 40 years = 1030,6; 50 years = 1410,7.

| GA_5 | for: DEC = 1,0 and other inputs as in GA_4
has: 4 generated variants (GV)

| GV_5 | for NMI = 2,5

This generated variant of new PEEM mining technology is the "cheapest" one, similarly, GV_1 and its UCOST are: 10 years = 259,3; 20 years = 269,3; 30 years = 328,2; 40 years = 429,6; 50 years = 584,1. Curves of variables as for GA_6.

| GV_6 | for NMI = 5,0

The UCOST of this variant are in Table 10 and the curves in Figure 7 (shape of the curves for all variants of GA_6 are identical).

Table 9 Values of outputs for GV_3

TIME	OTA	NTA	OCOST	NCOST	OLABOR	NLABOR	UCOST
0,0	100,0	0,0	24,3	0,0	9,5	0,0	338,5
10,0	56,6	43,3	16,8	17,1	7,8	1,4	433,2
20,0	50,7	48,9	18,4	23,7	10,3	2,4	548,5
30,0	50,9	50,7	22,5	30,0	15,2	3,6	714,5
40,0	52,9	52,9	28,7	38,2	23,3	5,4	957,0
50,0	56,1	56,1	49,5	86,6	36,3	8,4	1315,4

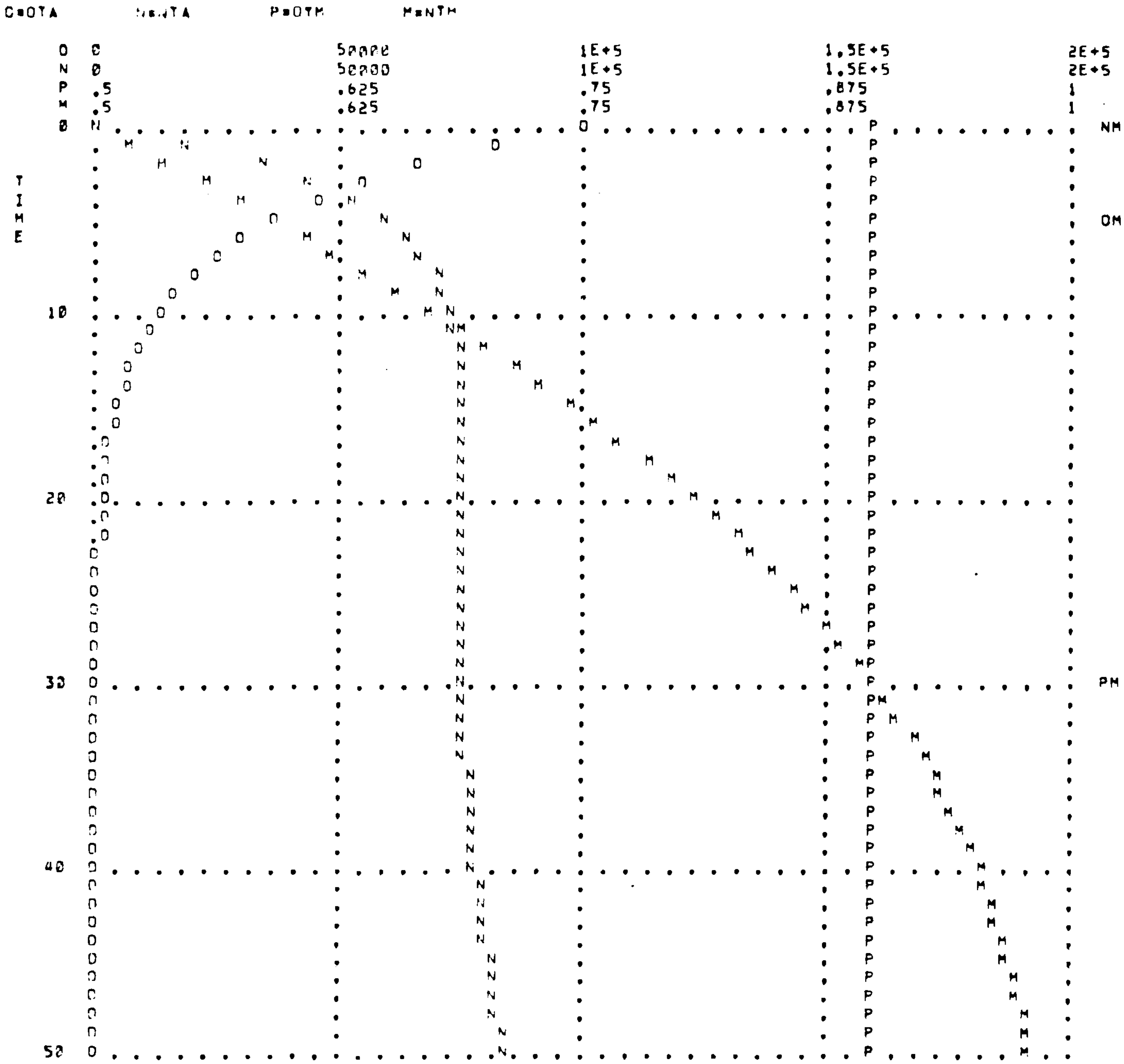

Figure 7 Behavior of key variables of GA_6

Table 10 Values of outputs for GV_7

TIME	OTA	NTA	OCOST	NCOST	OLABOR	NLABOR	UCOST
0,0	100,0	0,0	24,3	0,0	9,5	0,0	338,5
10,0	13,3	72,6	3,9	28,8	1,9	2,4	370,3
20,0	1,7	74,7	0,6	36,2	0,3	3,6	408,6
30,0	0,2	75,0	0,1	44,4	0,1	5,3	499,1
40,0	0,0	78,3	0,0	56,6	0,0	8,1	647,5
50,0	0,0	84,2	0,0	74,2	0,0	12,6	869,8

GV_7 for NMI = 7,5

The character of this variant is as GV_3 and therefore it is suitable again to select some values of outputs as in Table 10.

GV_8 for NMI = 10,0

Some of the output results for the generated variant GV_8 are shown in Appendix 2 for all time horizons of key variables by comparing them with other alternatives or variants, e.g., in spite of the fact that GV_8 is more "expensive" than GA_6: after 25 years its UCOST are even under the "cheapest" variant of GA_6 (i.e., for DEC = 0,5).

This is really only an introduction to the ranking of alternatives or variants and their consequences, but it is necessary for the understanding of the problems and for future investigation. As a tentative conclusion it would be suitable to sum up at least the UCOST for the main time horizon (see Table 11). An interesting feature of this table of values is, for example, the fact that for some variants in certain time horizons, variants of new PEEM mining technology are more expensive (!) than the old technology alternative (GA_4). The variant GV_4 (DEC = 0,5 and NMI = 10) has the "more expensive period" approximately 14 years and the GV_8 (DEC = 1,0 and NMI = 10) 6 years. A cumulative output of each time horizon are not shown in Table 11, but it is quite clear that for a longer time period these variants (GV_4 and GV_8) are still more profitable.

We can observe the opposite tendency in variants GV_5, GV_6 and GV_7 where even the UCOST are starting under UCOST level = 338,5 in period era 30, 20, 7 years again! Research is required to ascertain whether this pattern is realistic. Similar observations can be made using Figure 8.

Table 11 The UCOST for GA_4, GA_5, GA_6 and their variants

(GA_4) DEC = 0,0	DEC	NMI → / TIME ↓	2,5	5,0	7,5	10,0	$12,5^{+}$	$15,0^{+}$
338,5	0,5	0,0	338,5	338,5	338,5	338,5	338,5	338,5
376,4	(GA_5)	4,0	340,0	358,9	377,9	396,8	415,8	434,7
450,6		10,0	367,1	400,2	433,2	466,2	499,3	532,3
549,0		16,0	415,3	456,4	497,5	538,6	579,7	620,8
630,6		20,0	457,3	502,9	548,5	594,1	639,7	685,4
905,2		30,0	599,0	656,8	714,5	772,2	830,0	887,7
1941,9		50,0	1124,8	1220,1	1315,4	1410,7	1506,1	1601,4
	1,0	0,0	338,5	338,5	338,5	338,5	338,5	338,5
	(GA_6)	4,0	293,3	328,6	363,9	399,7	435,5	469,8
$^{+}$only orientation variants		10,0	259,5	314,9	370,3	425,7	481,1	536,5
		16,0	258,1	322,6	387,2	451,7	516,3	580,8
		20,0	269,3	338,9	408,6	478,3	548,0	617,7
		30,0	328,2	413,6	499,1	558,4	669,9	755,4
		50,0	584,1	726,9	869,8	1012,7	1155,6	1298,5

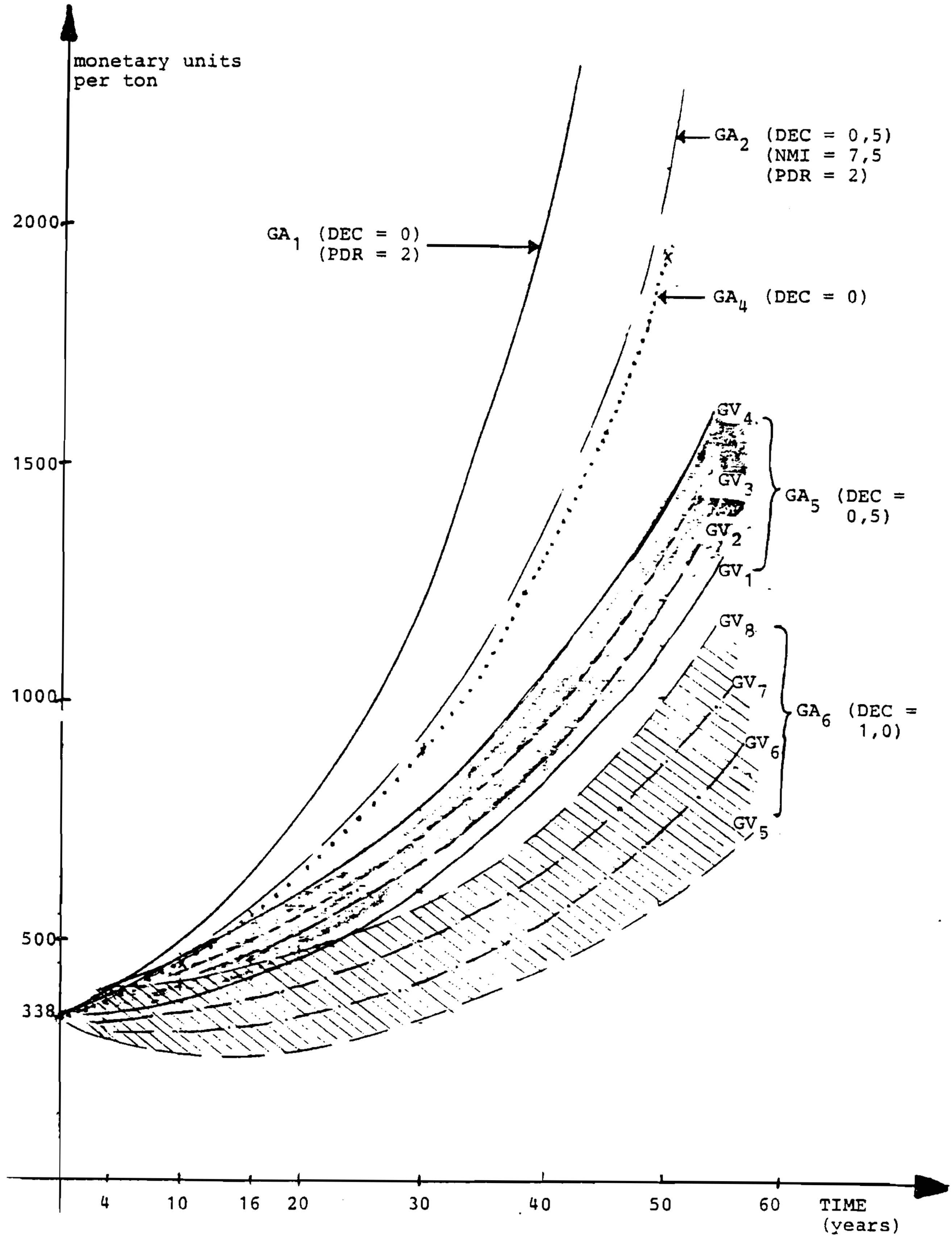

Figure 8 Comparing UCOST curves of generated technological variants and alternatives of FA_1

Figure 8 compares the UCOST curves of several generated alternatives and variants by COMTEM model--but only in the framework of the fundamental alternative FA_1, which is corresponds to Table 3 (for $k_n = k_1$). Indeed, one could generate a very wide spectrum of alternatives merely by changing values of the input parameters (box C in Figure 3), but each expert, e.g., in the framework of the IIASA seminar could object that the assessment of the parameters (see Table 3) of new PEEM mining technology attractive though it is, is incorrect or does not correspond to coal deposit conditions in his country.

He would be right--therefore the COMTEM model would work out other fundamental alternatives for him (FA_2--e.g., by 50% worse assessment of new technology parameters k_2, see Appendix 3) and the discussion would continue. Analogous discussions will be possible in a framework of Decision Support Systems for coal industry managers, because such a model must be one certain part of them.

What is more important is the fact that there are also ways of gaming with this model (see above) for managers and analysts, i.e., a simulation of the future development of the new PEEM mining technology per-partes. For example, the input (rate) PDR will be increasing not 1%/year, but 2%/year after 25 years because mining depth will be over 700 m (critical depth from the temperature and rock pressure point of view)--a computation flow can be interrupted and modifications can be made (or an influence of the scarcity of new mining equipment for PEEM technology on the "manager" input DEC, or an influence of a limitation of coal resources in the given coal mine on the input PDR, etc.).

TENTATIVE CONCLUSION

The above facts should serve as a reminder that this dynamics model is only a rough approximation of reality, and that per-partes simulation (gaming) is a better analytic tool to help the analyst in his computer dialogue.

It seems, then, to be more useful for coal industry managers because such a kind of simulation facilitates working out a fundamental alternative FA_x (for a SB_y) and several generated alternatives (or variants) which really would better reflect most concrete mining conditions of a certain coal deposit, or group of mines over a given time period. Furthermore, the per-partes simulation by the COMTEM model facilitates the inclusion into the model of every type of change in the inputs (see the examples above). What this does is to "buy" more accuracy which is usually less than one assumes.

Bearing this in mind, we can expect that such future alternatives and variants will improve the quality of understanding of these managers as well as other specialists from various sectors. It will be very important for future comparing and ranking of alternatives in real practice.

We do not claim that all the above decisions have to be faced at once. But one's thinking should be organized in this or a similar fashion. This could mean that in early decisions, one could look for ways that keep future mining options open. Relatively little can be added to what has been said here and therefore only several summary remarks may be made:

- The consequences of these basic alternatives, i.e., the old and the new PEEM mining technologies, are clearly more positive in the case of the PEEM method for:

  (1) costs of coal mining
  (2) amount of manpower (see Figure 9)
  (3) environmental impact (especially stone).

  Costs are expressed adequately in monetary units, the manpower only partly because a question arises which is how can the fact be expressed that people are becoming less willing to work underground (only the percent wage rate--see the input WUR is not sufficient) and the same problem occurs with the environmental impact--therefore, it is necessary that these results be considered within the framework of a scenario (see below);

- The model's sensitivity to mining equipment investment cost (NMI) over a very wide spectrum (2,5...15,0, see variants GV) and for some values of the inputs MCR, PDR, OAL, NAL, etc., including different impacts of strategies of engaged eligible new PEEM technologies (DEC) has satisfied our requirements;

- The strategies of engaging the new technology very strongly influences the UCOST in all time horizons (see above) including the case, if a <u>new</u> mine starts with new PEEM technology (hypothetical alternative of GA_7 of the FA_1, see Appendix 4), there are several extremely "cheaper" variants;

- The selecting, comparing, ranking, etc., of alternatives (FA, GA) and variants (GV) merits a more detailed analysis and more concrete conditions--in the case of the illustrative example, these alternatives serve as a tool to judge a "price space" which is opened up by new mining technology especially for:

  -- coal industry top managers,
  -- designers of electronics and machinery, engineers.

- The new mining technology (PEEM method) enables those managers, engineers, etc., to "spend", e.g., 7-10 times (it depends on the type of technological alternative or variants) more money and to keep UCOST on the same level as the old technology (e.g., if the old technology = $20 \cdot 10^6$ monetary units for a long wall face, then the new one can be (if NMI = 10) $20 \cdot 10^7$ monetary units, and if the new technology has, e.g., 3,5 times higher performance (lower than in the Karaganda, USSR) and it works 7 days/week then it means that its performance per calendar

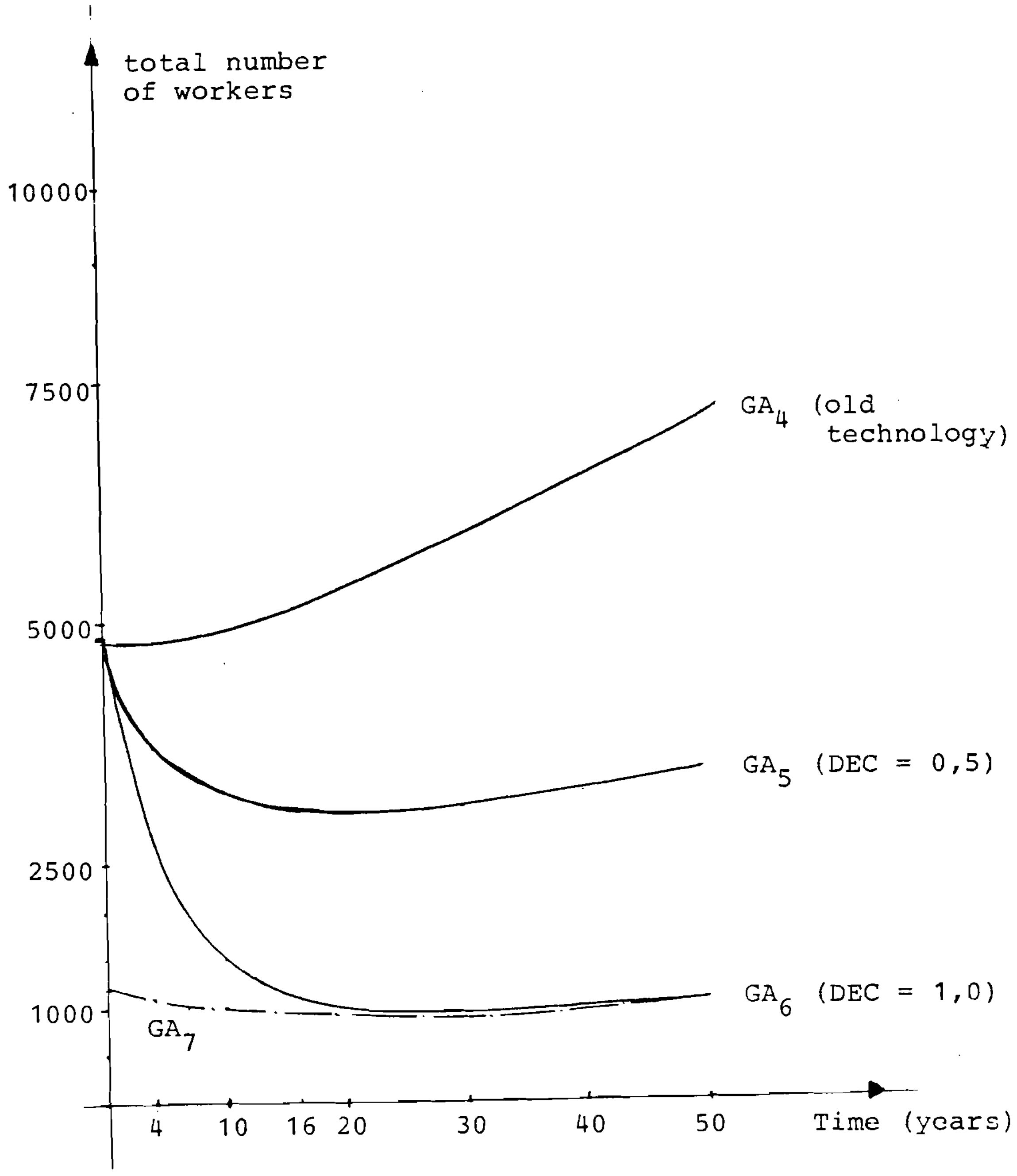

Figure 9 Manpower for the old and the new mining technologies (GA_4, GA_5, GA_6 and GA_7 are generated alternatives of FA_1)

week is approximately 5 times higher. From this result we can see the price of such a mining device can be about $5.20.10^7 = 10^9$ monetary units!! It is lower than e.g., the price of a modern coal excavator for an open mine and higher than the price of a full driving shield).

- o A scenario must be worked out following stages of the systems analysis, which is able, e.g., to say: if the external influences (before all the price of coal, CH_4, electronic equipments for remote control and monitoring, etc.) follow the scenario no. 1 for the FA1, the results of the new PEEM mining technology will be positive and therefore they will be suitable for further investigation on a national or international level.

- o The price of energy will increase (Häfele 1980) and therefore it is of primary importance to begin with a research activity. Such a scenario should take into account not only the energy price productive model, but also the following factors:

  -- the new PEEM mining technology (or method) is able to extract CH_4 (for the illustrative example it is cca $3.10^6 m^3 CH_4$/year) as the <u>second</u> output;

  -- underground construction investment will probably be lower for the new mining method (technology), but we are not able to estimate this now;

  -- the problem of the "recovery" factor which is very important for the coal deposit life time will be influenced by the new mining method positively.

This means that not only the model's results, but even these factors support the idea of cheaper coal mining in the future by PEEM technology. At this stage we must point out that systems analysis of the problem is not yet in a position to indicate whether or not the technology is a passable one. To this extent the reasoning in this paper is not strict enough. However, there is good reason to be concerned about possible impacts of negative results of the new technology because even this sort of result is very important--nobody will have to go back to this technology way.

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APPENDIX 1 - DOCUMENTED PROGRAM LISTING

```
      MINE TECHNOLOGY

* * * * *     S O U R C E     L I S T I N G     * * * * *

TITLE MINE TECHNOLOGY
* FULLER
* HOWARD
C ASML=18
C ASMM=9
C ASME=2
C ASMI=25
C ASDL=11
C ASDM=17
C ASDE=2
C ASDI=2
C ASTL=9
C ASTM=2
C ASTE=1.5
C ASTI=2
C ASOL=39
C ASOM=25
C ASOE=6
C ASOI=34
C ASSL=18
C ASSM=22
C ASSE=11
C ASSI=82
C ASGL=0
C ASGM=0
C ASGE=0
C ASGI=0
C OSML=1
C OSMM=1
C OSME=1
C OSMI=1
C OSDL=1
C OSDM=1
C OSDE=1
C OSDI=1
C OSTL=1
C OSTM=1
C OSTE=1
C OSTI=1
C OSOL=1
C OSOM=1
C OSOE=1
C OSOI=1
C OSSL=1
C OSSM=1
C OSSE=1
C OSSI=1
C OSGL=1
C OSGM=1
C OSGE=1
C OSGI=1
C USML=1.15
C USMM=1.5
C USME=1.5
C USMI=2.5
```

```
C NSDL=0.35
C NSDM=0.35
C NSDE=0.55
C NSDI=0.55
C NSTL=0.25
C NSTM=0.45
C NSTE=0.45
C NSTI=0.45
C NSOL=0.2
C NSOM=0.45
C NSOE=0.45
C NSOI=0.45
C NSSL=0.35
C NSSM=0.5
C NSSE=0.75
C NSSI=0.75
C NSGL=1
C NSGM=1
C NSGE=1
C NSGI=1
L OTA.K=INTGRL(OIN.JK-ODP.JK)
N OTA=OTAN
C OTAN=100000
R ODP.KL=OTA.K/OAL
C OAL=5.0
R OIN.KL=OINV.K
A OINV.K=INV.K*(1.0-DEC)
L NTA.K=INTGRL(NIN.JK-NDP.JK)
N NTA=NTAN
C NTAN=0
R NDP.KL=NTA.K/NAL
C NAL=5.0
R NIN.KL=NINV.K
A NINV.K=INV.K*DEC
N ALLTA=(OTAN+NTAN)
L OTM.K=INTGRL(OMI.JK)
R OMI.KL=OINV.K*OMF.K/(OMP*ALLTA/OAL)
A OMF.K=-64./9.*((OTM.K-1.25)*OTM.K+0.25)
N OTM=OTMN
C OMP=50
C OTMN=0.0
L NTM.K=INTGRL(NMI.JK)
R NMI.KL=NINV.K*NMF.K/(NMP*ALLTA/OAL)
A NMF.K=-64./9.*((NTM.K-1.25)*NTM.K+0.25)
N NTM=NTMN
C NMP=50
C NTMN=0.5
L PROD.K=INTGRL(PD.JK)
R PD.KL=PROD.K*PDP*OUT.K/ALLTA
N PROD=PRODN
C PRODN=1
C PDP=-0.01
A OUT.K=(OTM.K/OTMN*OTA.K+NTM.K/NTMN*NTA.K)*PROD.K
L MCL.K=INTGRL(MCI.JK)
R MCI.KL=MCF*MCL.K
N MCL=MCLN
C MCLN=1
```

```
C MCR=0.02
L NUL.K=INTGRL(NUI.JK)
R NUI.KL=NUF*NUL.K
N NUL=NULN
C NULN=1
C NUF=0.04
L NSL.K=INTGRL(NSI.JK)
R NSI.KL=NSF*NSL.K
N NSL=NSLN
C NSLN=1
C NSF=0.03
N OLU=(A$ML*O$ML+A$DL*O$DL+A$TL*O$TL+A$OL*O$OL)
N NLU=(A$ML*N$ML+A$DL*N$DL+A$TL*N$TL+A$OL*N$OL)
N OLS=(A$SL*O$SL+A$GL*O$GL)
N NLS=(A$SL*N$SL+A$GL*N$GL)
N OM=(A$MM*O$MM+A$DM*O$DM+A$TM*O$TM+A$OM*O$OM+A$SM*O$SM+A$GM*O$GM)
N NM=(A$MM*N$MM+A$DM*N$DM+A$TM*N$TM+A$OM*N$OM+A$SM*N$SM+A$GM*N$GM)
N OE=(A$ME*O$ME+A$DE*O$DE+A$TE*O$TE+A$OE*O$OE+A$SE*O$SE+A$GE*O$GE)
N NE=(A$ME*N$ME+A$DE*N$DE+A$TE*N$TE+A$OE*N$OE+A$SE*N$SE+A$GE*N$GE)
N OI=(A$MI*O$MI+A$DI*O$DI+A$TI*O$TI+A$OI*O$OI+A$SI*O$SI+A$GI*O$GI)
N NI=(A$MI*N$MI+A$DI*N$DI+A$TI*N$TI+A$OI*N$OI+A$SI*N$SI+A$GI*N$GI)
N OC=OM+OE+OI
N NC=NM+NE+NI
A OCOSTS.K=OTA.K*OC*MCL.K
A NCOSTS.K=NTA.K*NC*MCL.K
A COSTS.K=OCOSTS.K+NCOSTS.K
A OLABOR.K=OTA.K*(OLU*NUL.K+OLS*NSL.K)
A NLABOR.K=NTA.K*(NLU*NUL.K+NLS*NSL.K)
A LABOR.K=OLABOR.K+NLABOR.K
A UCOST.K=(COSTS.K+LABOR.K)/OUT.K
A INV.K=INVP.K+INVR.K
L INVP.K=INTGRL(INVP1.JK)
R INVP1.KL=2.0*(ALLTA-OUT.K)
N INVP=ALLTA*ALLTA/(OTA*OAL+NTA*NAL)
A INVR.K=2.0*(ALLTA-OUT.K)
C DEC=1.0
PARM DT=0.08333333
PARM START=0
PARM STOP=50
PARM PRTPER=2
PARM PLTPER=1
PRINT INV,OTA,NTA,OTM,NTM,PROD,OUT
PRINT MCL,NUL,NSL
PRINT OCOSTS,NCOSTS,COSTS,OLABOR,NLABOR,LABOR,UCOST
PLOT OTA=O(0,2E5)/NTA=N(0,2E5)/OTM=P(.5,1)/NTM=M(.5,1)
RERUN NI = 5.0
C NSMI=5.0
RERUN NI = 7.5
C NSMI=7.5
RERUN NI = 10.0
C NSMI=10.0
```

MINE TECHNOLOGY

* * *   S T A T S   A N D   O P T I O N S   * * *

163 SOURCE STATEMENTS

NO DIAGNOSTIC MESSAGES

CARD TYPE	OCCURANCE
C	92
PARM	5
N	22
L	9
A	14
R	11
*	2
PRINT	3
PLOT	1
RERUN	3
TITLE	1

OPTIONS IN EFFECT:

NOCHECK	NOSYSTEM	NODOCUMENT	WIDE
STATS	GO	NOSYMBOL	NOXREF
NOWARN	NOOBJECT	SOURCE	NOTIME

INTEGRATION METHOD:

EULER LOWER SUM

APPENDIX 2

OUTPUT RESULTS OF $GV_8(GA_6)$
(NMI = 10,0)

MINE TECHNOLOGY

TIME E+00	INV E+13	HTA E+13	HTA E+03	QTM E-03	NTM E-03	PROD E+00	OUT E+03
0.000	20.000	100.21	0.000	900.00	500.00	1.0000	100.00
2.000	19.057	66.81	33.171	900.00	536.73	0.9802	100.38
4.000	17.517	44.63	52.306	900.00	571.80	0.9607	100.34
6.000	16.672	29.82	63.254	900.00	605.62	0.9416	100.22
8.000	16.179	19.92	69.395	900.00	638.34	0.9229	100.15
10.000	15.657	13.31	72.667	900.00	669.86	0.9046	100.11
12.000	15.355	8.89	74.260	900.00	700.08	0.8867	100.08
14.000	15.142	5.94	74.903	900.00	728.84	0.8691	100.05
16.000	14.997	3.97	75.039	900.00	756.03	0.8519	100.04
18.000	14.979	2.65	74.939	900.00	781.55	0.8350	100.02
20.000	14.868	1.77	74.767	900.00	805.35	0.8185	100.01
22.000	14.867	1.18	74.618	900.00	827.33	0.8022	100.00
24.000	14.991	0.79	74.549	900.00	847.56	0.7863	99.99
26.000	14.968	0.53	74.588	900.00	866.33	0.7708	99.98
28.000	15.064	0.35	74.750	900.00	882.79	0.7555	99.98
30.000	15.137	0.24	75.041	900.00	897.90	0.7405	99.97
32.000	15.334	0.16	75.459	900.00	911.46	0.7259	99.96
34.000	15.503	0.11	76.002	900.00	923.54	0.7115	99.96
36.000	15.694	0.07	76.664	900.00	934.26	0.6974	99.95
38.000	15.913	0.05	77.438	900.00	943.71	0.6836	99.95
40.000	16.131	0.03	78.319	900.00	952.41	0.6701	99.94
42.000	16.376	0.02	79.300	900.00	959.25	0.6568	99.94
44.000	16.636	0.01	80.375	900.00	965.54	0.6438	99.93
46.000	16.911	0.01	81.538	900.00	970.95	0.6311	99.93
48.000	17.211	0.01	82.785	900.00	975.67	0.6186	99.93
50.000	17.503	0.00	84.109	900.00	979.68	0.6063	99.92

TIME	MCL	MHL	VSL
0.000	1.0000	1.0000	1.0000
2.000	1.0408	1.0831	1.0618
4.000	1.0832	1.1732	1.1273
6.000	1.1274	1.2707	1.1969
8.000	1.1734	1.3764	1.2709
10.000	1.2212	1.4908	1.3494
12.000	1.2710	1.6148	1.4327
14.000	1.3228	1.7490	1.5212
16.000	1.3768	1.8945	1.6151
18.000	1.4329	2.0520	1.7149
20.000	1.4913	2.2226	1.8208
22.000	1.5521	2.4074	1.9332
24.000	1.6154	2.6075	2.0526
26.000	1.6813	2.8243	2.1793
28.000	1.7499	3.0592	2.3139
30.000	1.8212	3.3135	2.4568
32.000	1.8955	3.5890	2.6086
34.000	1.9720	3.8874	2.7697
36.000	2.0532	4.2106	2.9407
38.000	2.1369	4.5607	3.1223
40.000	2.2241	4.9399	3.3151
42.000	2.3147	5.3506	3.5199
44.000	2.4091	5.7955	3.7373
46.000	2.5074	6.2773	3.9681
48.000	2.6096	6.7992	4.2131
50.000	2.7160	7.3645	4.4733

TIME E+00	OCOSTS E+06	NCOSTS E+06	COSTS E+06	OLABOR E+06	NLABOR E+06	LABOR E+06	UCOST E+03
0.000	24.350	0.000	24.350	9.5000	0.000	9.500	0.3385
2.000	16.931	13.381	30.311	6.8486	0.818	7.667	0.3783
4.000	11.772	21.959	33.731	4.9374	1.390	6.328	0.3992
6.000	8.185	27.638	35.824	3.5598	1.811	5.371	0.4111
8.000	5.691	31.558	37.250	2.5668	2.141	4.708	0.4189
10.000	3.957	34.394	38.351	1.8508	2.416	4.267	0.4257
12.000	2.751	36.581	39.333	1.3347	2.661	3.996	0.4330
14.000	1.913	38.402	40.315	0.9625	2.893	3.855	0.4415
16.000	1.330	40.040	41.371	0.6941	3.123	3.817	0.4517
18.000	0.925	41.618	42.543	0.5006	3.362	3.863	0.4640
20.000	0.643	43.215	43.858	0.3611	3.616	3.977	0.4783
22.000	0.447	44.888	45.335	0.2605	3.891	4.151	0.4949
24.000	0.311	46.675	46.986	0.1879	4.191	4.379	0.5137
26.000	0.216	48.604	48.820	0.1355	4.521	4.657	0.5349
28.000	0.150	50.696	50.846	0.0978	4.886	4.983	0.5584
30.000	0.105	52.968	53.072	0.0705	5.289	5.360	0.5845
32.000	0.073	55.435	55.508	0.0509	5.736	5.787	0.6132
34.000	0.051	58.111	58.161	0.0367	6.231	6.267	0.6446
36.000	0.035	61.007	61.042	0.0265	6.779	6.805	0.6788
38.000	0.024	64.136	64.160	0.0191	7.386	7.405	0.7160
40.000	0.017	67.510	67.527	0.0138	8.058	8.072	0.7564
42.000	0.012	71.143	71.155	0.0100	8.802	8.812	0.8002
44.000	0.008	75.048	75.056	0.0072	9.625	9.632	0.8474
46.000	0.006	79.238	79.244	0.0052	10.535	10.540	0.8985
48.000	0.004	83.730	83.734	0.0037	11.541	11.545	0.9535
50.000	0.003	88.538	88.541	0.0027	12.653	12.655	1.0127

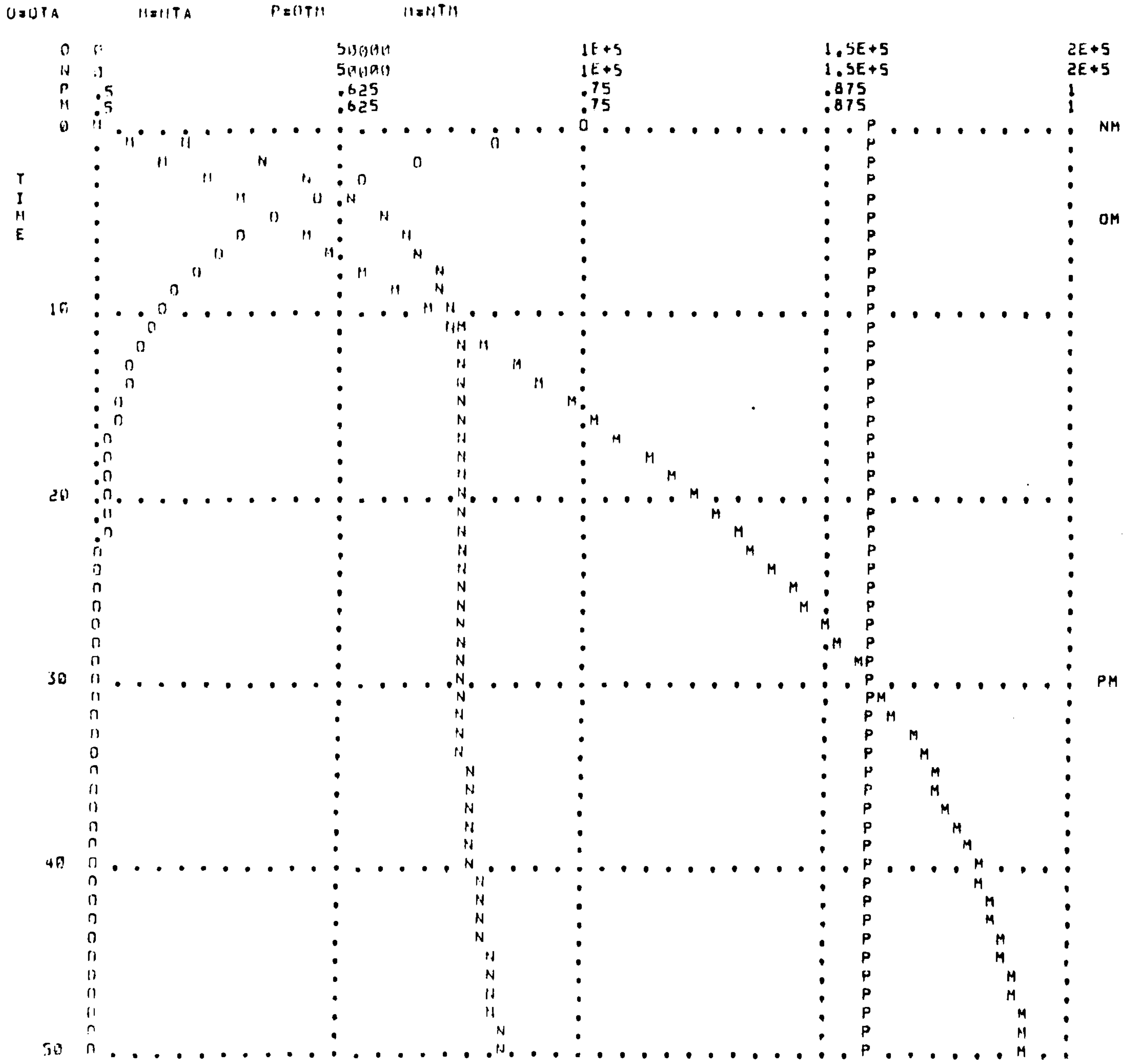
APPENDIX 3

OUTPUTS OF FA_2(GA_2 for DEC = 1)
(6 variants for NMI 2,5....15,0)

COMTEM - FA_2 - GA_2 (DEC = 1,0)

TIME E+00	INV E+03	OTA E+03	NTA E+03	OTM E-03	NTM E-03	PROD E+00	OUT E+03
0.000	20.000	100.00	0.000	900.00	500.00	1.0000	100.00
2.000	19.057	66.81	33.171	900.00	536.73	0.9802	100.38
4.000	17.517	44.63	52.306	900.00	571.80	0.9607	100.34
6.000	16.672	29.82	63.254	900.00	605.62	0.9416	100.22
8.000	16.079	19.92	69.395	900.00	638.34	0.9229	100.15
10.000	15.657	13.31	72.667	900.00	669.86	0.9046	100.11
12.000	15.355	8.89	74.260	900.00	700.08	0.8867	100.08
14.000	15.142	5.94	74.903	900.00	728.84	0.8691	100.05
16.000	14.997	3.97	75.039	900.00	756.03	0.8519	100.04
18.000	14.909	2.65	74.939	900.00	781.55	0.8350	100.02
20.000	14.868	1.77	74.767	900.00	805.33	0.8185	100.01
22.000	14.867	1.18	74.618	900.00	827.33	0.8022	100.00
24.000	14.901	0.79	74.549	900.00	847.56	0.7863	99.99
26.000	14.968	0.53	74.588	900.00	866.03	0.7708	99.98
28.000	15.064	0.35	74.750	900.00	882.79	0.7555	99.98
30.000	15.187	0.24	75.041	900.00	897.90	0.7405	99.97
32.000	15.334	0.16	75.459	900.00	911.46	0.7259	99.96
34.000	15.503	0.11	76.002	900.00	923.54	0.7115	99.96
36.000	15.694	0.07	76.664	900.00	934.26	0.6974	99.95
38.000	15.903	0.05	77.438	900.00	943.71	0.6836	99.95
40.000	16.131	0.03	78.319	900.00	952.31	0.6701	99.94
42.000	16.376	0.02	79.300	900.00	959.25	0.6568	99.94
44.000	16.636	0.01	80.375	900.00	965.54	0.6438	99.93
46.000	16.911	0.01	81.538	900.00	970.98	0.6311	99.93
48.000	17.201	0.01	82.785	900.00	975.67	0.6186	99.93
50.000	17.503	0.00	84.109	900.00	979.68	0.6063	99.92

COMTEM - FA_2 - GA_2 (DEC = 1,0)



COMTEM - FA_2 - GA_2 (DEC = 1,0)

TIME E+00	LAH E+03	LAP E+03	LAT E+03	LAD E+03	LAS E+03	LAG E+00	LAUG E+03	LASF E+03	LAALL E+03
0.000	7.0000	5.0000	5.0000	19.000	12.000	0.0000	36.000	12.000	48.000
2.000	5.1989	4.2111	3.9623	14.584	10.107	0.0000	27.956	10.107	38.063
4.000	3.9480	3.6046	3.2123	11.461	8.651	0.0000	22.226	8.651	30.877
6.000	3.0834	3.1512	2.6768	9.271	7.563	0.0000	18.182	7.563	25.745
8.000	2.4873	2.8176	2.2971	7.740	6.762	0.0000	15.342	6.762	22.104
10.000	2.0760	2.5729	2.0279	6.670	6.175	0.0000	13.347	6.175	19.522
12.000	1.7919	2.3938	1.8369	5.922	5.745	0.0000	11.945	5.745	17.690
14.000	1.5955	2.2632	1.7014	5.398	5.432	0.0000	10.958	5.432	16.389
16.000	1.4596	2.1682	1.6054	5.031	5.204	0.0000	10.264	5.204	15.468
18.000	1.3658	2.0997	1.5376	4.775	5.039	0.0000	9.778	5.039	14.818
20.000	1.3115	2.0512	1.4904	4.598	4.923	0.0000	9.441	4.923	14.364
22.000	1.2581	2.0179	1.4582	4.478	4.843	0.0000	9.212	4.843	14.055
24.000	1.2295	1.9964	1.4373	4.399	4.791	0.0000	9.063	4.791	13.854
26.000	1.2117	1.9843	1.4249	4.352	4.762	0.0000	8.973	4.762	13.735
28.000	1.2020	1.9798	1.4192	4.328	4.752	0.0000	8.929	4.752	13.680
30.000	1.1984	1.9816	1.4188	4.322	4.756	0.0000	8.921	4.756	13.677
32.000	1.1995	1.9887	1.4227	4.331	4.773	0.0000	8.942	4.773	13.715
34.000	1.2044	2.0003	1.4303	4.352	4.801	0.0000	8.987	4.801	13.788
36.000	1.2124	2.0159	1.4410	4.383	4.838	0.0000	9.052	4.838	13.891
38.000	1.2229	2.0351	1.4543	4.423	4.884	0.0000	9.135	4.884	14.019
40.000	1.2357	2.0574	1.4701	4.470	4.938	0.0000	9.233	4.938	14.171
42.000	1.2504	2.0827	1.4879	4.524	4.998	0.0000	9.345	4.998	14.344
44.000	1.2669	2.1105	1.5077	4.584	5.065	0.0000	9.469	5.065	14.535
46.000	1.2849	2.1409	1.5293	4.649	5.138	0.0000	9.605	5.138	14.743
48.000	1.3043	2.1734	1.5525	4.720	5.216	0.0000	9.750	5.216	14.966
50.000	1.3250	2.2081	1.5772	4.795	5.299	0.0000	9.905	5.299	15.205

COMTEM - FA_2 - GA_2 (DEC = 1,0)

TIME	WCL	WUL	WSL
0.000	1.0000	1.0000	1.0000
2.000	1.0408	1.0831	1.0618
4.000	1.0832	1.1732	1.1273
6.000	1.1274	1.2707	1.1969
8.000	1.1734	1.3764	1.2709
10.000	1.2212	1.4908	1.3494
12.000	1.2710	1.6148	1.4327
14.000	1.3228	1.7490	1.5212
16.000	1.3768	1.8945	1.6151
18.000	1.4329	2.0520	1.7149
20.000	1.4913	2.2226	1.8208
22.000	1.5521	2.4074	1.9332
24.000	1.6154	2.6075	2.0526
26.000	1.6813	2.8243	2.1793
28.000	1.7499	3.0592	2.3139
30.000	1.8212	3.3135	2.4568
32.000	1.8955	3.5890	2.6086
34.000	1.9728	3.8874	2.7697
36.000	2.0532	4.2106	2.9407
38.000	2.1369	4.5607	3.1223
40.000	2.2241	4.9399	3.3151
42.000	2.3147	5.3506	3.5199
44.000	2.4091	5.7955	3.7373
46.000	2.5074	6.2773	3.9681
48.000	2.6096	6.7992	4.2131
50.000	2.7160	7.3645	4.4733

COMTEM - FA_2 - GA_2 (GV_1 for NMI = 2,5)

TIME E+00	OCOSTS E+06	NCOSTS E+06	COSTS E+06	OLABOR E+06	NLABOR E+06	LABOR E+06	UCOST E+00
0.000	24.350	0.000	24.350	9.5000	0.000	9.500	338.50
2.000	16.931	9.282	26.213	6.8486	1.227	8.076	341.58
4.000	11.772	15.233	27.005	4.9374	2.085	7.023	339.12
6.000	8.185	19.173	27.358	3.5598	2.717	6.277	335.62
8.000	5.691	21.892	27.583	2.5668	3.212	5.778	333.12
10.000	3.957	23.859	27.816	1.8508	3.624	5.475	332.56
12.000	2.751	25.376	28.128	1.3347	3.991	5.326	334.29
14.000	1.913	26.640	28.553	0.9625	4.339	5.301	338.36
16.000	1.330	27.776	29.106	0.6941	4.685	5.379	344.73
18.000	0.925	28.871	29.795	0.5006	5.043	5.544	353.32
20.000	0.643	29.979	30.622	0.3611	5.424	5.785	364.03
22.000	0.447	31.139	31.586	0.2605	5.836	6.097	376.83
24.000	0.311	32.379	32.689	0.1879	6.286	6.474	391.67
26.000	0.216	33.717	33.933	0.1355	6.782	6.917	408.57
28.000	0.150	35.168	35.318	0.0978	7.328	7.426	427.55
30.000	0.105	36.744	36.849	0.0705	7.934	8.004	448.66
32.000	0.073	38.456	38.528	0.0509	8.604	8.655	472.00
34.000	0.051	40.312	40.362	0.0367	9.346	9.383	497.66
36.000	0.035	42.321	42.356	0.0265	10.168	10.195	525.75
38.000	0.024	44.491	44.516	0.0191	11.079	11.098	556.43
40.000	0.017	46.832	46.849	0.0138	12.087	12.101	589.84
42.000	0.012	49.352	49.364	0.0100	13.203	13.213	626.15
44.000	0.008	52.061	52.069	0.0072	14.437	14.444	665.57
46.000	0.006	54.968	54.974	0.0052	15.802	15.808	708.30
48.000	0.004	58.084	58.088	0.0037	17.311	17.315	754.58
50.000	0.003	61.419	61.422	0.0027	18.979	18.982	804.65

COMTEM - FA_2 - GA_2 (GV_2 for NMI = 5,0)

TIME E+00	OCOSTS.2 E+06	NCOSTS.2 E+06	COSTS.2 E+06	OLABOR.2 E+06	NLABOR.2 E+06	LABOR.2 E+06	UCOST.2 E+00
0.000	24.350	0.000	24.350	9.5000	0.000	9.500	338.50
2.000	16.931	11.440	28.371	6.8486	1.227	8.076	363.07
4.000	11.772	18.774	30.546	4.9374	2.085	7.023	374.41
6.000	8.185	23.630	31.815	3.5598	2.717	6.277	380.10
8.000	5.691	26.981	32.672	2.5668	3.212	5.778	383.93
10.000	3.957	29.406	33.363	1.8508	3.624	5.475	387.96
12.000	2.751	31.276	34.027	1.3347	3.991	5.326	393.23
14.000	1.913	32.832	34.745	0.9625	4.339	5.301	400.25
16.000	1.330	34.233	35.563	0.6941	4.685	5.379	409.28
18.000	0.925	35.582	36.507	0.5006	5.043	5.544	420.41
20.000	0.643	36.948	37.591	0.3611	5.424	5.785	433.72
22.000	0.447	38.378	38.825	0.2605	5.836	6.097	449.21
24.000	0.311	39.905	40.216	0.1879	6.286	6.474	466.95
26.000	0.216	41.554	41.770	0.1355	6.782	6.917	486.96
28.000	0.150	43.343	43.493	0.0978	7.328	7.426	509.32
30.000	0.105	45.286	45.390	0.0705	7.934	8.004	534.11
32.000	0.073	47.395	47.468	0.0509	8.604	8.655	561.43
34.000	0.051	49.682	49.733	0.0367	9.346	9.383	591.41
36.000	0.035	52.159	52.194	0.0265	10.168	10.195	624.18
38.000	0.024	54.834	54.858	0.0191	11.079	11.098	659.91
40.000	0.017	57.719	57.736	0.0138	12.087	12.101	698.77
42.000	0.012	60.825	60.837	0.0100	13.203	13.213	740.95
44.000	0.008	64.163	64.171	0.0072	14.437	14.444	786.67
46.000	0.006	67.746	67.752	0.0052	15.802	15.808	836.17
48.000	0.004	71.586	71.590	0.0037	17.311	17.315	889.70
50.000	0.003	75.697	75.700	0.0027	18.979	18.982	947.53

COMTEM - FA_2 - GA_2 (GV_3 for NMI = 7,5)

TIME E+00	OCOSTS.3 E+06	NCOSTS.3 E+06	COSTS.3 E+06	OLABOR.3 E+06	NLABOR.3 E+06	LABOR.3 E+06	UCOST.3 E+03
0.000	24.350	0.000	24.350	9.5000	0.000	9.500	0.3385
2.000	16.931	13.598	30.528	6.8486	1.227	8.076	0.3846
4.000	11.772	22.316	34.088	4.9374	2.085	7.023	0.4097
6.000	8.185	28.087	36.272	3.5598	2.717	6.277	0.4246
8.000	5.691	32.070	37.761	2.5668	3.212	5.778	0.4347
10.000	3.957	34.952	38.909	1.8508	3.624	5.475	0.4434
12.000	2.751	37.175	39.926	1.3347	3.991	5.326	0.4522
14.000	1.913	39.025	40.938	0.9625	4.339	5.301	0.4621
16.000	1.330	40.690	42.020	0.6941	4.685	5.379	0.4738
18.000	0.925	42.293	43.218	0.5006	5.043	5.544	0.4875
20.000	0.643	43.916	44.560	0.3611	5.424	5.785	0.5034
22.000	0.447	45.616	46.064	0.2605	5.836	6.097	0.5216
24.000	0.311	47.432	47.743	0.1879	6.286	6.474	0.5422
26.000	0.216	49.392	49.608	0.1355	6.782	6.917	0.5653
28.000	0.150	51.518	51.668	0.0978	7.328	7.426	0.5911
30.000	0.105	53.827	53.932	0.0705	7.934	8.004	0.6195
32.000	0.073	56.334	56.407	0.0509	8.604	8.655	0.6509
34.000	0.051	59.053	59.104	0.0367	9.346	9.383	0.6852
36.000	0.035	61.996	62.032	0.0265	10.168	10.195	0.7226
38.000	0.024	65.176	65.201	0.0191	11.079	11.098	0.7634
40.000	0.017	68.606	68.623	0.0138	12.087	12.101	0.8077
42.000	0.012	72.297	72.309	0.0100	13.203	13.213	0.8557
44.000	0.008	76.265	76.274	0.0072	14.437	14.444	0.9078
46.000	0.006	80.524	80.530	0.0052	15.802	15.808	0.9640
48.000	0.004	85.088	85.092	0.0037	17.311	17.315	1.0248
50.000	0.003	89.974	89.977	0.0027	18.979	18.982	1.0904

COMTEM - FA_2 - GA_2 (GV_4 for NMI = 10,0)

TIME E+00	OCOSTS.4 E+06	NCOSTS.4 E+06	COSTS.4 E+06	OLABOR.4 E+06	NLABOR.4 E+06	LABOR.4 E+06	UCOST.4 E+03
0.000	24.350	0.00	24.35	9.5000	0.000	9.500	0.3385
2.000	16.931	15.76	32.69	6.8486	1.227	8.076	0.4061
4.000	11.772	25.86	37.63	4.9374	2.085	7.023	0.4450
6.000	8.185	32.54	40.73	3.5598	2.717	6.277	0.4690
8.000	5.691	37.16	42.85	2.5668	3.212	5.778	0.4856
10.000	3.957	40.53	44.46	1.8508	3.624	5.475	0.4988
12.000	2.751	43.07	45.83	1.3347	3.991	5.326	0.5111
14.000	1.913	45.22	47.13	0.9625	4.339	5.301	0.5240
16.000	1.330	47.15	48.48	0.6941	4.685	5.379	0.5384
18.000	0.925	49.00	49.93	0.5006	5.043	5.544	0.5546
20.000	0.643	50.89	51.53	0.3611	5.424	5.785	0.5731
22.000	0.447	52.86	53.30	0.2605	5.836	6.097	0.5940
24.000	0.311	54.96	55.27	0.1879	6.286	6.474	0.6175
26.000	0.216	57.23	57.45	0.1355	6.782	6.917	0.6437
28.000	0.150	59.69	59.84	0.0978	7.328	7.426	0.6729
30.000	0.105	62.37	62.47	0.0705	7.934	8.004	0.7050
32.000	0.073	65.27	65.35	0.0509	8.604	8.655	0.7403
34.000	0.051	68.42	68.47	0.0367	9.346	9.383	0.7789
36.000	0.035	71.83	71.87	0.0265	10.168	10.195	0.8210
38.000	0.024	75.52	75.54	0.0191	11.079	11.098	0.8669
40.000	0.017	79.49	79.51	0.0138	12.087	12.101	0.9166
42.000	0.012	83.77	83.78	0.0100	13.203	13.213	0.9705
44.000	0.008	88.37	88.38	0.0072	14.437	14.444	1.0289
46.000	0.006	93.30	93.31	0.0052	15.802	15.808	1.0919
48.000	0.004	98.59	98.59	0.0037	17.311	17.315	1.1599
50.000	0.003	104.25	104.25	0.0027	18.979	18.982	1.2333

COMTEM - FA_2 - GA_2 (GV_5 for NMI = 12,5)

TIME E+00	OCOSTS.5 E+06	NCOSTS.5 E+06	COSTS.5 E+06	OLABOR.5 E+06	NLABOR.5 E+06	LABOR.5 E+06	UCOST.5 E+03
0.000	24.350	0.00	24.35	9.5000	0.000	9.500	0.3385
2.000	16.931	17.91	34.84	6.8486	1.227	8.076	0.4276
4.000	11.772	29.40	41.17	4.9374	2.085	7.023	0.4803
6.000	8.185	37.00	45.19	3.5598	2.717	6.277	0.5135
8.000	5.691	42.25	47.94	2.5668	3.212	5.778	0.5364
10.000	3.957	46.04	50.00	1.8508	3.624	5.475	0.5542
12.000	2.751	48.97	51.72	1.3347	3.991	5.326	0.5701
14.000	1.913	51.41	53.32	0.9625	4.339	5.301	0.5859
16.000	1.330	53.60	54.93	0.6941	4.685	5.379	0.6029
18.000	0.925	55.72	56.64	0.5006	5.043	5.544	0.6217
20.000	0.643	57.85	58.50	0.3611	5.424	5.785	0.6428
22.000	0.447	60.09	60.54	0.2605	5.836	6.097	0.6664
24.000	0.311	62.49	62.80	0.1879	6.286	6.474	0.6928
26.000	0.216	65.07	65.28	0.1355	6.782	6.917	0.7221
28.000	0.150	67.87	68.02	0.0978	7.328	7.426	0.7546
30.000	0.105	70.91	71.01	0.0705	7.934	8.004	0.7904
32.000	0.073	74.21	74.29	0.0509	8.604	8.655	0.8297
34.000	0.051	77.80	77.85	0.0367	9.346	9.383	0.8727
36.000	0.035	81.67	81.71	0.0265	10.168	10.195	0.9195
38.000	0.024	85.86	85.89	0.0191	11.079	11.098	0.9703
40.000	0.017	90.38	90.40	0.0138	12.087	12.101	1.0256
42.000	0.012	95.24	95.25	0.0100	13.203	13.213	1.0853
44.000	0.008	100.47	100.48	0.0072	14.437	14.444	1.1500
46.000	0.006	106.08	106.09	0.0052	15.802	15.808	1.2198
48.000	0.004	112.09	112.10	0.0037	17.311	17.315	1.2951
50.000	0.003	118.53	118.53	0.0027	18.979	18.982	1.3762

COMTEM - FA_2 - GA_2 (GV_6 for NMI = 15,0)

TIME E+00	OCOSTS.6 E+06	NCOSTS.6 E+06	COSTS.6 E+06	OLABOR.6 E+06	NLABOR.6 E+06	LABOR.6 E+06	UCOST.6 E+03
0.000	24.350	0.00	24.35	9.5000	0.000	9.500	0.3385
2.000	16.931	20.07	37.00	6.8486	1.227	8.076	0.4490
4.000	11.772	32.94	44.71	4.9374	2.085	7.023	0.5156
6.000	8.185	41.46	49.64	3.5598	2.717	6.277	0.5580
8.000	5.691	47.34	53.03	2.5668	3.212	5.778	0.5872
10.000	3.957	51.59	55.55	1.8508	3.624	5.475	0.6096
12.000	2.751	54.87	57.62	1.3347	3.991	5.326	0.6290
14.000	1.913	57.60	59.52	0.9625	4.339	5.301	0.6478
16.000	1.330	60.06	61.39	0.6941	4.685	5.379	0.6675
18.000	0.925	62.43	63.35	0.5006	5.043	5.544	0.6888
20.000	0.643	64.82	65.47	0.3611	5.424	5.785	0.7124
22.000	0.447	67.33	67.78	0.2605	5.836	6.097	0.7388
24.000	0.311	70.01	70.32	0.1879	6.286	6.474	0.7680
26.000	0.216	72.91	73.12	0.1355	6.782	6.917	0.8005
28.000	0.150	76.04	76.19	0.0978	7.328	7.426	0.8364
30.000	0.105	79.45	79.56	0.0705	7.934	8.004	0.8759
32.000	0.073	83.15	83.23	0.0509	8.604	8.655	0.9191
34.000	0.051	87.17	87.22	0.0367	9.346	9.383	0.9664
36.000	0.035	91.51	91.55	0.0265	10.168	10.195	1.0179
38.000	0.024	96.20	96.23	0.0191	11.079	11.098	1.0738
40.000	0.017	101.27	101.28	0.0138	12.087	12.101	1.1345
42.000	0.012	106.71	106.73	0.0100	13.203	13.213	1.2001
44.000	0.008	112.57	112.58	0.0072	14.437	14.444	1.2711
46.000	0.006	118.86	118.86	0.0052	15.802	15.808	1.3476
48.000	0.004	125.59	125.60	0.0037	17.311	17.315	1.4302
50.000	0.003	132.81	132.81	0.0027	18.979	18.982	1.5191

APPENDIX 4

OUTPUT OF GA_7 (FA_1)
(for new mines)

TIME E+00	INV E+03	OTA E+00	NTA E+03	OTM E-03	NTM E-03	PROD E+00	OUT E+03
0.000	20.000	0.0000	100.00	900.00	500.00	1.0000	100.00
2.000	17.019	0.0000	96.14	900.00	532.47	0.9801	100.34
4.000	16.713	0.0000	92.26	900.00	564.82	0.9606	100.12
6.000	16.275	0.0000	89.00	900.00	597.33	0.9416	100.11
8.000	15.910	0.0000	86.15	900.00	629.46	0.9229	100.09
10.000	15.614	0.0000	83.70	900.00	660.89	0.9046	100.07
12.000	15.378	0.0000	81.62	900.00	691.30	0.8867	100.06
14.000	15.198	0.0000	79.89	900.00	720.45	0.8691	100.04
16.000	15.067	0.0000	78.48	900.00	748.15	0.8519	100.03
18.000	14.982	0.0000	77.36	900.00	774.25	0.8350	100.02
20.000	14.939	0.0000	76.50	900.00	798.63	0.8185	100.01
22.000	14.933	0.0000	75.89	900.00	821.25	0.8022	100.00
24.000	14.961	0.0000	75.50	900.00	842.08	0.7864	99.99
26.000	15.022	0.0000	75.32	900.00	861.13	0.7708	99.98
28.000	15.112	0.0000	75.32	900.00	878.43	0.7555	99.98
30.000	15.228	0.0000	75.50	900.00	894.06	0.7405	99.97
32.000	15.370	0.0000	75.83	900.00	908.08	0.7259	99.96
34.000	15.534	0.0000	76.30	900.00	920.60	0.7115	99.96
36.000	15.720	0.0000	76.91	900.00	931.70	0.6974	99.95
38.000	15.926	0.0000	77.65	900.00	941.51	0.6836	99.95
40.000	16.150	0.0000	78.49	900.00	950.11	0.6701	99.94
42.000	16.392	0.0000	79.45	900.00	957.63	0.6568	99.94
44.000	16.650	0.0000	80.50	900.00	964.17	0.6438	99.94
46.000	16.923	0.0000	81.64	900.00	969.82	0.6311	99.93
48.000	17.211	0.0000	82.87	900.00	974.69	0.6186	99.93
50.000	17.512	0.0000	84.18	900.00	978.86	0.6063	99.92

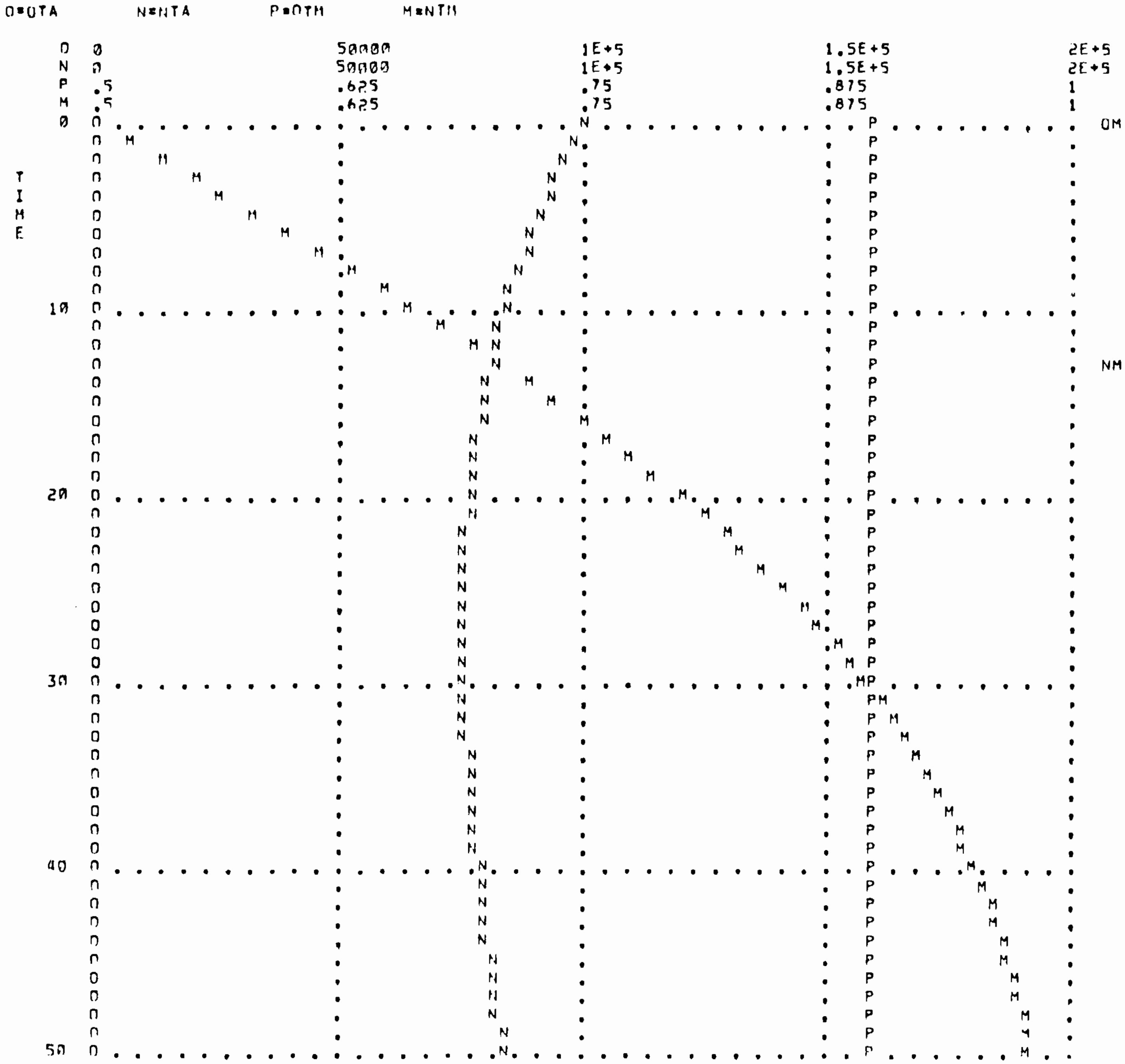
COMTEM - $GA_7(FA_1)$

TIME E+00	LAM E+03	LAD E+03	LAT E+03	LAO E+03	LAS E+03	LAG E+00	LAUG E+03	LASF E+03	LAALL E+03
0.000	1.0500	1.7500	1.2500	3.8000	4.2000	0.0000	7.8500	4.2000	12.050
2.000	1.0095	1.6824	1.2017	3.6533	4.0378	0.0000	7.5469	4.0378	11.585
4.000	0.9688	1.6146	1.1533	3.5060	3.8751	0.0000	7.2427	3.8751	11.118
6.000	0.9345	1.5574	1.1125	3.3819	3.7379	0.0000	6.9862	3.7379	10.724
8.000	0.9045	1.5076	1.0768	3.2736	3.6181	0.0000	6.7625	3.6181	10.381
10.000	0.8788	1.4647	1.0462	3.1804	3.5152	0.0000	6.5701	3.5152	10.085
12.000	0.8570	1.4283	1.0202	3.1015	3.4280	0.0000	6.4071	3.4280	9.835
14.000	0.8388	1.3981	0.9986	3.0358	3.3553	0.0000	6.2713	3.3553	9.627
16.000	0.8240	1.3733	0.9810	2.9821	3.2960	0.0000	6.1604	3.2960	9.456
18.000	0.8122	1.3537	0.9670	2.9395	3.2490	0.0000	6.0725	3.2490	9.321
20.000	0.8033	1.3388	0.9563	2.9071	3.2131	0.0000	6.0054	3.2131	9.218
22.000	0.7969	1.3281	0.9486	2.8839	3.1874	0.0000	5.9575	3.1874	9.145
24.000	0.7928	1.3213	0.9438	2.8691	3.1712	0.0000	5.9271	3.1712	9.098
26.000	0.7909	1.3181	0.9415	2.8622	3.1634	0.0000	5.9126	3.1634	9.076
28.000	0.7909	1.3181	0.9415	2.8623	3.1635	0.0000	5.9128	3.1635	9.076
30.000	0.7927	1.3212	0.9437	2.8689	3.1708	0.0000	5.9264	3.1708	9.097
32.000	0.7962	1.3270	0.9478	2.8814	3.1847	0.0000	5.9524	3.1847	9.137
34.000	0.8012	1.3353	0.9538	2.8995	3.2047	0.0000	5.9898	3.2047	9.195
36.000	0.8076	1.3460	0.9614	2.9227	3.2303	0.0000	6.0376	3.2303	9.268
38.000	0.8153	1.3588	0.9706	2.9505	3.2611	0.0000	6.0951	3.2611	9.356
40.000	0.8242	1.3736	0.9812	2.9827	3.2967	0.0000	6.1616	3.2967	9.458
42.000	0.8342	1.3903	0.9931	3.0189	3.3367	0.0000	6.2365	3.3367	9.573
44.000	0.8452	1.4087	1.0062	3.0589	3.3809	0.0000	6.3190	3.3809	9.700
46.000	0.8572	1.4287	1.0205	3.1024	3.4289	0.0000	6.4088	3.4289	9.838
48.000	0.8701	1.4502	1.0359	3.1491	3.4806	0.0000	6.5054	3.4806	9.986
50.000	0.8839	1.4732	1.0523	3.1989	3.5356	0.0000	6.6083	3.5356	10.144

COMTEM - $GA_7(FA_1)$

TIME	MCL	WUL	WSL
0.000	1.0000	1.0000	1.0000
2.000	1.0408	1.0831	1.0618
4.000	1.0832	1.1732	1.1273
6.000	1.1274	1.2707	1.1969
8.000	1.1734	1.3764	1.2709
10.000	1.2212	1.4908	1.3494
12.000	1.2710	1.6148	1.4327
14.000	1.3228	1.7490	1.5212
16.000	1.3768	1.8945	1.6151
18.000	1.4329	2.0520	1.7149
20.000	1.4913	2.2226	1.8208
22.000	1.5521	2.4074	1.9332
24.000	1.6154	2.6075	2.0526
26.000	1.6813	2.8243	2.1793
28.000	1.7499	3.0592	2.3139
30.000	1.8212	3.3135	2.4568
32.000	1.8955	3.5890	2.6086
34.000	1.9728	3.8874	2.7697
36.000	2.0532	4.2106	2.9407
38.000	2.1369	4.5607	3.1223
40.000	2.2241	4.9399	3.3151
42.000	2.3147	5.3506	3.5199
44.000	2.4091	5.7955	3.7373
46.000	2.5074	6.2773	3.9681
48.000	2.6096	6.7992	4.2131
50.000	2.7160	7.3645	4.4733

COMTEM - $GA_7(FA_1)$



COMTEM - $GA_7(FA_1)$ for NMI = 2,5

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+00
0.000	0.0000	20.008	20.008	0.0000	2.290	2.290	222.98
2.000	0.0000	20.019	20.019	0.0000	2.372	2.372	223.15
4.000	0.0000	19.996	19.996	0.0000	2.452	2.452	224.21
6.000	0.0000	20.074	20.074	0.0000	2.548	2.548	225.98
8.000	0.0000	20.224	20.224	0.0000	2.658	2.658	228.61
10.000	0.0000	20.450	20.450	0.0000	2.783	2.783	232.15
12.000	0.0000	20.755	20.755	0.0000	2.925	2.925	236.66
14.000	0.0000	21.144	21.144	0.0000	3.085	3.085	242.18
16.000	0.0000	21.617	21.617	0.0000	3.266	3.266	248.75
18.000	0.0000	22.177	22.177	0.0000	3.471	3.471	256.42
20.000	0.0000	22.826	22.826	0.0000	3.700	3.700	265.24
22.000	0.0000	23.568	23.568	0.0000	3.957	3.957	275.24
24.000	0.0000	24.403	24.403	0.0000	4.245	4.245	286.50
26.000	0.0000	25.337	25.337	0.0000	4.565	4.565	299.06
28.000	0.0000	26.371	26.371	0.0000	4.923	4.923	313.01
30.000	0.0000	27.509	27.509	0.0000	5.321	5.321	328.40
32.000	0.0000	28.756	28.756	0.0000	5.764	5.764	345.32
34.000	0.0000	30.117	30.117	0.0000	6.255	6.255	363.87
36.000	0.0000	31.595	31.595	0.0000	6.801	6.801	384.14
38.000	0.0000	33.197	33.197	0.0000	7.406	7.406	406.23
40.000	0.0000	34.927	34.927	0.0000	8.076	8.076	430.27
42.000	0.0000	36.793	36.793	0.0000	8.818	8.818	456.39
44.000	0.0000	38.800	38.800	0.0000	9.640	9.640	484.71
46.000	0.0000	40.956	40.956	0.0000	10.548	10.548	515.40
48.000	0.0000	43.269	43.269	0.0000	11.553	11.553	548.61
50.000	0.0000	45.745	45.745	0.0000	12.664	12.664	584.53

COMTEM - $GA_7(FA_1)$ NMI = 5,0

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+00
0.000	0.0000	26.258	26.258	0.0000	2.290	2.290	285.48
2.000	0.0000	26.273	26.273	0.0000	2.372	2.372	285.47
4.000	0.0000	26.242	26.242	0.0000	2.452	2.452	286.59
6.000	0.0000	26.345	26.345	0.0000	2.548	2.548	288.62
8.000	0.0000	26.541	26.541	0.0000	2.658	2.658	291.73
10.000	0.0000	26.838	26.838	0.0000	2.783	2.783	295.99
12.000	0.0000	27.239	27.239	0.0000	2.925	2.925	301.46
14.000	0.0000	27.749	27.749	0.0000	3.085	3.085	308.20
16.000	0.0000	28.370	28.370	0.0000	3.266	3.266	316.26
18.000	0.0000	29.105	29.105	0.0000	3.471	3.471	325.69
20.000	0.0000	29.957	29.957	0.0000	3.700	3.700	336.54
22.000	0.0000	30.930	30.930	0.0000	3.957	3.957	348.86
24.000	0.0000	32.027	32.027	0.0000	4.245	4.245	362.74
26.000	0.0000	33.251	33.251	0.0000	4.565	4.565	378.22
28.000	0.0000	34.608	34.608	0.0000	4.923	4.923	395.40
30.000	0.0000	36.103	36.103	0.0000	5.321	5.321	414.36
32.000	0.0000	37.739	37.739	0.0000	5.764	5.764	435.19
34.000	0.0000	39.525	39.525	0.0000	6.255	6.255	457.99
36.000	0.0000	41.465	41.465	0.0000	6.801	6.801	482.88
38.000	0.0000	43.567	43.567	0.0000	7.406	7.406	509.99
40.000	0.0000	45.838	45.838	0.0000	8.076	8.076	539.44
42.000	0.0000	48.287	48.287	0.0000	8.818	8.818	571.39
44.000	0.0000	50.921	50.921	0.0000	9.640	9.640	606.00
46.000	0.0000	53.750	53.750	0.0000	10.548	10.548	643.43
48.000	0.0000	56.785	56.785	0.0000	11.553	11.553	683.87
50.000	0.0000	60.035	60.035	0.0000	12.664	12.664	727.53

COMTEM - $GA_7(FA_1)$ for NMI = 7,5

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+00
0.000	0.0000	32.508	32.508	0.0000	2.290	2.290	347.98
2.000	0.0000	32.527	32.527	0.0000	2.372	2.372	347.80
4.000	0.0000	32.489	32.489	0.0000	2.452	2.452	348.98
6.000	0.0000	32.616	32.616	0.0000	2.548	2.548	351.26
8.000	0.0000	32.859	32.859	0.0000	2.658	2.658	354.84
10.000	0.0000	33.226	33.226	0.0000	2.783	2.783	359.82
12.000	0.0000	33.723	33.723	0.0000	2.925	2.925	366.26
14.000	0.0000	34.354	34.354	0.0000	3.085	3.085	374.22
16.000	0.0000	35.122	35.122	0.0000	3.266	3.266	383.76
18.000	0.0000	36.032	36.032	0.0000	3.471	3.471	394.95
20.000	0.0000	37.088	37.088	0.0000	3.700	3.700	407.83
22.000	0.0000	38.292	38.292	0.0000	3.957	3.957	422.49
24.000	0.0000	39.650	39.650	0.0000	4.245	4.245	438.97
26.000	0.0000	41.166	41.166	0.0000	4.565	4.565	457.38
28.000	0.0000	42.846	42.846	0.0000	4.923	4.923	477.80
30.000	0.0000	44.696	44.696	0.0000	5.321	5.321	500.32
32.000	0.0000	46.722	46.722	0.0000	5.764	5.764	525.05
34.000	0.0000	48.933	48.933	0.0000	6.255	6.255	552.11
36.000	0.0000	51.335	51.335	0.0000	6.801	6.801	581.63
38.000	0.0000	53.937	53.937	0.0000	7.406	7.406	613.74
40.000	0.0000	56.749	56.749	0.0000	8.076	8.076	648.61
42.000	0.0000	59.780	59.780	0.0000	8.818	8.818	686.40
44.000	0.0000	63.042	63.042	0.0000	9.640	9.640	727.28
46.000	0.0000	66.544	66.544	0.0000	10.548	10.548	771.45
48.000	0.0000	70.301	70.301	0.0000	11.553	11.553	819.13
50.000	0.0000	74.325	74.325	0.0000	12.664	12.664	870.54

COMTEM - $GA_7(FA_1)$ for NMI = 10,0

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+03
0.000	0.0000	38.757	38.757	0.0000	2.290	2.290	0.4105
2.000	0.0000	38.780	38.780	0.0000	2.372	2.372	0.4101
4.000	0.0000	38.735	38.735	0.0000	2.452	2.452	0.4114
6.000	0.0000	38.887	38.887	0.0000	2.548	2.548	0.4139
8.000	0.0000	39.176	39.176	0.0000	2.658	2.658	0.4180
10.000	0.0000	39.614	39.614	0.0000	2.783	2.783	0.4237
12.000	0.0000	40.206	40.206	0.0000	2.925	2.925	0.4311
14.000	0.0000	40.959	40.959	0.0000	3.085	3.085	0.4402
16.000	0.0000	41.875	41.875	0.0000	3.266	3.266	0.4513
18.000	0.0000	42.960	42.960	0.0000	3.471	3.471	0.4642
20.000	0.0000	44.218	44.218	0.0000	3.700	3.700	0.4791
22.000	0.0000	45.654	45.654	0.0000	3.957	3.957	0.4961
24.000	0.0000	47.273	47.273	0.0000	4.245	4.245	0.5152
26.000	0.0000	49.081	49.081	0.0000	4.565	4.565	0.5365
28.000	0.0000	51.084	51.084	0.0000	4.923	4.923	0.5602
30.000	0.0000	53.289	53.289	0.0000	5.321	5.321	0.5863
32.000	0.0000	55.705	55.705	0.0000	5.764	5.764	0.6149
34.000	0.0000	58.341	58.341	0.0000	6.255	6.255	0.6462
36.000	0.0000	61.204	61.204	0.0000	6.801	6.801	0.6804
38.000	0.0000	64.307	64.307	0.0000	7.406	7.406	0.7175
40.000	0.0000	67.660	67.660	0.0000	8.076	8.076	0.7578
42.000	0.0000	71.274	71.274	0.0000	8.818	8.818	0.8014
44.000	0.0000	75.162	75.162	0.0000	9.640	9.640	0.8486
46.000	0.0000	79.339	79.339	0.0000	10.548	10.548	0.8995
48.000	0.0000	83.818	83.818	0.0000	11.553	11.553	0.9544
50.000	0.0000	88.615	88.615	0.0000	12.664	12.664	1.0135

COMTEM - $GA_7(FA_1)$ for NMI = 12,5

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+03
0,000	0,0000	45,01	45,01	0,0000	2,290	2,290	0,4730
2,000	0,0000	45,03	45,03	0,0000	2,372	2,372	0,4724
4,000	0,0000	44,98	44,98	0,0000	2,452	2,452	0,4738
6,000	0,0000	45,16	45,16	0,0000	2,548	2,548	0,4765
8,000	0,0000	45,49	45,49	0,0000	2,658	2,658	0,4811
10,000	0,0000	46,00	46,00	0,0000	2,783	2,783	0,4875
12,000	0,0000	46,69	46,69	0,0000	2,925	2,925	0,4959
14,000	0,0000	47,56	47,56	0,0000	3,085	3,085	0,5063
16,000	0,0000	48,63	48,63	0,0000	3,266	3,266	0,5188
18,000	0,0000	49,89	49,89	0,0000	3,471	3,471	0,5335
20,000	0,0000	51,35	51,35	0,0000	3,700	3,700	0,5504
22,000	0,0000	53,02	53,02	0,0000	3,957	3,957	0,5697
24,000	0,0000	54,90	54,90	0,0000	4,245	4,245	0,5914
26,000	0,0000	57,00	57,00	0,0000	4,565	4,565	0,6157
28,000	0,0000	59,32	59,32	0,0000	4,923	4,923	0,6426
30,000	0,0000	61,88	61,88	0,0000	5,321	5,321	0,6722
32,000	0,0000	64,69	64,69	0,0000	5,764	5,764	0,7048
34,000	0,0000	67,75	67,75	0,0000	6,255	6,255	0,7403
36,000	0,0000	71,07	71,07	0,0000	6,801	6,801	0,7791
38,000	0,0000	74,68	74,68	0,0000	7,406	7,406	0,8213
40,000	0,0000	78,57	78,57	0,0000	8,076	8,076	0,8669
42,000	0,0000	82,77	82,77	0,0000	8,818	8,818	0,9164
44,000	0,0000	87,28	87,28	0,0000	9,640	9,640	0,9698
46,000	0,0000	92,13	92,13	0,0000	10,548	10,548	1,0275
48,000	0,0000	97,33	97,33	0,0000	11,553	11,553	1,0897
50,000	0,0000	102,90	102,90	0,0000	12,664	12,664	1,1566

COMTEM - $GA_7(FA_1)$ for NMI - 15,0

TIME E+00	OCOSTS E+00	NCOSTS E+06	COSTS E+06	OLABOR E+00	NLABOR E+06	LABOR E+06	UCOST E+03
0,000	0,0000	51,26	51,26	0,0000	2,290	2,290	0,5355
2,000	0,0000	51,29	51,29	0,0000	2,372	2,372	0,5348
4,000	0,0000	51,23	51,23	0,0000	2,452	2,452	0,5361
6,000	0,0000	51,43	51,43	0,0000	2,548	2,548	0,5392
8,000	0,0000	51,81	51,81	0,0000	2,658	2,658	0,5442
10,000	0,0000	52,39	52,39	0,0000	2,783	2,783	0,5513
12,000	0,0000	53,17	53,17	0,0000	2,925	2,925	0,5607
14,000	0,0000	54,17	54,17	0,0000	3,085	3,085	0,5723
16,000	0,0000	55,38	55,38	0,0000	3,266	3,266	0,5863
18,000	0,0000	56,82	56,82	0,0000	3,471	3,471	0,6027
20,000	0,0000	58,48	58,48	0,0000	3,700	3,700	0,6217
22,000	0,0000	60,38	60,38	0,0000	3,957	3,957	0,6433
24,000	0,0000	62,52	62,52	0,0000	4,245	4,245	0,6677
26,000	0,0000	64,91	64,91	0,0000	4,565	4,565	0,6949
28,000	0,0000	67,56	67,56	0,0000	4,923	4,923	0,7250
30,000	0,0000	70,48	70,48	0,0000	5,321	5,321	0,7582
32,000	0,0000	73,67	73,67	0,0000	5,764	5,764	0,7946
34,000	0,0000	77,16	77,16	0,0000	6,255	6,255	0,8345
36,000	0,0000	80,94	80,94	0,0000	6,801	6,801	0,8779
38,000	0,0000	85,05	85,05	0,0000	7,406	7,406	0,9250
40,000	0,0000	89,48	89,48	0,0000	8,076	8,076	0,9761
42,000	0,0000	94,26	94,26	0,0000	8,818	8,818	1,0314
44,000	0,0000	99,40	99,40	0,0000	9,640	9,640	1,0911
46,000	0,0000	104,93	104,93	0,0000	10,548	10,548	1,1555
48,000	0,0000	110,85	110,85	0,0000	11,553	11,553	1,2249
50,000	0,0000	117,19	117,19	0,0000	12,664	12,664	1,2996

APPENDIX 5

ACRONYM LIST OF "COMTEM" MODEL

Integration is a process that relates a quantity to the time rate of change of that quantity, e.g.:

quantity now = quantity earlier + elapsed time* rate of change.

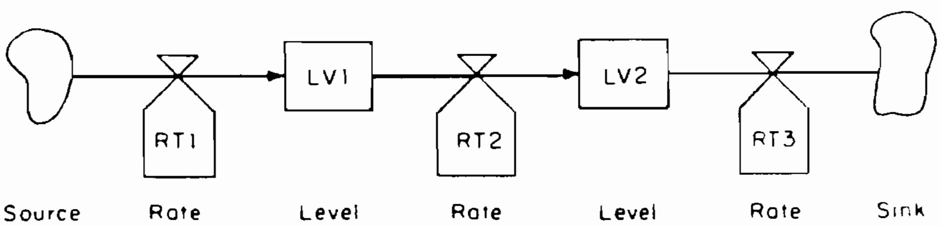
If we indicate the present time by the subscript K, the earlier time by the subscript J, and call the elapsed time between J and K, DT, we can rewrite the equation:

quantity · K = quantity · J + DT* rate of change.

This type of equation is called a level equation and the quantity is a level. The level equations that correspond to the following figure are:

LV1 · K = LV1 · J + DT* (RT1 · JK − RT2 · JK)

LV2 · K = LV2 · J + DT* (RT2 · JK − RT3 · JK)



A case from documented program listing of the COMTEM model the position 0056 (see Appendix 1):

0056 C N$DL = 0,35

a single letter designating the type of equation:

L = level equation (e.g., position no. 0076)

A = auxiliary equation (0082)

R = rate equation (0079)

N = initial value equation (0077)

C = constant--from Table 3--e.g., N$DL (i.e., the parameter of development labor for the New mining technology)--or from Table 2--e.g., O$DL (e.g., the same parameter for the Old mining technology).

Other acronyms from the program listing are:

OIN (NIN) = the investment into the old (O) and new (N) mining technology

OTA (NTA) = old (new) technology amount

ODP (NDP) = depreciation rate (amount of technology retired)

OAL (NAL) = average life time of technology

OMP (NMP) = innovation cycle period (maturity period)

OTM (NTM) = old (new) technology maturity

OUT = output of coal extracted

PROD = productivity of technology

INV = investment into both technologies

PDR = productivity depreciation rate

WUR = wage underground rate

WSR = wage surface rate

WUL = wage underground level

WSL = wage surface level

MCR = material cost rate (including water, energy and machinery investment costs)

OCOST(NCOST) = non wage costs, see Table 1 = Σ MM + DM + TM + + OM + SM + GM + ME + DE + TE + OE + SE + GE + + MI + DI + TI + OI + SI + GI ;

COSTS = OCOST + NCOST (unit non-wage costs for both technologies)

OLABOR (NLABOR) = wage costs, see Table 1 = Σ ML + DL + TL + + OL + SL + GL ;

LABOR = OLABOR + NLABOR (unit wage costs for both technologies)

UCOST = LABOR + COSTS (total unit costs of coal extracted)

LAM = number of workers in mining

LAD = number of workers in development activity

LAT = number of workers in transportation

LAO = number of workers in other underground activities

LAS = number of workers on the surface

LAG = number of workers in extracting of CH_4

LAUG = LAM + LAD + LAT + LAO (the sum of the underground labor)

LASF = LAS + LAG (the sum of the labor on the surface)

LAALL = LASF + LAUG (the total number of the workers of a mine)

DEC = sharing ratio (the proportion between the old and the new mining technology, i.e., their rate in addition to the amount of technology retired--it is the tool for engaging eligible new technology) (see page 15)

SB = starting base (cost matrix for the old technology)

FA = fundamental alternatives (cost matrix for the new technology)

GA = generated alternatives

GV = generated variants.