SYSTEMS ASSESSMENT OF NEW TECHNOLOGY IN DECISION-MAKING IN GOVERNMENT AND INDUSTRY

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PREFACE

Since the autumn of 1976, IIASA's Management and Technology Area has been working on the task, "Dynamics and Management of Technological Change". As an exploratory task the feasibility of this new field of research in IIASA had to be defined, together with the possibilities for application and international cooperation in the field. Some results are generalized in this paper.

ABSTRACT

In this paper, Technology is analyzed as (i) a specific system consisting of "Hardware", "Software", and "Orgware"; (ii) a man-made environment; (iii) an holistic object of management and type of organized activity. The concept of Systems Assessment of New Technology (SANT) is proposed and methods and models of SANT are reviewed. The author's original ideas and experience in the field are discussed.

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1. STATEMENT OF THE QUESTION

Increasing the efficiency of the management of technological development on all levels of decision making is a vital need for any country in the world, regardless of the acuteness with which they presently recognise the finite character of all other resources.

There are several circumstances which necessitate systems-analytic basing of decision-making in the development of science and technology. Among these circumstances, the most important are as follows:

- the rapidly growing role of science and its technical applications in the solution of a very broad spectrum of problems disturbing contemporary soceity; this circumstance is shaped by the regular process of transforming practically applied scientific knowledge into direct productive power and social capabilities;
- the growing complexity of newly created technological systems, the diversity of their forms, and the intensification of their ties with other systems; this circumstance determines the character and dynamic structure of the positive and negative consequences of the functioning of technological systems;
- the colossal amount of material and intellectual resources allotted to technological development, which doubles in volume approximately every decade; in not a single country, however, has this process been accompanied by a correspondingly rapid rate of growth in the efficiency with which these resources are used.

The general scheme of relations on managerial decision-making with applied systems analysis is shown in Figure 1. This diagram reflects our poitn of view about the configuration of what is traditionally discussed in systems analysis.[1,2]

Here, we understand applied systems analysis as a process of studying some of the real problems, typically by mathematical

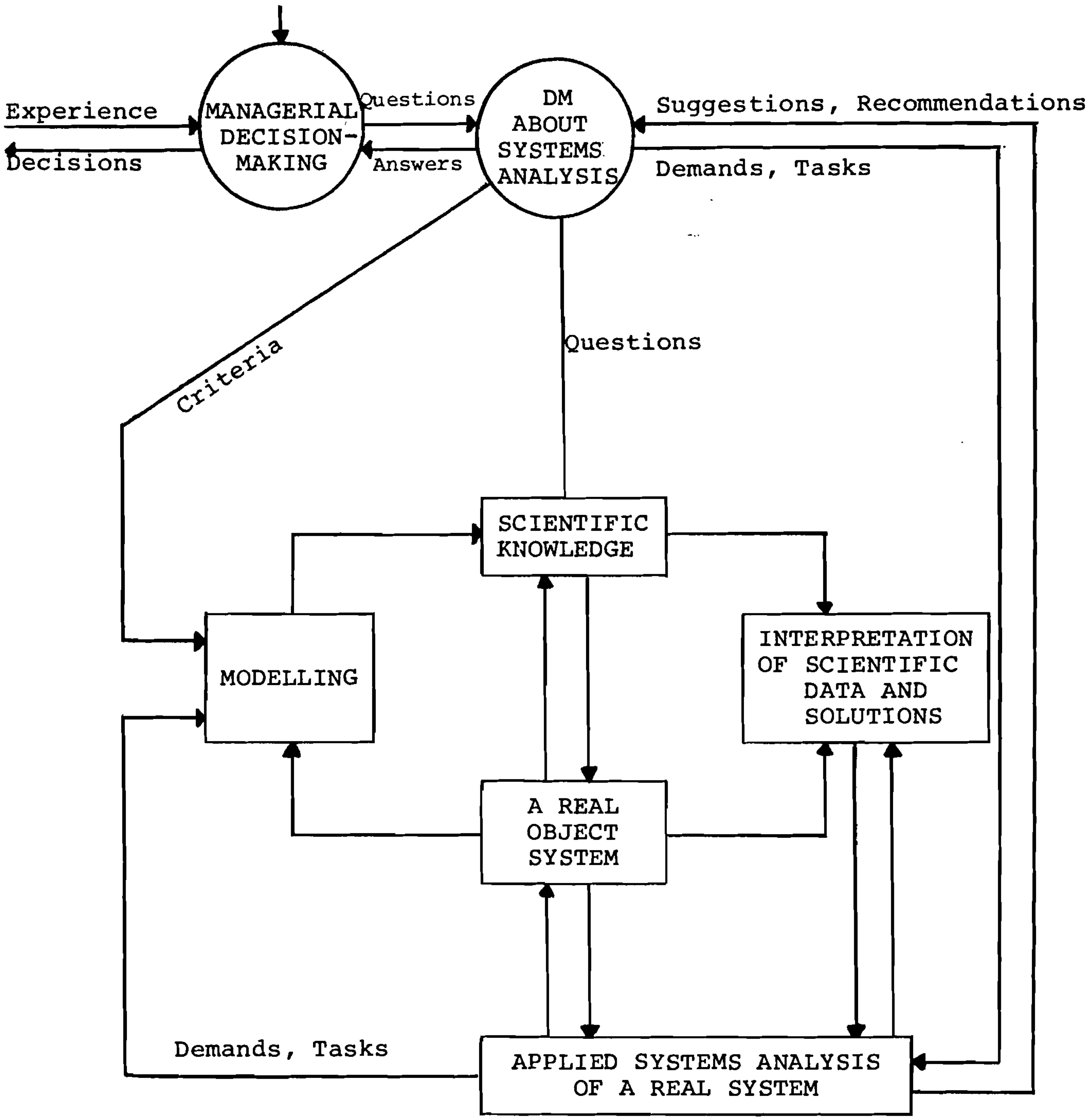
Experience
Decisions
MANAGERIAL DECISION-MAKING
Questions
Answers
DM ABOUT SYSTEMS ANALYSIS
Suggestions, Recommendations
Demands, Tasks
Criteria
Questions
SCIENTIFIC KNOWLEDGE
MODELLING
INTERPRETATION OF SCIENTIFIC DATA AND SOLUTIONS
A REAL OBJECT SYSTEM
Demands, Tasks
APPLIED SYSTEMS ANALYSIS OF A REAL SYSTEM

Figure 1

means, in order to assist managerial practice in the definition of goals, allocation of resources and discovering ways for performing an activity more efficiently. (Compare with [3], p.1184.)

Systems Assessment of Technology is one particular kind of applied systems analysis which is, in this care, called upon to define and evaluate the dynamics and quality of technological development, and of managerial actions.

Systems analysis in these conditions must be interdisciplinary, intersectorial and carried out as an interative process. The analysis must embrace a broad range of factors, properties, and consequences and the decision which is being substantiated must be directed toward the achievement not only of near but also of remote effects. The global character of the problem and the universality of the methods for its investigation naturally harmonize with the international content of science and technology as such.

Among the first facets of a systems analysis in this new area are the following:

- understanding of the qualitative peculiarities of the man-made technological environment;
- assessment of the quantitative characteristics of this dynamically developing system; and
- generalization of experience in organizing and managing the science and technology (ST) process.

Also, from the very first steps, systems analysts have been focussing attention on the modelling of technological development processes and phenomena, and on the search for possible ways to increase the effectiveness of the management of ST activity. This last relates both to international technological cooperation and to a set of universal problems of managerial practice on governmental and industrial levels.

2. WHAT IS TECHNOLOGY?

In the systems framework a definition such as TECHNOLOGY has some meanings which complement each other and which should be taken into account when we consider management in the field of science and technology. They are:

a) A system consisting of a set of technical means (HARDWARE), methods and procedures to use those means effectively (SOFTWARE or KNOWHOW) and a special organization (ORGWARE) designed to provide the utilization of the individual(1) skills and interaction between that system and other systems of various natures;

b) A man-made environment, that is the result of the implementation of knowledge, which permanently changes the amount and structure of the resources and the opportunities available to society;

c) A process of organized activities and an holistic object of social management at different levels of decision making.

The first aspect of systems definition mentioned above is a further development of the concept traditionally accepted in engineering but is not equivalent to it. Because of differences in terminology and traditions in different countries, technology is defined either in the narrow sense as the process of production, or more comprehensively as a set of actions (for example - "social technology"). It is important to stress that nowadays the process of putting forth the concept of technology as a system, unity of means, processes and organization has been taking place in all countries (see Figures 2 and 3).

Many issues which are of crucial importance for providing conditions for the most effective use of results of progress in science and technology (both social and economic) happen to have depended directly on a systems understanding of technology.

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(1) Here "the individual" is "the decision maker".

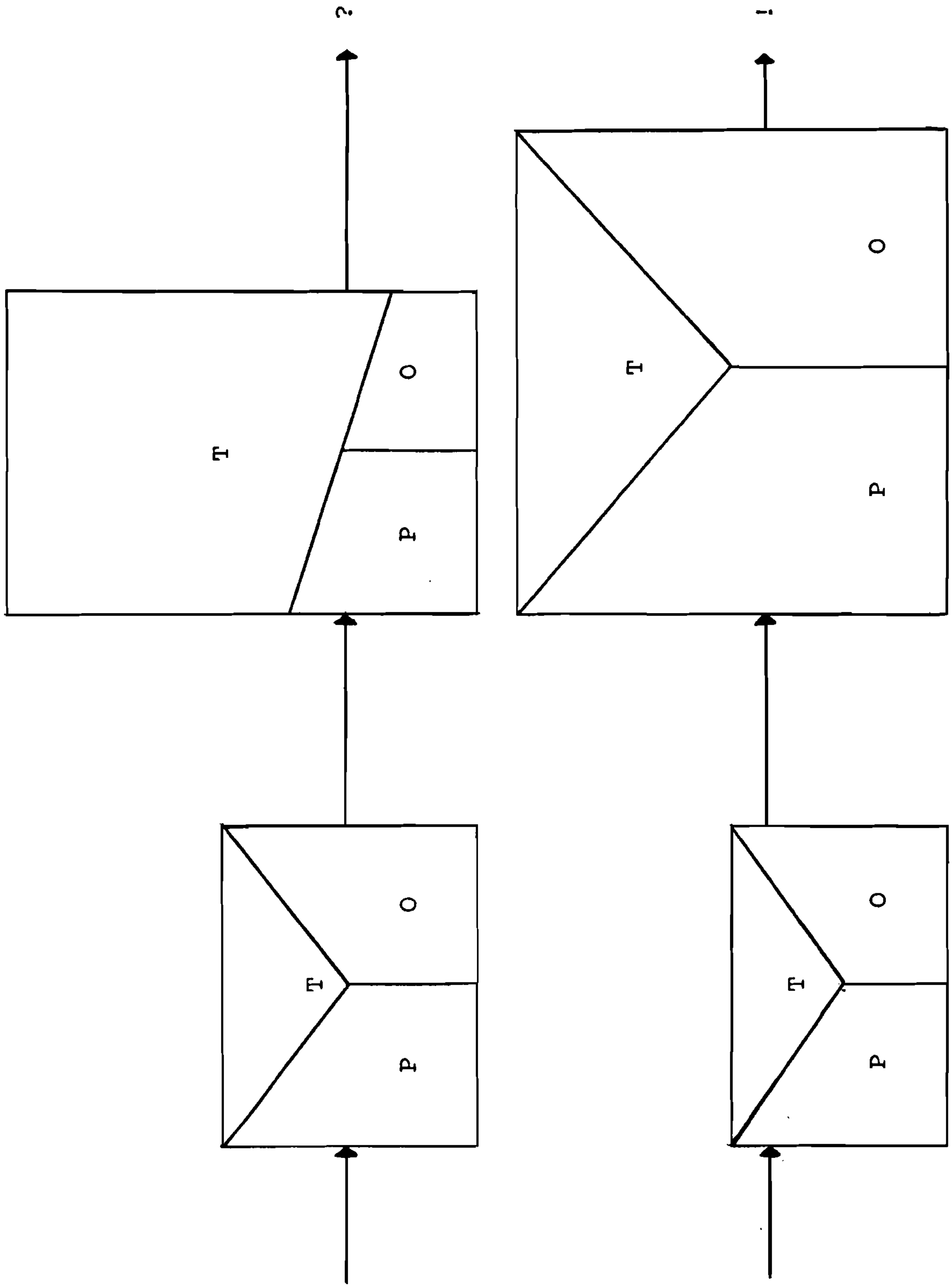
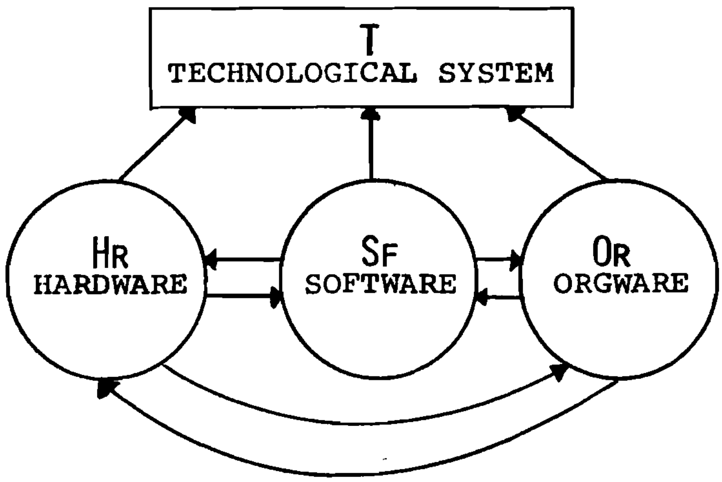


Figure 2

A) FUNCTIONAL STRUCTURE OF TECHNOLOGY



B) TRENDS IN THE STRUCTURE OF THE COST OF TECHNOLOGY

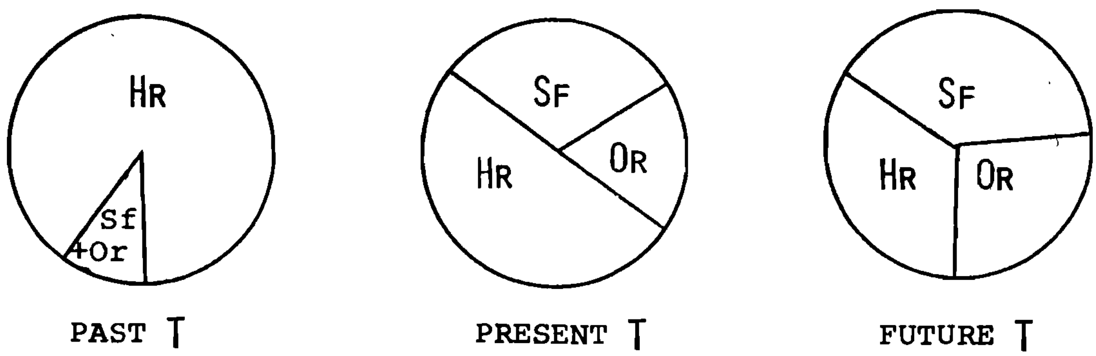


Figure 3

Some of them are:

- the effective application of the latest developments in science and technology;
- processes of "technological substitution"[4];
- implementation of new technical means, machines, tools, devices, etc.;
- mutually beneficial international exchange in the field of science and technology, etc.

For example, it was not so long ago that an answer to the question, "What should be introduced into the manufacturing process?" was acceptable in terms of "machines" or "apparatus". (See Figure 2.) In the present age of revolution in science and technology when there exists clear evidence that a scientific component of technology itself as well as principles and ideas of the technology, has begun playing a leading role, the second element of systems technology has been properly recognised. The answer to the above question has become more of a systems one, that is to say, "computer and software" or "modes of production and means of application".

Experiences gained during the last decade has made it clear that as a rule it is not enough to have only a set of technical means or even skilled staff. It has to be supplemented by special organizational (in more general terms, socio-economic) innovations. To prove the point we can recall lessons learned in connection with:

- the introduction of computerized management systems into practice;
- the transfer of agriculture to a new technological base;
- the creation and mastery of new transport systems, etc.

One particular illustration is progress in steel making, so called open hearth technology (see Figure 4).(1) The first

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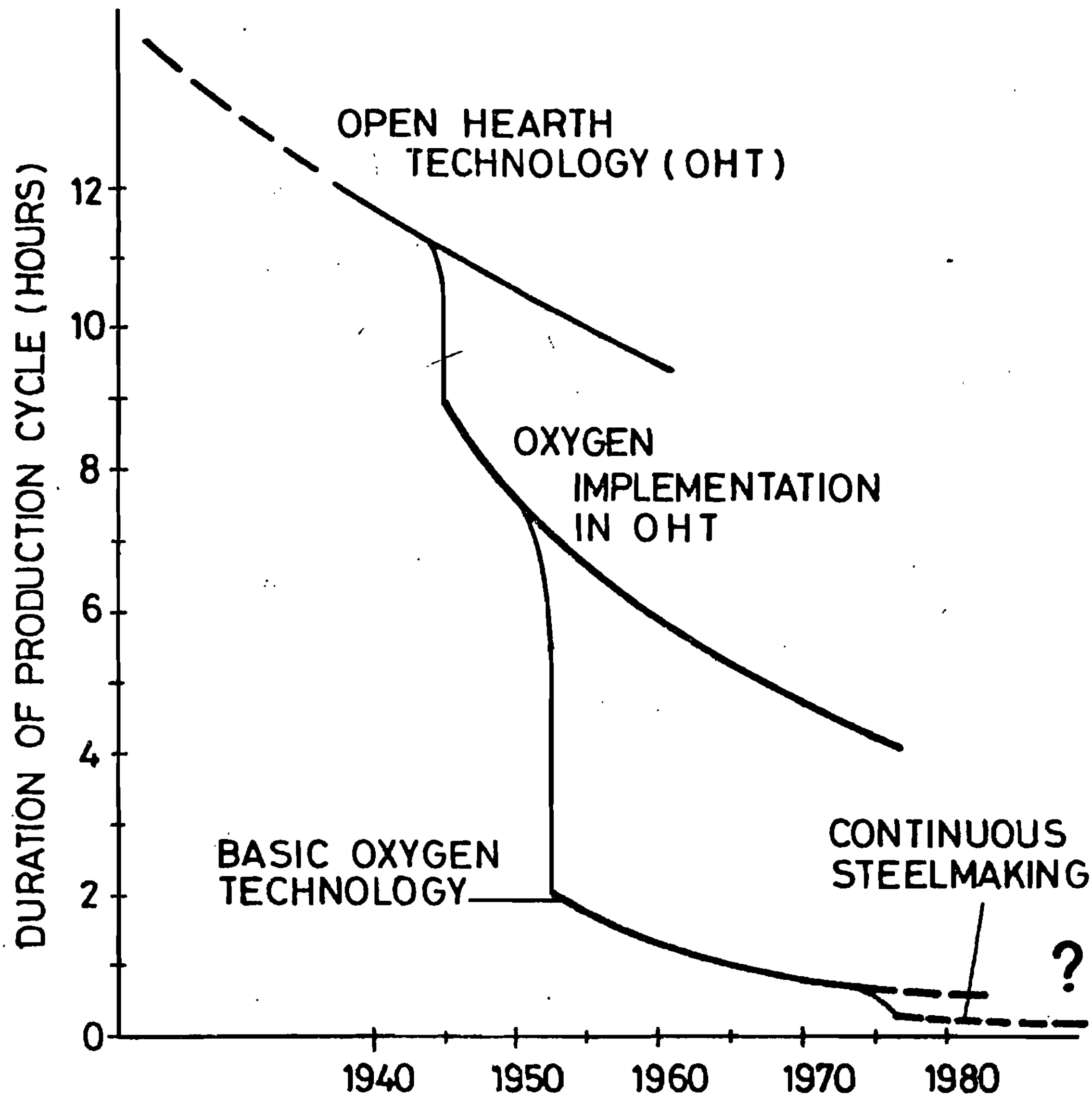
(1) G. Surguchov, Industrial Technology: Problem Oriented Approach, RM-76-77, IIASA, Austria, November 1976.



OPEN HEARTH TECHNOLOGY (OHT)
OXYGEN IMPLEMENTATION IN OHT
BASIC OXYGEN TECHNOLOGY
CONTINUOUS STEELMAKING
?
DURATION OF PRODUCTION CYCLE (HOURS)
0
2
4
6
8
10
12
1940
1950
1960
1970
1980

Figure 4

essential change was achieved on the basis of using the new technical means and metalurgical processes. The Second crucial change was a result of uniting information technology with partial innovations in the organization of production. The remaining achievements in the development of this technological system are results of complex solution engineering and organizational problems brought use an essentially new kind of production.

For each modern system technology to achieve success, it is urgently necessary to have a specially designed organization corresponding to a level of scientific principles which are rbought to life by the new technology and specific features and functions of that technology.

We named this as ORGWARE. On the macro level ORGWARE seizes a set of special economic and legal regulations (a system of prices, taxes, stimuli and constraints). On the operative level ORGWARE includes organization-structural solutions, procedures for management, training of manpower, maintenance service and special ways of interacting with other systems. There is a general rule: the more potentially effective a new technology is the more urgent the need for specially designed ORGWARE.

Organizational framework for technological progress has to be designed with the help of reliable special analytical methods, as well as hardware and software are designed with the help of their appropriate methods. It is one of our main research hypothesis and applied aims. In many regions of the world, a number of very acute problems which have to be solved, demand that a policy design for new technologies should be reconsidered from the systems point of view. I wish to mention some of those problems which are the crucial ones for various parts of the world. They are (for example):

- accelerated growth of labour productivity as a result of the wide use of new technology;
- solving a complex food and agriculture problem on the basis of systems realization of new technologies;

- "blue revolution" in environment and nature use expected in view of forthcoming technological opportunities;
- creation of a "zero-waste" technology for the whole chain of productive processes, from discovering resources to the finished goods utilization.

The experience gained, both through IIASA investigations and our previous scientific activies, strongly supports the idea that in cases where organizational and managerial aspects of systems technologies do not get proper considerations, the effect expected by society for solving exciting problems is not often achieved, in spite of considerable investment made in the other two components of technology.

The specific organization (ORGWARE) should be designed as both problem-oriented and machine-oriented. There are also some whole-system criterions: minimization of time-delays, optimal storage and using information, etc. A development of models and methods for designing the ORGWARE of new technologies is one of the most acute problems of systems analysis in the management and technology field.

Case studies on specific kinds of technology which are in pogress in various IIASA Areas and Programs could be a good basis for the applied analysis of experience and problems of the system evolution of new technologies. This is one of the points of our common research interests.

The second aspect of the systems concept of technology is to a considerable extent similar to the systems approach adopted in ecology. Water, land, air, etc., are studied by specific sciences. Each of those sciences has its own language, indicators and models which very often happen to be incompatible. At the same time the importance of social consideration of those elements in the framework of the theory of ecological systems and practical environment management has been widely recognized and those issues are rapidly becoming more acute.

Various "families" of technologies have been created and are being used, as well as those that are being mastered at present, form a new kind of unity (see Figure 5). This unity specifically interacts with nature and society. An applied systems analysis approach to complex technological environment is the only way to elaborate and put into operation such concepts which are of practical importance as "rate of technological substitution", "a quality of technological environment", "a technological risk" and "flexibility of technological system". It means the capacity of the technological environment to accept new scientific and technological opportunities and to respond to changes of social, economic and ecologic demands, etc., and also to those which will develop in the future. Figure 6 shows one example of the ordered list of future technologies (so called "candidate technologies").

There is common understanding that an analytical policy design is an important and final step of modern systems analysis. Many issues like natural resources, environment, energy complexes and agri-production, human settlements and healthcare systems that are subjects to which systems analysis is applied, can be reasonably explained only when long-range scientific and technological factors and socio-economic criteria related to these factors are taken into account.

In fact, we deal with the state of affairs that is precipitated by technology (see Figure 7) in every case of policy design for various kinds of activity (industry, agriculture, public health service, administration, etc.).

In Figure 7, available technologies, within its family (beginning with widely known and practically used ones, to hypothetical or theoretically possible ones) are all ordered along an axis of T_{AV}. The axis E^T is used to rank a "feasibility index" which characterizes those technologies which are economically applicable and those that are not (under existing conditions). The location of that region of the stated space that is taken into consideration in a process of policy design changes rather rapidly. On one hand, success in the R & D field expands a set of technologies available from the viewpoint of science and

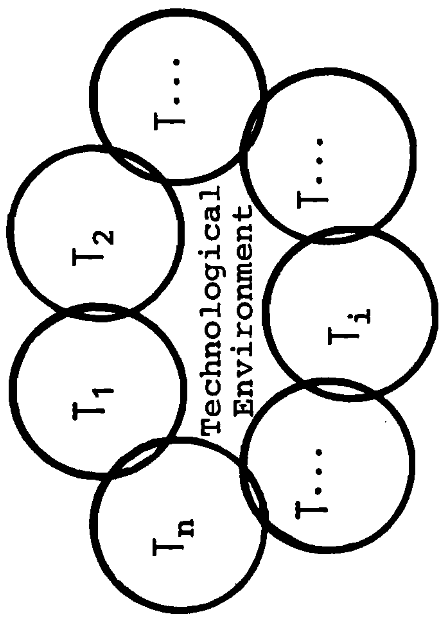


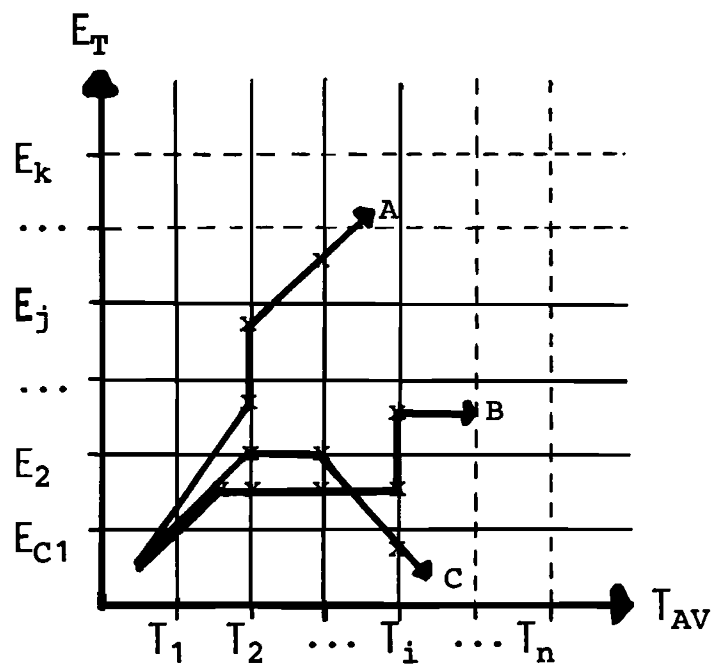
Figure 5

Figure 6 CANDIDATE TECHNOLOGIES (Field: E; TF-73)

REGISTER (FILE)	PRIOR-ITY	BRIEF NAME OF TECHNOLOGY	PROBABLE PRACTICAL USE UNTIL 1983										SPECIAL REMARKS
			DEFINITELY YES		POSSIBLY YES		EQUAL YES/NO		MORE NO THAN YES		DEFINITELY NO		
			A	B	A	B	A	B	A	B	A	B	
E-53/$\frac{7}{72}$	1	Breeders	6.5	8.1	33.3	32.4	18.7	13.5	22.6	21.4	18.9	24.6	A=75 B=37
E-25/$\frac{6}{15}$	2	Benzin from coal	30.7	37.0	48.0	47.0	13.3	4.3	5.3	6.2	2.7	4.5	A=75 B=46
...	...	...	...	...	...	...	...	...	...	...	...	...	

A = Experts in the subject E-53.

B = Experts in the field - E



<u>**The Space of Technologically-caused States for Policy Design**</u>

<u>Figure 7</u>

technology. On the other hand the society become richer or having been influenced by some acute needs, can change economic criteria by itself and improvement in technology can lead to better "cost-benefit" indices.(1) It is in order to mention that modern techniques of systems analysis applied in the field of technology (technological forecasting, technology assessment, choice of technological alternatives, etc.) not only permit analysis of those tendencies in terms of quality and structure, but also definitely estimate future states in the space in quantitative terms. Here the main applied sense of the "models of technological substitutions" and the methods of "cross impact analysis" were successfully developed during past years.[5] For decision makers it is quite evident (see Figure 7) that trajectories A,B or C differe considerably from the impact on the results of modelling used in policy design.

The above approach could serve as a solid base for cooperation of systems analysts engaged in the development of theory and methodology for technology analysis and those scientists who are mainly interested in systems analysis, modelling and policy design which demands that scientific and technological factors should be taken into account.

It is natural that a sense of the axes of the state space can vary considerably. For example, in some cases, it is of special interest to consider and estimate the perspective for minimizing technological wastes of resources including the creation of the so-called "O-WASTE" technologies in the chain of extraction-manufacturing-utilization. We may think that this aspect of cooperation will turn out to be an attractive one both for areas dealing with non-renewable resources (oil, coal) and for those concerning problems of renewable resources (forests, land) as well as areas dealing with resources transformed cyclically (water, money).

In connection with the aspects under discussion, it is worth noting that the so-called WELMM approach to systems examination (Water, Energy, Land, Manpower and Materials) is considered in

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(1) One particular kind of such a diagram is known in geology as McKelvey's Diagram. We propose a more universal approach.

many cases to be complementary to resources for development.

I believe that applied systems analysis has come to be understood as the success or failure of R & D activities as well as efforts directed toward creation, transfer and mastering new technology is of vital importance for WELMM estimates of resources and the future of the process of their mutual substitution and effective utilization which is considered to be the main factor for existing resources for the further development of mankind.[6] To put it in another way, it is high time the WELMM approach was combined with the STM (Science, Technology, Management) approach in the methodology and practice of systems analysis (see Figure 8).

The third aspect of the systems concept of technology assumes that technology should be studied as a unique object of management. In this case, the management of technologies influences the activities and behaviour of individuals, collectives and organizations, using the knowledge, investment and natural resources available (Figure 9). Then, technology is treated by ASA (Applied Systems Analysis) from the unified viewpoint as a chain: research - development - project realization - technology transfer - innovation - mastering - supporting technological benefits - full substitution with new technologies.

However, between the benefits and levels of those activities on the one hand and the final economic indices on the other, only implicit connections exist through complicated social and economic mechanisms, so-called "national engines". The attempts of their study looks encouraging only on the level of macro models and taking into account essential time-lag between "input" and "output". Such connections are among the main sources of data for the estimation of the benefits of technological development.

Systems analysts use such concepts as "technology as integrity", "a vector of technologies", "effectiveness and quality of technology as a whole" and other social concepts of special importance for national and international studies. Professor P.K. M'Pherson has had a positive influence on efforts in this direction at IIASA. Our discussion follows his ideas on Integral Model of Technological Change. I would like to note that the data collected and analyzed

W E L M M approach + **S T M** approach = **A S A** approach

Water, Energy, Land, Materials, Manpower

Science, Technology, Management

Applied Systems Analysis

Figure 8

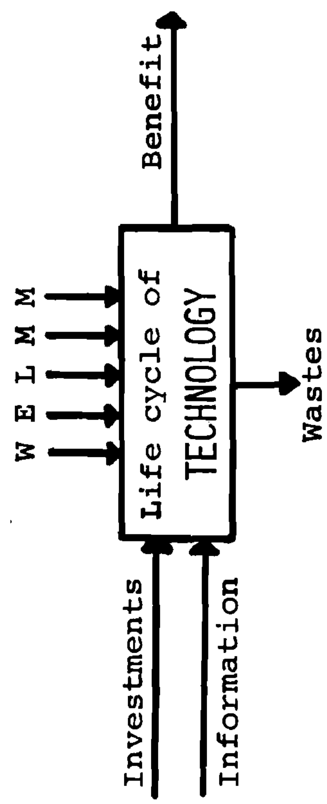

W
E
L
M
M
Life cycle of
TECHNOLOGY
Benefit
Wastes
Investments
Information

Figure 9

during the study has created a basis for further interfpretation of correlations between development indices of certain technologies in the states and different policies concerning those technologies (see Figure 10).

Let I_T be an index characterizing a certain class of technologies. For example, this can be an amount of energy per individual occupied in production as it was in M'Pherson's study. Figure 10 presents data for countries (1), (2), (3) and (4), and the order of indexes corresponds to a chronological row. Let I_g in its turn be chosen from a set of social indicators. For example, in statistics used during the study, there was data about levels of GNP per capita.

Data of this kind which is known to us far from being complete and homogenous. The results of processing them should be considered as the first approximation of real figures. However, in spite of the fact that we should be as careful and scrupulous as possible when considering and interpreting such data, we could draw attention to essential differences of policy in the field of technology.

The curve (1) represents a common practice in many countries. The shape of the curve (2) which corresponds to when the technological growth takes place without a growth of social indicators, can be positively explained only by the fact that during short periods of development, some actions aimed at forming technological potential or bridging a gap which exists in some fields of technology as soon as possible, were taken at the expense of national efforts. The curve (3) corresponds to the case of "dangerous" policies in this respect.

Recently, we have come across more countries who consciously follow policies of the type (4). This case shows the possibilities for increasing the social technologies decreases (for example, those technologies that require a lot of labour or energy). For example, this policy has been carried out in some Scandinavian countries. Such changes in policy usually also mean a transition from extensive methods of scientific and technological development to intensive ones. In the latter case, higher quality and

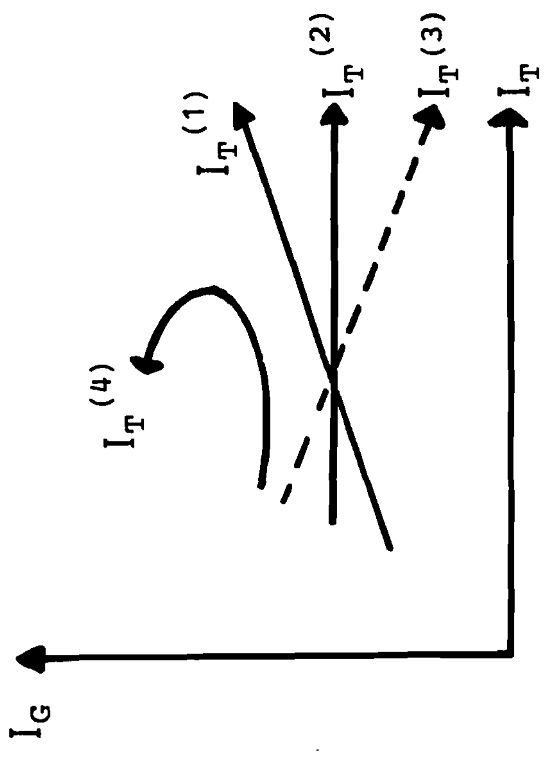


Figure 10

effectiveness of systems technologies are considered to be the main source for solving problems which exist at present in contrast to the former where more supplies of machinery are used for the same purpose.

The concept of technological potential is of special importance when a systems technology "as a whole" is treated as a process of organized activities. The technological potential is quantified capabilities of a certain state or region of the world for the creation and application of new technologies which meet the challenges of further social and economic development.

The concept of "technological potential" being complementary to the well known conept of "scientific potential"[7] together form a systems concept of "scientific and technological potential" which is of special importance for analyzing problems of international cooperation in the field of science and technology and for preparing mutually beneficial plans and programs of scientific and technological exchange and transfer of technologies as well as for global, national or industrial technological policy design.

Experiences gained by our country[8,9] and a lot of studies carried out by UNESCO[10], CMEA[8], OECD[11] and other international institutions as well as recent studies of the problems concerning information technology[12], have made it possible to present a method for defining an index of technological potential (TP) as follows. The main components of TP can be defined; they are the:

- economical component;
- material and technological component;
- manpower component; and
- information component.

For each of the above components, variables characterizing functional capabilities used in the definition of "technological potential" are identified.

About 12-15 varieities are defined and some value of "weight" V is assigned to each of them ($\Sigma V = 100$). The "weight" reflects an impact of variables on the "technological potential". They can be calculated by means of factor analysis and econometric models of the production function type with so-called "Abramovitz reminder".

A forecasting hypothesis "Base of 1990" or "Base of 2000" are in preparation. They are, in fact, a scenario of the future for a country. This hypothesis is used to compare policies from the viewpoint of possibilities necessary to provide a basis for the future progress in the social and economic field. It is natural that the hypothesis includes only aggregated estimates of macro-variables of the "technological potential". I would like to note that there have been studies showing how biases in basic estimates influence current estimates and forecasts. They have made it possible to adjust the whole system of estimates reasonably when policies are being implemented.[13]

Current states of variables of TP for a certain country or world region are calculated in terms of parts of corresponding values of "the Base". Then a systems estimate of the "technological potential" index is defined as a weighted sum of all the variables.

The methodology of technology potential assessment permanently improves. The results gained permit analysis of dynamics, perspectives and needs of countries and regions of the world in expanding and enhancing an international scientific and technological cooperation and mutually beneficial exchange of new technologies.

It would be especially interesting to study the technological potential of a number of regions of the world within this framework. The regions to be studied could be selected by following the example of Mesarovich and Pestel or by organizing the study as part of IIASA's program. It might be interesting to estimate to what extent the countries and the regions are "technologically" ready to meet the "green revolution", the "blue revolution" and other crucial changes in science and technology.

This aspect of the systems conception of organized technology can be discussed not only on the macro level but also on operative levels of the life cycle of specific technological systems. (See Figures 11a and 11b). Here D_1, D_2 ... D_7 denote appropriate stages of systems analysis and decision making.

The practice of technological change management knows some alternative trends:

(i) the rate of substitutions of technology generations increases. During the 20th century the time-periods for changes becomes two times smaller about every twenty years;

(ii) the time and cost of R & D parts of technology life cycle (Figure 11a) enlarge. During the last 5-7 years the statistically estimated length of projects increased by 1,3 to 1,5 times and their cost - more than twice;

(iii) the time spent on systems analysis and decision making in organizational managements tends towards growth. Known data together with our observations show that the summary time of waiting for managerial decisions T_D can exceed the general duration of all other actions of the life cycle. The average estimation is:

$$\sum_{D_1}^{D_7} T_D = (\tfrac{1}{4} \div 1/3) T_{L.C.},$$

$T_{L.C.}$ represents time-length of life cycle.

The active patent and licence policy, international cooperation and technology exchange are important for all countries, but especially developed ones, as an effective option in the above mentioned constraints. Applied systems analysis of this problem is topical for IIASA.

Technologically developed countries also have more experience in solving problems in other ways: MBO (Management of Objectives), PPBS (Planning, Programming, Budgeting System), Selection of Portfolio R & D Ideas, Technological Program Risk Evaluation, etc. The USSR has experience of long-range and operative planning of R & D, Goal-oriented programs of Technological Advance, improvement of managerial efficiency by applying the set of systems demands - "speed up", "wide spread" and "complete" utilization of available R & D results to the life cycle of technology. The

LIFE CYCLE OF ORGANIZED TECHNOLOGY

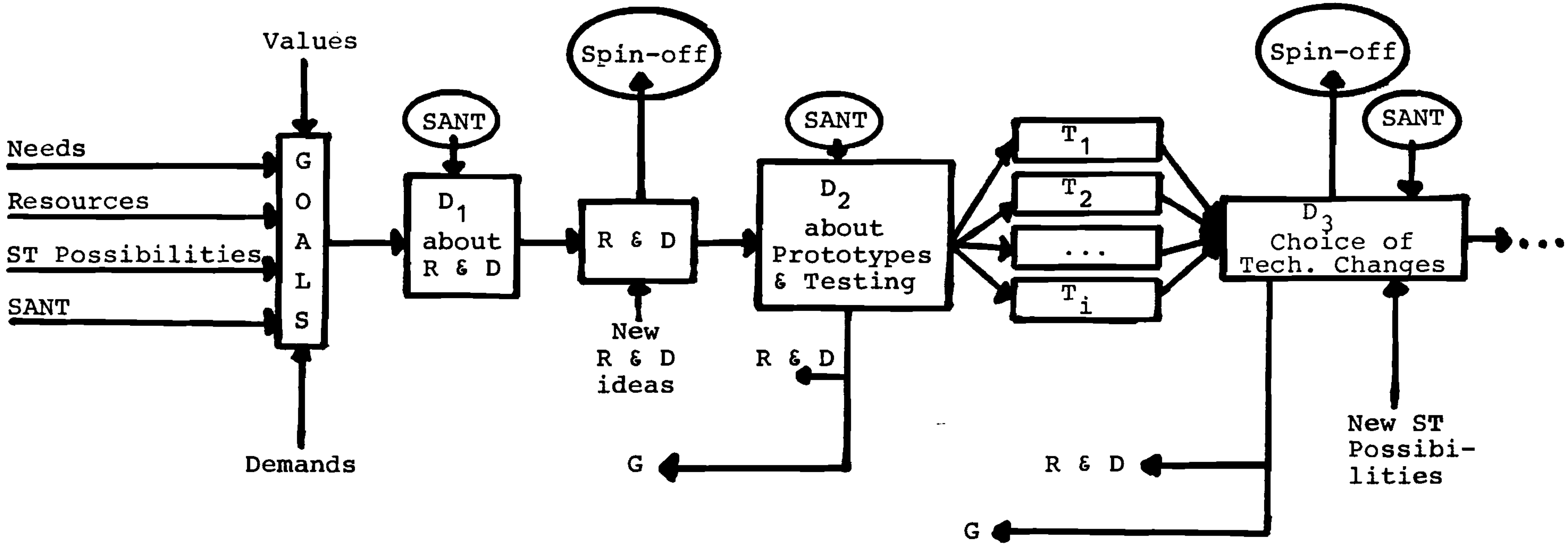


Figure 11a

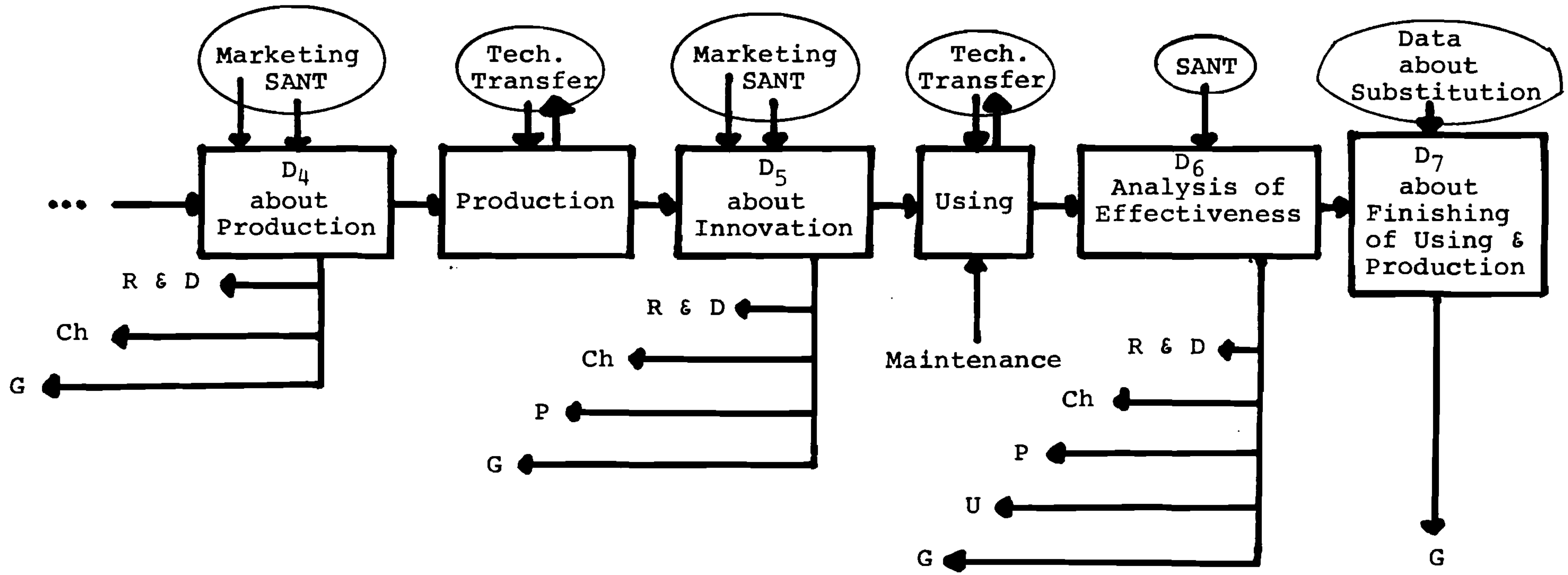

Marketing
SANT
Tech.
Transfer
Marketing
SANT
Tech.
Transfer
SANT
Data
about
Substitution
...
D4
about
Production
Production
D5
about
Innovation
Using
D6
Analysis of
Effectiveness
D7
about
Finishing
of Using &
Production
R & D
Ch
G
R & D
Ch
P
G
Maintenance
R & D
Ch
P
U
G
G

Figure 11b

generalization of such experience is a promised field of international cooperation for applied systems analysis.

Finally, our answer to the question "What is Technology?" given from the viewpoint of the M & T Area of ASA. This can be summarized in the next three main classes of problems for studying technology as an organized system (see Figure 12).

APPLIED ANALYSIS OF TECHNOLOGY AS AN ORGANIZED SYSTEM

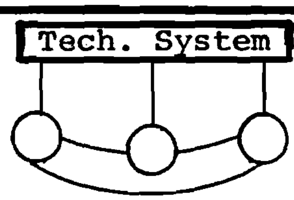
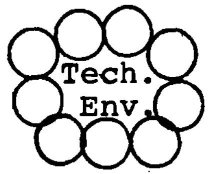
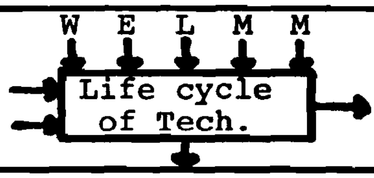
	CONTENT	LOGICAL SCHEME
CASE I	A system that consists of technical means ("hardware"), principles and methods ("software" or "knowhow"), and special organization ("orgware")	
CASE II	A man-made environment and materialized knowledge which permanently modifies the volume and structure of available natural resources and mankinds' possibilities	
CASE III	A process of organized activity and a holistic object of management on the different levels of decision-making	

Figure 12

3. A SYSTEMS INTERPRETATION OF THE MANAGEMENT OF TECHNOLOGICAL DEVELOPMENT

The activity of people and organizations in the investigation, creation, transfer, and utilization of technological innovations in all countries and in various forms is directed by:

- organs of legislative and executive state power;
- leading organs in various social and economic sectors;
- the leaders of the organizations and collectives involved in the process of technological development; and
- various communities and groups of people concerned with science and technology or with use of possibilities connected with this.

It is natural that the social essence of this complex process is different in different countries (especially the systems of values, criteria, and preferences which determine the goal function and character of managerial decisions; and also systems for stimulation of the process of technological activity itself). Also different are the organizational structure and procedures of decision-making organs. Often there are grounds for discussing these as fundamentally different, mutually competitive, or contradictory to one another in some regard. This happens not only in the case of international analysis, but also on the scale of each country being examined.

Nevertheless, the experience of managing technological development which has been accumulated and is being accumulated in various countries allows us also to distinguish some general systems characteristics of this process.

In Figure 13 is presented a generalized scheme of the interaction among the basic elements of the structure for management of national ST activity. In the terms adopted by UNESCO, this is a "cybernetic model of the national R & D system".[1]

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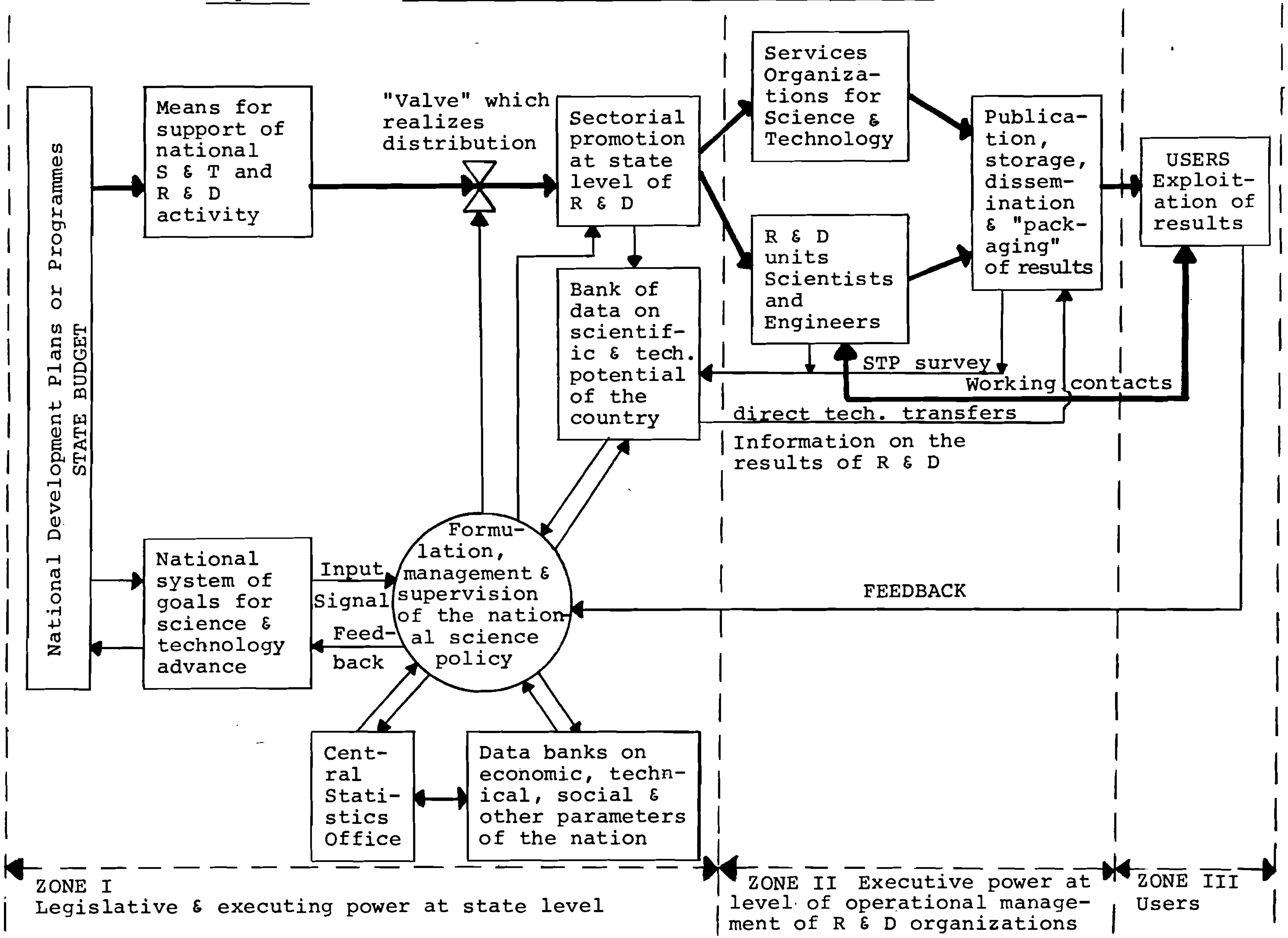
(1) Following the recommendations of the Science and Technology Policies Division of UNESCO, this model is used in the analysis of systems for management of ST activity that have been established in various countries, and also in the designing of such systems for developing countries. The author has taken part in projects for Iraq and the UAR.

Figure 13 CYBERNETIC MODEL OF NATIONAL R & D SYSTEM



Among the characteristics of this mechanism are the following:

(a) managerial functions are separated between the levels of legislative and executive power, direct production of technological results, and their practical use (from which data about the consequences of technological activity are obtained);

(b) fundamental significance has to be given to the effective functioning of developed feedback channels for transmission of data about the dynamics and qualitative structure of technology;

(c) the system must include well-developed services performing the "memory" function - the accumulation and systematization of data about the needs, potential, activity, and results of technological development;

(d) decisions made at all levels of management must take account of the significant time-lag which exists in the system between "input" and the signals really received through the feedback channels, in view of which the management information must include specially future-oriented assessments.

The experience of many countries, and their science policy studies, show that failure to meet any of the indicated demands for ST management leads to a sharp reduction in its effectiveness. In all known cases, losses from incomplete use of technological possibilities exceed the colossal economic and social benefits which society receives from technological progress. Duplication of technological work, deceleration of the R & D cycle, irrational structuring of efforts, and failure of science and education to meet national needs - all these are examples of direct losses. Growth of the gap in levels of development of various countries, delay in the "substitution" and utilization of new resources and unforeseen negative ecological and social effects - these are examples of losses which will be felt through generations of people, ideas, and things.

In many countries, original and valuable experience is now being accumulated in the perfecting of national systems for the organization and management of ST activity. Such measures are also being taken on the international level (by the specialized agencies of the UN, CMEA, OECD, etc.). This experience and the problems newly being raised by it are a very important object of applied systems analysis deserving IIASA's attention.

In recent years, in the USSR, the USA, and other countries, special investigations have been conducted regularly and on an ever greater scale, oriented toward the analysis and comprehensive evaluation of the state-of-art in various technological areas, toward the forecasting of their development, and toward estimation of their possible influence on the economy, on resources, on the environment, on other technical systems, and on society itself. Such systems investigations, undertaken on behalf of agencies which formulate and execute ST policy, have urgently required state organization of research as well as professional participation by systems analysts. Applied systems analysis of this kind is known in world practice under various names: "Technology Assessment", "Technology Forecasting" and others. The general rubric which encompasses all of these concepts is "Systems Assessment of New Technologies" (SANT).

To understand the essence of SANT, one must bear in mind that the discussion is not about traditionally practiced special engineering assessments but about "S Y S T E M S   A S S E S S M E N T S", in which all the basic features of modern systems analysis are inherent. These features include:

- the multifaceted nature of the factors, properties, and consequences examined;
- an interdisciplinary and interinstitutional approach;
- attention not only to near but also to remote effects, needs, and possibilities;
- the combination of quantitative and qualitative analysis of situations and objects; and
- an orientation toward the practice of decision making.

Further, we should note that the definition of "N E W" presupposes attention to phenomena arising or potentially possible as a result of the use of the latest achievements of science, and that the concept of "T E C H N O L O G Y", as mentioned above implies not only technical innovations as such but organizational and managerial innovations as well.

In the composition of SANT (see Figure 14) are included the following:

- Technological Forecasts (TF);
- Evaluation of the consequences of the development of technology ("Technology Assessment", or TA);
- Evaluation of the variants for technological policy ("Alternative Technologies", or AT);
- Evaluation of the "usefulness" of contemplated and on-going research and development efforts ("Evaluation of R & D", or ER); and
- Various "indicators" of the level of ST potential of countries and regions ("Science-and-technology Potential Indicators", or SI).

	Technology Forecasting	(TF)
+	Technology Assessment	(TA)
+	Alternative Technologies	(AT)
+	Evaluation of R & D	(ERD)
+	ST Potential Indicators	(STP)
=	S A N T	
	(Systems Assessment of New Technologies)	

Figure 14

In other words, SANT (= TF + TA + AT + ERD + STP) is a system of data for the basing of ST management decisions.

The process of the professional formation of SANT as an element in the analytic substantiation of ST policy takes place in the essentially different socio-political, economic, and technological contexts of various countries. The systems for analysis and evaluation of technological development which have been formed in various countries in the last 5-8 years, though they have common structural and functional features (see Figures 15 and 16 for examples of the USA and UkSSR), nevertheless are essentially different in their social context and procedures of activity.

This last circumstance, however, must not hide from us the possibility of a generalized presentation of the informational model of the formation and use of Systems Analysis of New Technology.

In the author's opinion, it is useful to distinguish between three levels of technological development, namely, "technological changes", "technological advance", and "technological progress" (see Figure 17).

At the center of attention of systems analysts in this case is the basic complex of ST activities, including research, development, and the adoption of new technology. Society invests in ST activity a national resource (known, overall, as ST potential and consisting of skilled manpower, scientific ideas, material and technical resources, and economical possibilities). As results of this activity, society receives new or transformed technological possibilities. Management of processes of research, development, and transfer of innovation is otherwise called "management of technological changes".[1]

Use of newly emerging technological possibilities in the sphere of practical activity (in the most general sense, including industry, agriculture, medicine, everyday life, culture, politics, education etc., and also the subsequent

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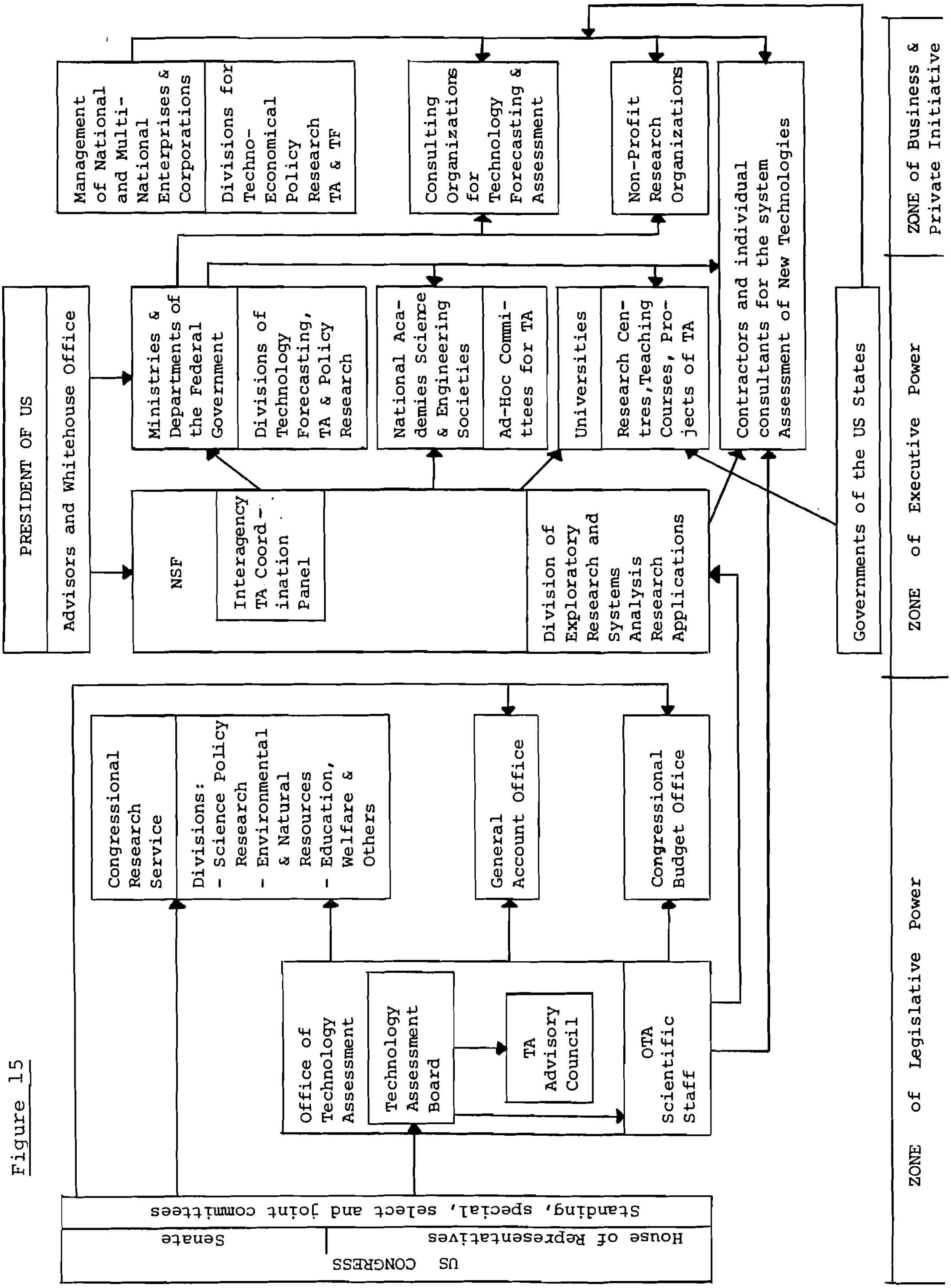
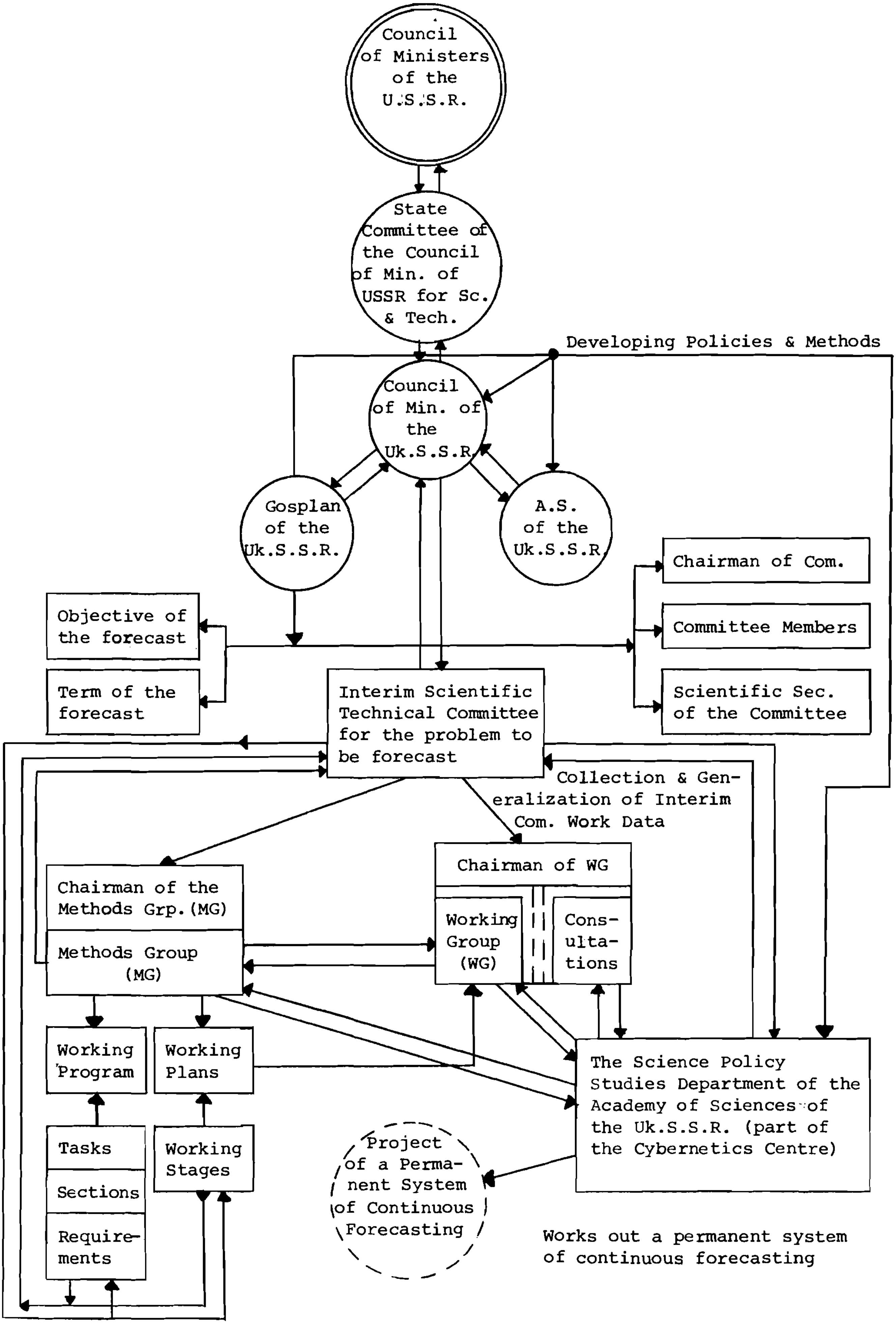
(1) In this case we are speaking about only one facet of production (N.B. See Figure 17 - "Production" with star *) i.e. adoption of ST results.

Figure 15



PRESIDENT OF US
Advisors and Whitehouse Office
Management of National and Multi-National Enterprises & Corporations
Divisions for Techno-Economical Policy Research TA & TF
Consulting Organizations for Technology Forecasting & Assessment
Non-Profit Research Organizations
Contractors and individual consultants for the system Assessment of New Technologies
Ministries & Departments of the Federal Government
Divisions of Technology Forecasting, TA & Policy Research
National Academies Science & Engineering Societies
Ad-Hoc Committees for TA
Universities
Research Centres, Teaching Courses, Projects of TA
Governments of the US States
NSF
Interagency TA Coordination Panel
Division of Exploratory Research and Systems Analysis Research Applications
Congressional Research Service
Divisions: - Science Policy Research - Environmental & Natural Resources - Education, Welfare & Others
General Account Office
Congressional Budget Office
Office of Technology Assessment
Technology Assessment Board
TA Advisory Council
OTA Scientific Staff
Standing, special, select and joint committees
House of Representatives
Senate
US CONGRESS
ZONE of Business & Private Initiative
ZONE of Executive Power
ZONE of Legislative Power

Figure 16 ORGANIZATION FOR SANT IN THE UKRAINIAN SSR



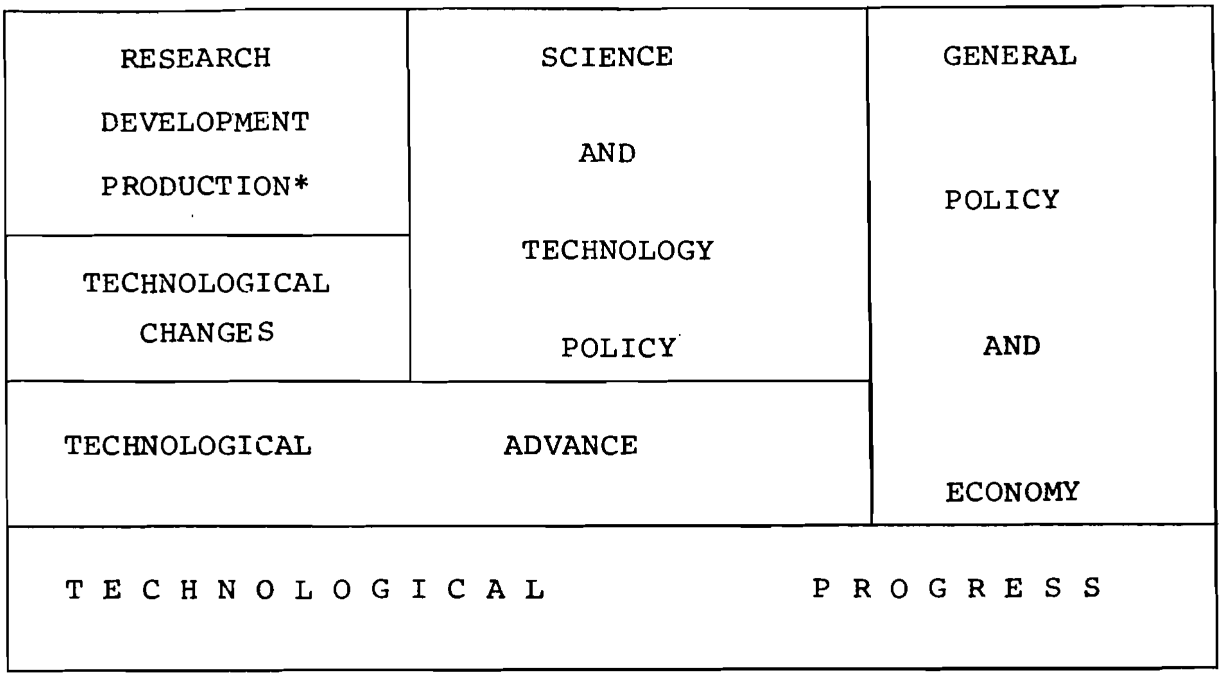


Figure 17

process of R & D) gives a broad range of effects. Ideas about these effects are quantitatively and qualitatively different according to their time-horizon. Comparison of the assessments of effects with estimates of the expenditures for their emergence gives data on effectiveness - one of the most important elements of SANT. A broader set of systems assessments of new technologies is obtained as a result of the analysis of such data in the context of needs and values, expressed within the system of science and technological policy.

Management of the processes of forming and implementing ST policy, including the acquisition, distribution, and utilization of technological results, is otherwise known as the management of technological advance.

In the case in which we use criteria, priorities, and ideas about needs and values - including data from the sphere of socio-economic and general state policy - and in which we also examine the whole range of profound influences on society exerted by the primary and secondary effects of the use of technological innovations, we have grounds to speak about technological progress. Here we are discussing the problems of the social management of technological progress in the largest possible sense.

4. INFORMATIONAL MODEL OF SANT

The proposed interpretation of the management of ST progress is the basis for a structural-informational model of the generation and utilization of SANT. Figure 18 shows the functional interactions and informational connections among the basic elements which are included in the subject of our research. The basic idea of this model is that:

> information about the dynamics and quality of development of technology is one of the most important prerequisites for wise management of technological progress.

This idea is also the basis for integration of the two underlined elements within our research task in IIASA.

The interconnections among the elements of "decision making" shown in the illustration have fundamental significance for the conception of SANT being developed here. One of these elements is the management of technological changes. The following are typical cases of such management:

- guidance of the activity of complex organizations which are engaged in R & D cycle;
- monitoring of a goal-oriented program of R & D; and
- management of the "life cycle" of a particular technological system - from the setting of the task for its creation, through many stages of research, development, experimentation, manufacture, utilization, modernization of the functioning technology, and finally replacement of the given technology by another which is more advanced.

The basic content of SANT is defined in this case both by the specific professional work carried out at time t_2 (usually of an engineering nature), and also by the possibilities for obtaining systematically coordinated assessments of other data distributed in time. A SANT performed at time t_i is based on data about one's own and others' past experience; about existing

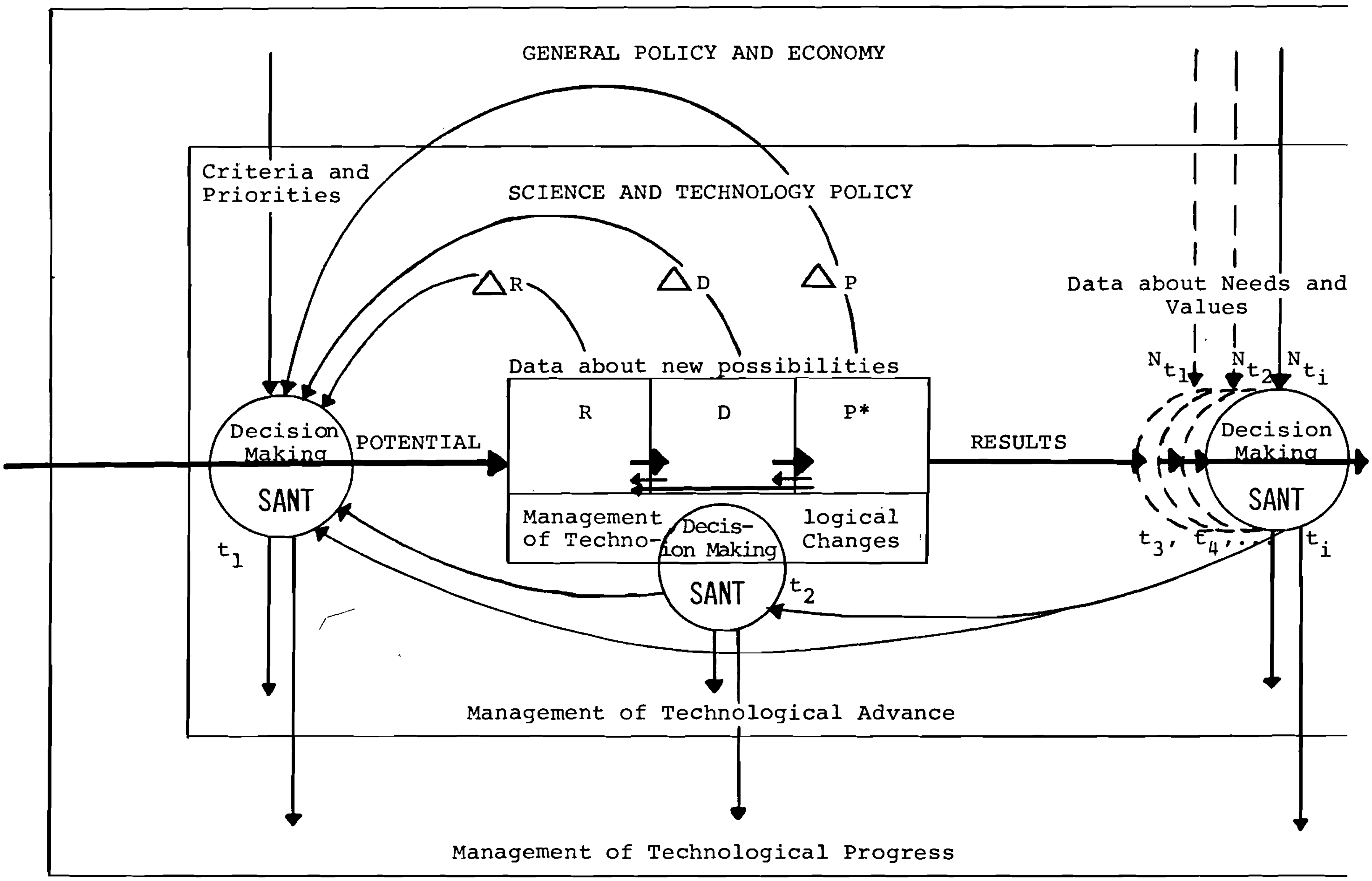

GENERAL POLICY AND ECONOMY
Criteria and Priorities
SCIENCE AND TECHNOLOGY POLICY
△R
△D
△P
Data about Needs and Values
Data about new possibilities
R
D
P*
Decision Making
SANT
POTENTIAL
RESULTS
Management of Techno-logical Changes
Decis-ion Making
SANT
t1
t2
t3, t4, ...
ti
Nt1
Nt2
Nti
Management of Technological Advance
Management of Technological Progress

Figure 18

needs and resources; about operative criteria and priorities; about possibilities newly created by science, technology and production; and other data. A SANT performed at time t_1 is based on data about expected effects, consequences, and effectiveness; about dynamically changing future demands and value systems; about forecasted characteristics of competing (alternative) technologies; about the dynamics and structure of needed resources; etc.

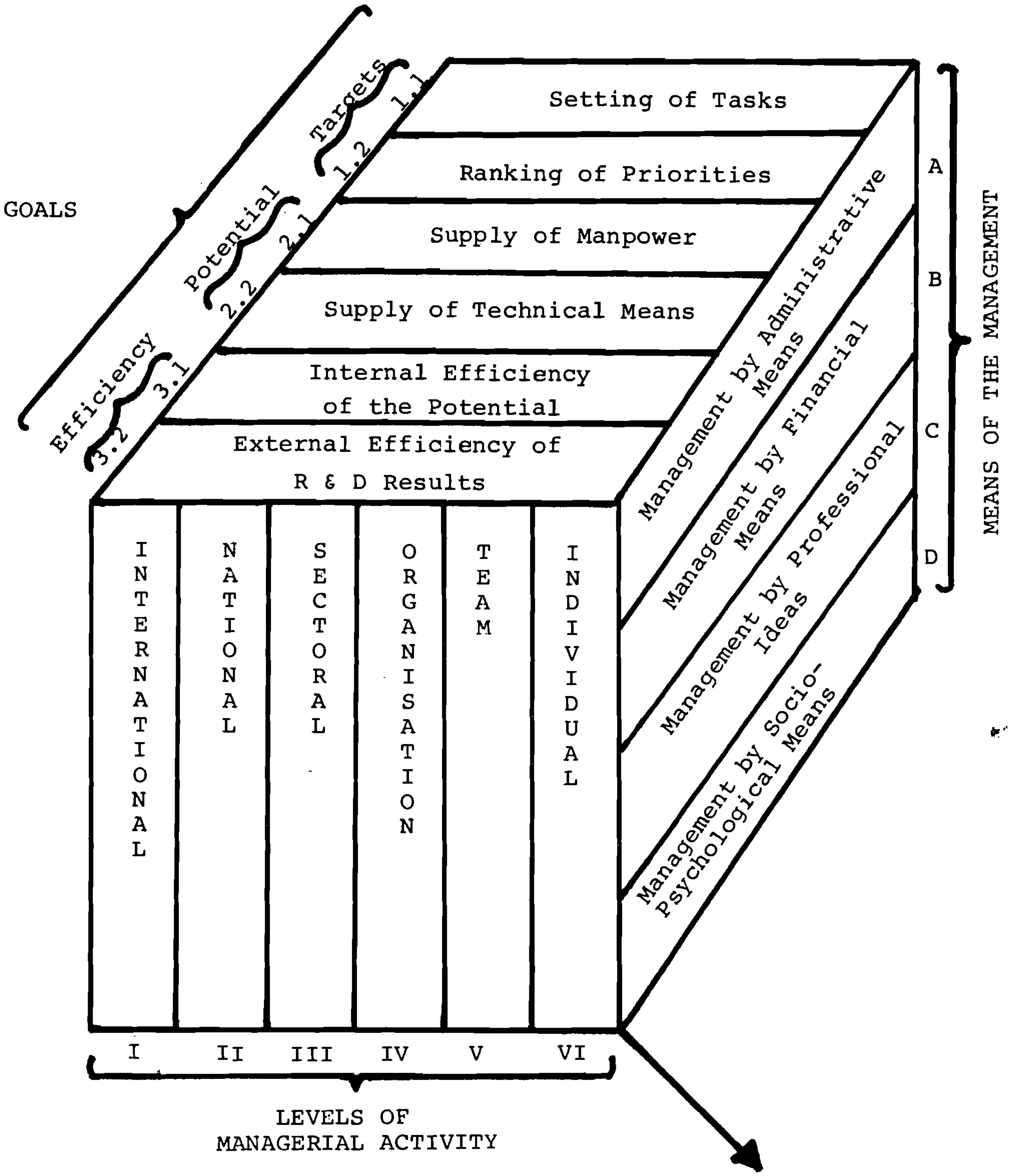
In the case of management of ST advance, there occurs an iterative process of mutual supplementation and substitution of SANTs performed at times t_1, t_2, ..., t_i. For example, in the case of decision-making about the distribution of resources for a planned complex of ST work, we are at time t_1, and all "feedback" from SANT at points t_2, ..., t_i must in point of fact be forecasted. The same applies to data about new possibilities of science, technology, and production, and estimates of future needs, demands, and values. However, in the case of solving a management problem of summing up results, we are at point t_i, and $SANT_{(t_1)}$ and $SANT_{(t_2)}$ have for us the character of data preserved in the system's memory.

We should note, therefore, that both SANTs themselves, performed at any moment in time, and also decisions taken on the basis of them, not only influence (through information) the object of management; they also transform the experience of ST policy, and they enrich the experience which is being accumulated in the broader spheres of socio-economic policy. The streams of data which have their source here - data necessary for the management of ST progress - can also have their source in the systems assessments of various kinds of social and economic indicators (which we shall not discuss).

The structure of demands placed upon the content of SANT comes from the practice of making decisions based on these assessments. For examination of these demands, we use a morphological box of the structure of decisions concerning the management of ST activity.[1] In Figure 19, this box is presented with three class-

1 This approach is set forth in greater detail in [14].

Figure 19 MORPHOLOGICAL BOX FOR DECISION MAKING IN SCIENCE AND TECHNOLOGY POLICY



ificatory axes: the goals of management decisions; the means of affecting the managed system, called for by these decisions; and, naturally, the levels of management corresponding to the object of management.

Both practical experience and theoretical investigations into the problems of ST management justify the system's demands upon the routine of management, which in the given case can be formulated in the following way: Management can count on stability and increasing success only if, in its decisions and implementations, it achieves systematic agreement:

(a) Among the choice of goals, the means for their effective achievement, and the resources (potential) required for this;

(b) In the harmonious use of the whole complex of management methods (administrative, economic, professional-technical, and social-psychological); and

(c) Among the applications of these principles in practical acts and procedures of management on the various levels of ST activity.

It is natural that SANT, as a specialized kind of information for the substantiation of management decisions, must:

- contain data for judging the goals of ST activity, the levels and effects of their achievement, and the needed or expended resources; and
- reflect experience with and demands for improvement of the organizational (legal), economic, "engineering", and socio-psychological regulation of ST activity.

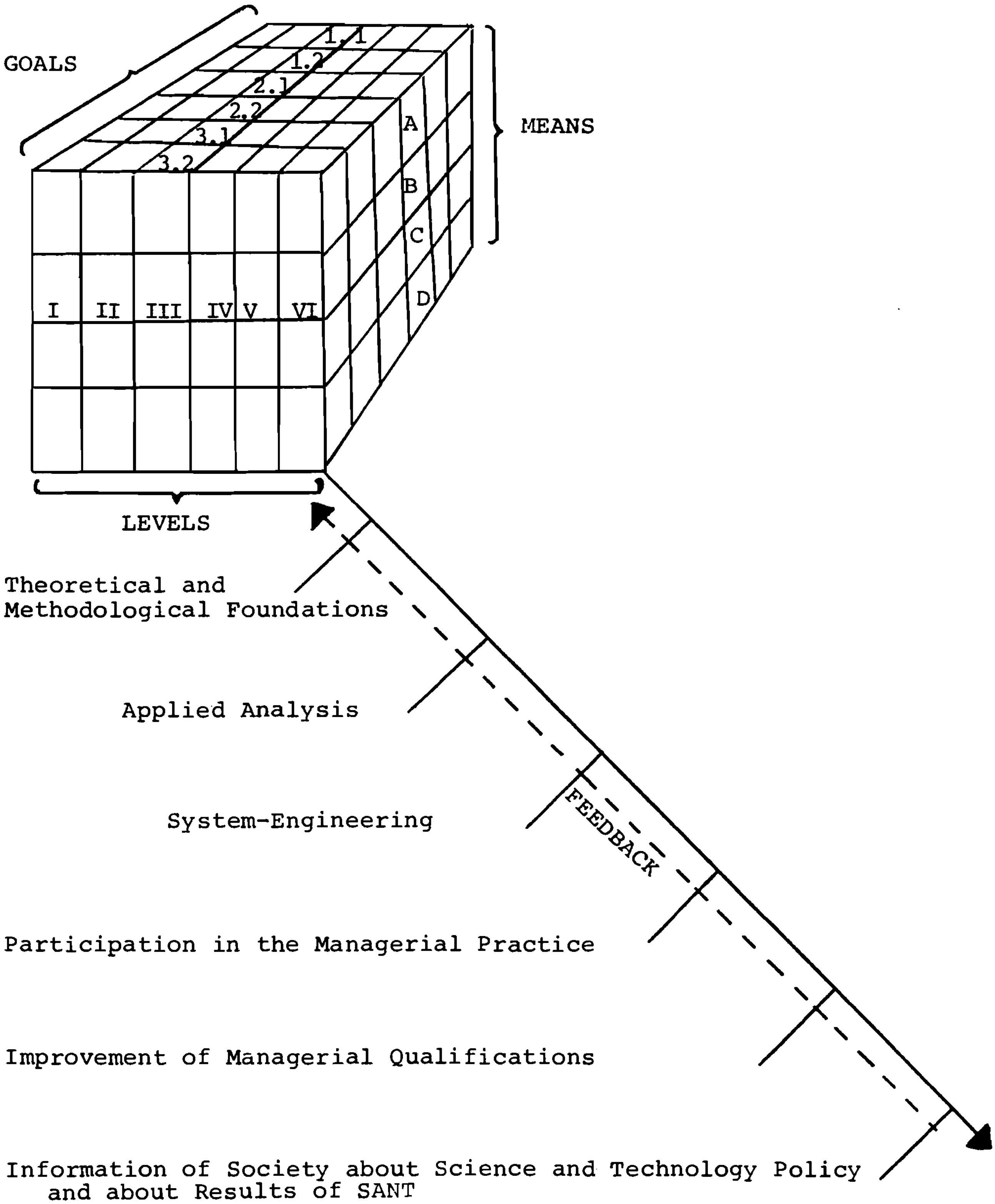
The information contained in a SANT must characterize these aspects of new technology from an intersectorial viewpoint and for various time horizons.

If to this we add the obligatory scientific demands of quantification, comparability, and systematic presentation, then the methodological difficulties of this area of applied systems analysis become even more obvious.

However, under insistent pressure by the demands of life, these difficulties have not halted either the practitioners of management, who are formulating and using SANT on a broad scale, or the system analysts, who have placed their professional knowledge at the service of solving this problem.

The types of activity carried out by specialists in applied systems analysis regarding SANT and the management of ST progress as a whole are shown in Figure 20. Each concrete researcher or group usually concentrates on one or a few kinds of activity. In every case, however, they are called upon to perform an exceptionally important function - to provide, by their analytic methods, feedback from the experience of life (including also "future experience") into the practice of management.

Figure 20 KINDS OF ACTIVITY FOR SPECIALISTS OF SYSTEMS ANALYSIS



5. THE METHODS AND MODELS FOR STUDYING ORGANIZED TECHNOLOGY

The methodological arsenal for applied systems analysis of problems of this kind is exceptionally varied. Every list of existing methods of analysis inevitably turns out to be incomplete. In Figure 21 is presented one of the latest lists according to data presented at the Second International Congress on Technology Assessment (USA, October 1976).[15] It lacks, as we can see, some methods which have been attracting more and more attention lately - such as the possibility of Fuzzy Logic and Rene Thom's idea of "catastrophe theory".

It would also be possible to indicate other methods which deserve testing on the proving ground of SANT. Some of these methods have already shown their usefulness relative to all the elements of SANT (= TF + TA + AT + ERD + STP). Others, however, have so far been tried only in particular cases.

Our general assessment of all known methods is this:

> There is not and cannot be one universally good (and "unified") method; but there is also no basis for saying that any methods are hopelessly bad for all cases.

The problem is to find systematic means of using a selection of methods which mutually compensate for each other's weaknesses.

This is the same as the problem of creating a reliable system from relatively unreliable parts. We know of at least one example of the successful solution of this problem (Homo Sapiens!) and this inspires hope.

In addition to all these difficulties every area of SANT is feeling the problem of noncomparability, and often even the absence, of the necessary initial data. This problem is particularly serious in light of the possibilities which have opened up in recent years for modeling and computerization of methods in this area.

Steps in an assessment of technological systems →

Study techniques	1 Structuring the problem	2 The systems alternatives	3 Possible impacts	4 Evaluating impacts	5 Identifying decision makers	6 Identifying possible action options for decision makers	7 Parties at interest	8 Macro systems alternatives	9 Exogenous variables state of society	10 Conclusions and recommendations	11 Participation of parties at interest	12 Presentation of results
Historical surveys	●	●	●		●	●	●	●	●	●		
Input/output	●			●			●					●
Compilation of prior work	●	●	●	●	●	●	●	●	●	●		
Cost-benefit	●			●			●					●
Systems analysis	●	●	●	●		●		●				
Risk-benefit	●			●			●					●
Systems engineering	●	●	●	●				●				
Simulation	●	●	●	●			●		●		●	●
Expert panels, workshops	●	●	●	●	●	●	●	●	●		●	●
Modeling	●	●	●	●			●		●		●	●
Hearings	●	●	●		●	●	●	●	●	●	●	●
Interpretive structural modeling	●				●		●			●	●	●
Field or on-site investigation	●		●	●	●		●				●	
Signed digraph	●		●	●	●	●						●
Trend extrapolation and analysis			●	●					●			
Physical models			●	●								●
Delphi	●	●	●	●	●	●	●	●	●		●	
Scenarios/games	●	●	●	●	●	●	●	●	●	●	●	●
Cross impact	●	●	●	●		●			●		●	
Moot courts			●	●	●	●	●			●	●	●
Check lists	●	●	●		●	●	●					●
Telecommunication participation			●	●	●	●	●		●	●	●	●
Morphological analysis	●	●						●				
Syncons			●	●	●	●	●	●	●	●	●	●
Historical analogy	●		●	●	●	●	●		●	●		
Survey techniques				●			●		●	●	●	●
Decision/relevance tree	●	●	●	●	●	●						●
Ballots				●			●		●	●	●	●
Fault tree	●		●	●								●
Decision theory				●		●				●		●
Scaling				●					●	●		●
Brainstorming	●	●	●		●	●	●	●	●	●	●	
Graphics				●							●	●
Judgment theory				●		●				●		
Dynamic modeling	●	●	●	●					●	●		●
KSIM	●	●	●	●				●	●	●	●	●

Figure 21 ELEMENTS IN A COMPREHENSIVE TECHNOLOGY ASSESSMENT (J. Coates)

In Figure 22, the situation which has taken shape is presented[1] in the following form. There exists a significant amount of uncoordinated "primary data" from scientific sources, including data from national and international statistics. These are only partly oriented toward the aims of SANT, but they can be valuable if used with sufficient care. A quite significant number of regular statistical samplings and computerized data banks ("secondary data") are already known. And the many organizations which regularly conduct SANTs have accumulated a rich archive of "transformed data", among which expert estimates are characteristic for this area.

Models (M_1, M_2,...,M_i) - which are being worked out and utilized for analysis of the dynamic development and assessment of the systems quality of new technologies - usually use one or another type of initial data, or in some rare cases a combination of types.[1] Especially promising in this area is the tendency toward integration of models both through commonality of apparatus and data, and through the systematic inclusion into the models of a broader set of organizational, economic, engineering, and socio-psychological characteristics of technological systems and ST activity.

As a conceptual basis for the integration of various technological-change-related models Prof. M'Pherson proposed to use a model of technological behaviour responding to economic, social, environmental and technological pressures, including its own self-induced influence.[16]

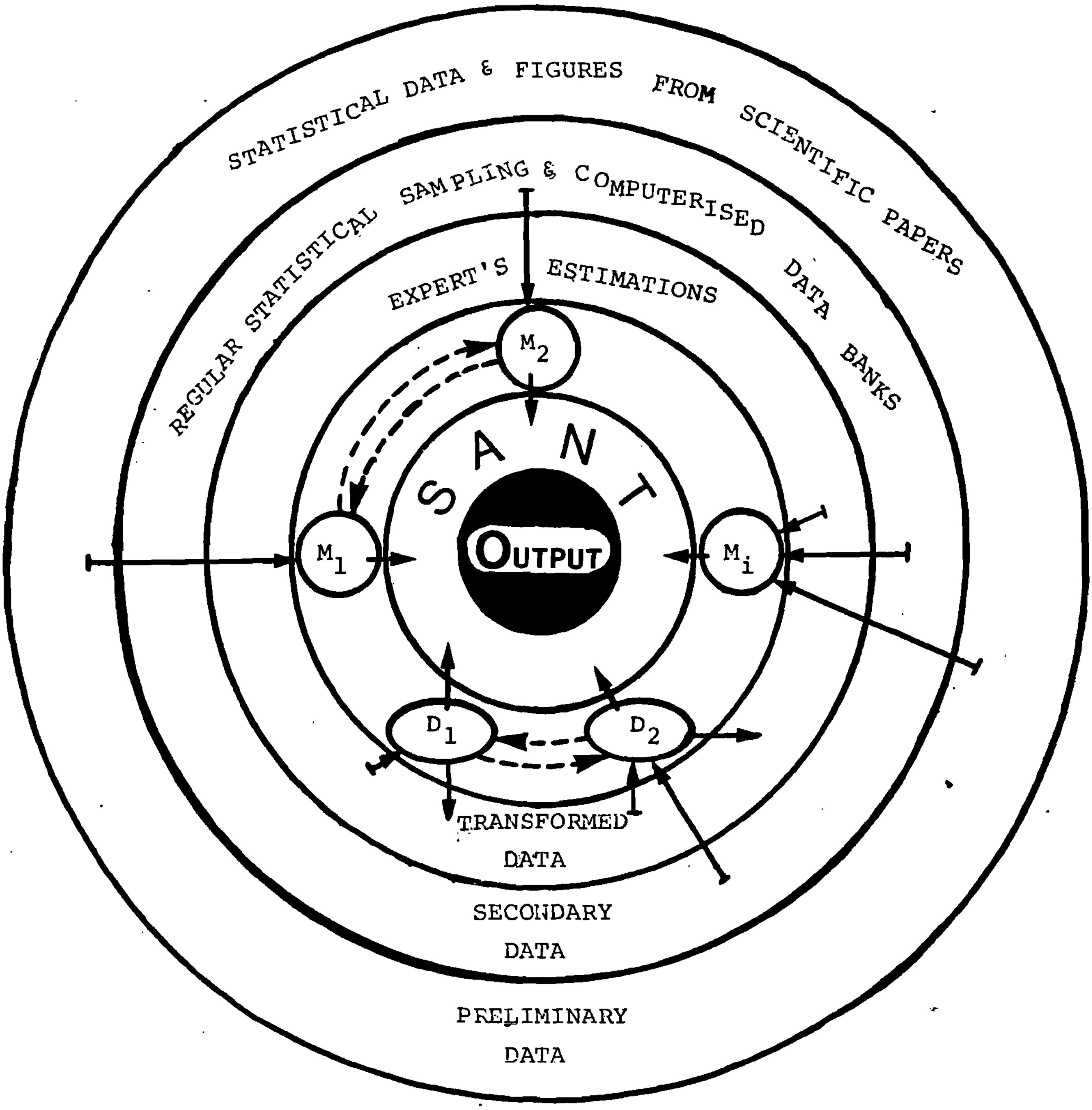
The model was referred to as the Integrated Model of Technological Change (IMTC).[2] See Prof. M'Pherson's diagram - Figure 23. In connection with this diagram Prof. M'Pherson wrote:

---

1 We are using the method of presentation accepted in IIASA's methodological project (R. Pestel).

2 As is clear from Prof. M'Pherson's paper [16], he mentions not only "technological changes" but also ST progress in the broad meaning of this term.

Figure 22



$M_1, M_2, \ldots, M_i$ - Models

D_1 - Dialogue with networks of experts through computer

D_2 - Man-machine dialogue and simulation

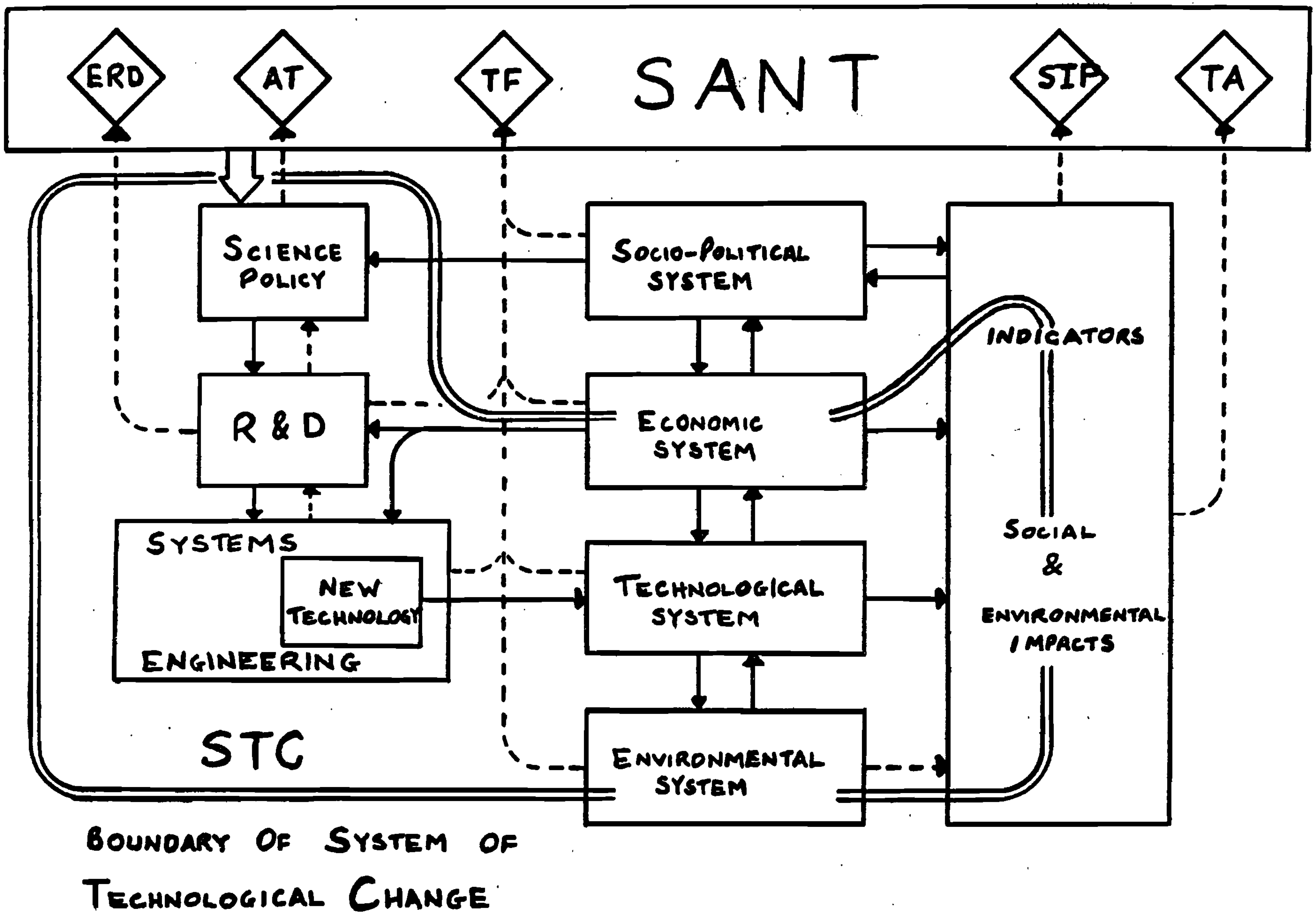


Figure 23 Sant and the System of Technological Change

"SANT is related to a general conceptual structure for the overall system of interacting and interdependent subsystems that go to make up the Socio-Technological" system. This structure provides the conceptual framework from which the IMTC is being developed. The boundary of the System of Technological Change (STC) is drawn in the figure to enclose (or semi-enclose) those subsystems that are specifically relevant to the study of Technological Change.

IMTC attempts to model, or simulate, all processes inside the STC boundary; it also operationalizes much of the evaluatory procedure inside SANT. Tanken together SANT + IMTC should provide a powerful aid to decision-making in the Science Policy field."

A number of models and methods were assessed by Prof. M'Pherson and some independent approaches to their formation was developed. This line of investigation is very important as well as difficult. Here, there is room for scientific efforts to be international in scope.

For the present stage in the development of applied systems analysis, it is vital to recognize that this kind of scientific activity, by its very principles, must be organized as a regularly performed procedure - as an I T E R A T I V E P R O C E S S which permits us to react to the naturally dynamic character of the factors which are taken into account, and which makes possible the elimination of weaknesses in existing methods by means of successive approximations. In Figure 22, two basic classes of systems-engineering (computer-based) instruments are shown which permit practical realization of the above-named procedures.

D_1 represents "dialogue systems" of the "computer conferencing" type, in which the computer is used as a means of organizing a dialogue among territorially distributed experts and groups of systems analysts.

D_2 denotes dialogue systems in which the computer itself (with its data banks, programs, computational power, memory of current decisions, and well-developed means for input and output of results) performs as an active participant in the dialogue. The "man-machine" dialogue is supplemented, in case of work via networks, by dialogues of the "machine-system" type. Special forms of work are also known in which collectives of experts participate in the formation of SANT through a dialogue involving "man-machine-community of specialists".[1] Obviously, to provide continuity and communications between systems of type D_1 and D_2 would have good prospects.

By now, a significant amount of experience has been accumulated regarding the presentation, in model form, of the interdependencies involved in the problem-area of ST policy. In all honesty, however, we must note that:

- in most cases, these efforts have been exploratory in character and have not gone beyond mathematical experimentation;
- the majority of the proposed models have operated with one certain class of methods for managerial influence upon the system under investigation (well-known examples include economic, informational, and organizational models); and
- the models have usually been stratified according to levels of management (technological change, technological advance, and technological progress), and the task of integrating these levels is only beginning to receive strict formulation.

The author of this report has, for the past ten years led a team of specialists on the applied systems analysis of ST management problems.[2] This area is known in the USSR as naukovedenie, or science policy studies.

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1 Our experience in modelling and main ideas of the INPROGS system, will be characterized below.

2 The Sector for Complex Problems of Naukovendie, of the Cybernetics Institute of the Ukrainian Academy of Sciences (Kiev). In this branch there are three structural scientific divisions, totaling about one hundred staff members: (1) a department which specializes in technological forecasting and systems assessments of technological prospects; (2) a department which specializes in problems of forecasting needs for ST potential and for management of its formation; and (3) a department which specializes in problems of managing R & D, including the creation of special management information systems for this purpose.

6. THE CASE STUDY OF A MACROMODEL FOR ST POLICY

In the formation of long-range and five-year plans for ST development, and also in the process of current management of the implementation of these plans, problems are constantly arising in regard to the balancing (coordination) of ST policy decisions with the aggregated indicators of social and economic progress - in the name of which ST activity is carried out. In connection with this, a task was posed for working out a model which reflects the interconnection of such variables as the following:

- National income, m, in percent relative to a base year, or M, in absolute figures (milliards of rubles). Here X indicates the statistically evaluated rate of annual growth of M.
- An economic estimate, l, of the growth in ST potential (that is, the annual appropriations for ST activity) in percent relative to a base year, or L, in absolute figures (milliards of rubles). Here Y represents the statistically estimated rate of annual growth of L.
- An indicator of the intensity of the process of transforming "input signals" in the system (i.e. the growth of ST potential) into final socio-economic effects. As such an indicator, "τ" was chosen - the delay (in years) between the appropriations and the outputs into national income.
- The time horizon of projected decisions - the time variable t (in years).

In the development of the model,[17] several basic ideas were used from econometrics and from the methodology of systems-management models with delay parameters. Also, a qualitative and quantitative analysis was made of existing statistics on ST advance. The mathematical description of the model was obtained on the basis of hypothesis that the most important <u>measure of the effectiveness</u> of the systems under examination is, in the final analysis, reduction in <u>the necessary time</u> of economic reproduction. The model turned out to be similar to a single-sector Harrod-Domar model with delayed return on investment without discounting.[18]

$$M_{(t+1)} - M_{(t)} \cong \frac{dM}{dt} = \eta(t,\theta)\ L\ (t-\theta);$$

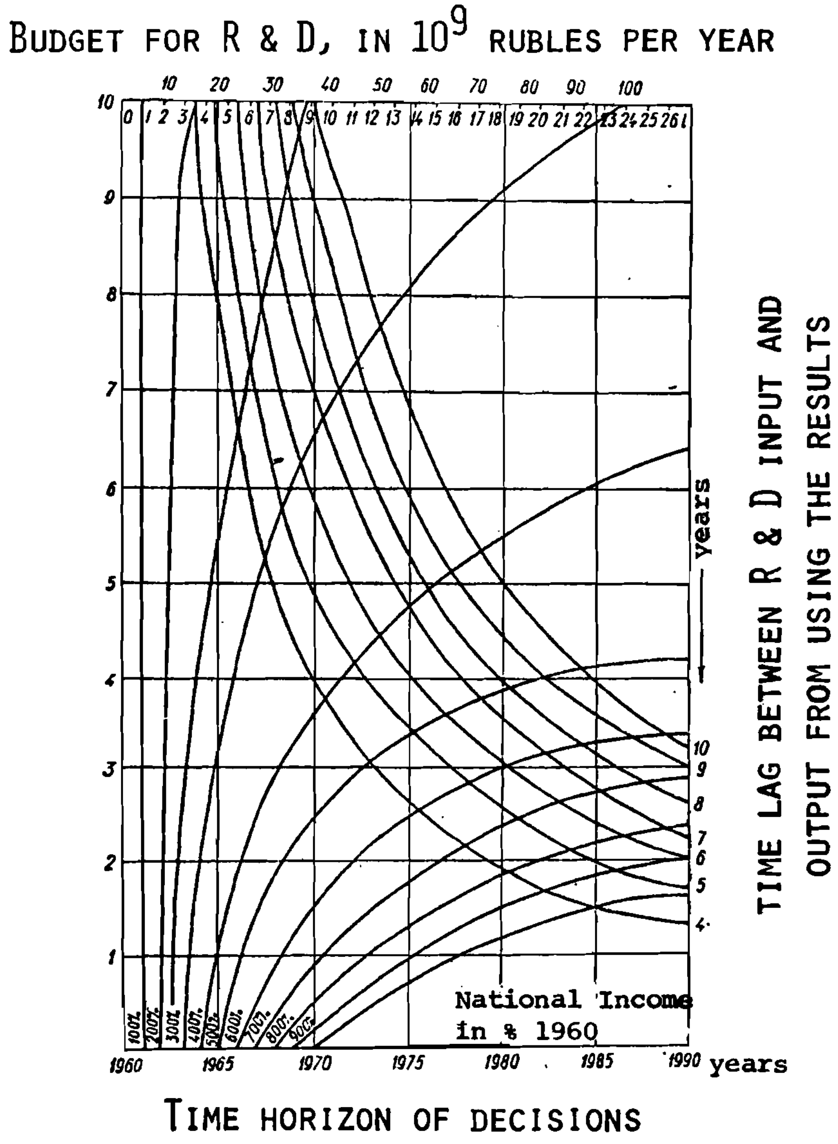
where $\eta(t,\theta)$ is a proportionality factor, a so-called "norm" for return on investment, and θ is the interval of real time needed for this return to be obtained.

$\theta = \theta_1 + \theta_2 + \theta_3$, where θ_1 is the delay in return on investment caused by the mean duration of R & D; θ_2 is the same, caused by the time required in the given national mechanism for technology transfer; and θ_3 is the same, caused by the level of intensity, characteristic for the given country, of the productive utilization of technological innovations.

The basic organization-management possibilities for accelerating national income reproduction through factors of technological progress were investigated and statistically evaluated. In particular, sets of absolute quantities τ (that is, the time required for realization of the applied potential of technological results) were obtained for various countries and various periods of development.

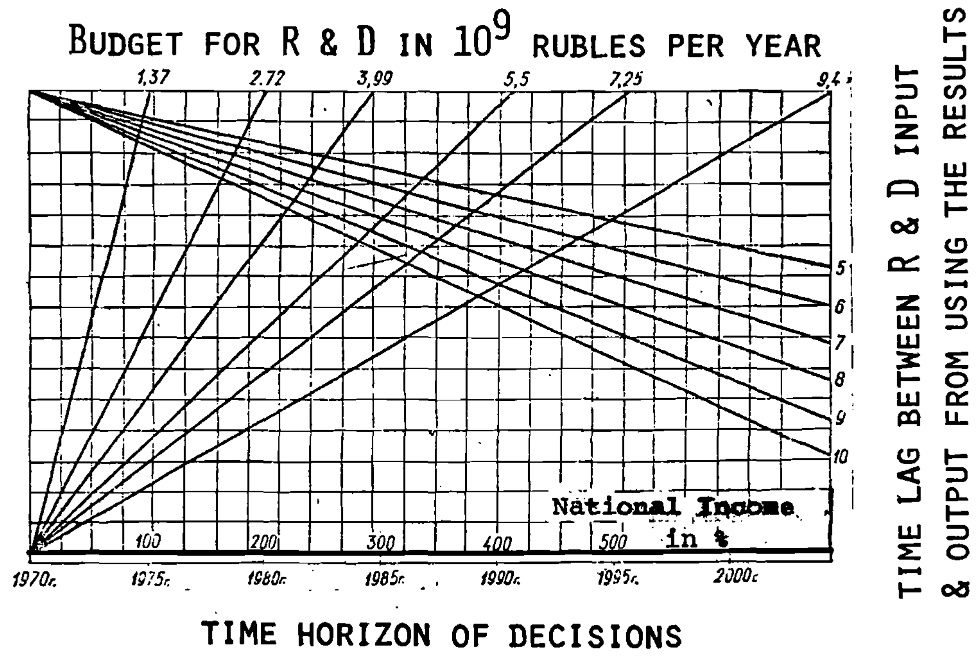
Using statistics for the USSR in the years 1961-1970, an estimate of $\tau \cong 9$ years was obtained. This coincides well with data obtained by other authors using different methods. Also well-known is the series of publications on the statistical analysis and evaluation of technological progress begun by the pioneering work of E. Mansfield.[19] In these publications, similar estimates of "lag" are repeatedly encountered, based on historical and statistical data relative to the experience of various technically developed countries. Typical estimates of τ range from 6 to 14 years.

The model developed here has been implemented in the form of computer programs. For convenience in preliminary approximate calculation, we can also use special nomograms which graphically illustrate the character of the internal dependencies among variables. In Figures 24 and 25 are presented



THE MACRO MODEL FOR SCIENCE AND TECHNOLOGY POLICY IN USSR

Figure 24



THE MACRO MODEL FOR SCIENCE AND
TECHNOLOGY POLICY IN THE UKRAINIAN SSR

Figure 25

nomograms of this type, which were prepared for use in prognostic calculations and the balancing of variants of planning decisions in the USSR and the Ukrainian SSR.[1]

Four classes of urgent practical problems have been discussed with the help of these models.

1. To substantiate an hypothesis about the needed level of funding for ST activity, when there is an intention to set a definite task for raising the level of national income (t, m, τ are given, and L is to be estimated).

2. To substantiate a prognostic supposition about the statistically expected increase in the level of national income, given imposed limitations on the budget for ST work and the already established level of intensity of the cycle of obtaining and implementing technological results (L, t, and τ are given, and m is to be estimated).

3. To prepare data for drafting variants of plans about the possible time-spans needed to achieve certain socio-economic goals, given the statistically expected contribution to solution of this problem which will be made by technological progress with its characteristic level of intensity in the engendering and transmission of new technology (m, L, and τ are given and t is to be determined).

4. To investigate how strenuously tasks for perfecting the organizational and economic mechanism for technology transfer and for acceleration of the whole cycle of ST work must be posed, if supposition about final economic goals and limitations on budgetary structure are already known (m, t, and L are given, and τ must be determined).

In this report we need not present further details of the model. In conclusion, however, it is appropriate to give some attention to one peculiarity of this model, namely its

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1 This kind of model also exists for the conditions of Bulgaria All these models have been used in the practice of forming and analyzing prognostic hypothesis.

orientation toward the generation of systematically substantiated answers to questions of the "what if" type. We are convinced that this approach is extremely valuable in any model which is used for policy planning.

This feature of the model is used in order to formulate clearly and assess critically the systems assumptions (the "if" conditions) corresponding to various alternative forecasts obtained by different methods. It often turns out that these assessments have not been taken into account.

Thus, for instance, the investigator may find an attractive hypothesis M (t_i) developed with a certain projected level of L (t_i). The analysis can show that these two estimates for the time t_i are probable and mutually compatible <u>only</u> if there is an unprecedentedly high level of intensity in the cycle of ST work and technology transfer (e.g., $\tau \leq 4$ years). Balancing of the system of hypotheses, reducing them to the level of the critical estimate (on the order of $\tau \cong 6$-7 years), makes the whole problem if not simple at least realistic.

Such an analysis, performed on the data of various countries, has also made it possible to identify "statistically significant" methods for intensifying the cycle of technological work and technology transfer - that is, methods which have a substantial influence on the final macro-indicators. Among them we can single out (for national ST policy) the rational structuring og the set of "candidate technologies"[1] by scale of utilization, rate and sequence of transfer, etc. We are talking here about the need for more profound substantiation of the "national assortment" of technological systems currently being developed.

For the international scale of ST policy, it is important to indicate that international exchange of new technology (in its various known forms) allows all countries to improve the structure of ST efforts. A significant part of their investments for ST can be diverted into projects having a naturally short cycle of realization. Thus they can intensify the process

1 "Candidate technologies" are R & D findings, the possibility of realization of which (from the physical, chemical, engineering, and other viewpoints) is not doubted by the majority of the specialists.

of technology transfer within the country and raise the effectiveness of technological progress. Both sets of measures must be examined, within the ST policy design, as mutually complementary and connected elements.

7. THE CASE STUDY OF A MODEL FOR THE MANAGEMENT OF TECHNOLOGICAL CHANGES

An Example of a Model for Management of Technological Change. The set of variables included in models on this level differs significantly from the case described above. First of all, systems analysts here are faced with the task of reflecting in the model the problem's cause-and-effect connections and a certain part of its engineering logic. At the same time, the model must also contain other data necessary for decision making relative to organizational management. One such model of technological change was worked out and implemented for the subject area which includes the science, technology and exploitation of computers.[20,21,22]

We set ourselves the task of reflecting in the model the ideas of specialists, quantitative assessments of events and possibilities, and also the qualitative peculiarities of the logic of the development of the chosen ST area. Assessed in the framework of SANT, "technological changes" in the model are related to four levels of scientific and engineering activity:

a) to the sphere of exploratory research, the forming of the "portfolio" of new ideas for further development;

b) to the sphere of applied research and development directed toward discovery of methods for practical use in technology of the already projected possibilities and established principles;

c) to the sphere which seeks economically and technologically effective methods for realization of the results of work at levels "a" and "b" in conditions of real production;

d) to the sphere of technology transfer and the utilization of "technological changes" in regular practice.

The essence of the methodology consists of informational and mathematical procedures for construction and analysis of a basic graph which reflects the generalized perception of a large group of specialists about needs, possibilities, and resources for technological changes in a definite area of R&D (see Figure 19).

The organizers of this SANT use a goal-oriented and multi-stage expert inquiry[1] in striving to clarify and formulate the set of expected and needed events. These events reflect the conditions for achievement of each level of progress in the area. Each such event is accompanied by a system of quantitative estimates (t_j - the expected time of occurance of event j; $P_{ij}(t)$ - the relative probability of the transition of events from condition i to condition j in time t; C_{ij} - an estimate of the cost of realizing the indicated elementary step of technological progress; Z_{ij} - the relative importance of the i-th event as one of the conditions for occurence of event j). The structure of the graph reflects a logical network of cause-effect relations among the set of events included in the graph. The sequence followed in constructing the graph amounts to "extending" some problem (the final goal of the program) from the future down into the present, creating a structure of intermediate events and fixing cause-effect relations among them.

"Technological changes" per se are modeled by means of a combination of several formal transformations of the graph (see Figure 26):

I - introduction (or removal) of events which reflect possibilities for achievement of previously established goals;

II - introduction of new formulations of conditions or description of new sub-goals;

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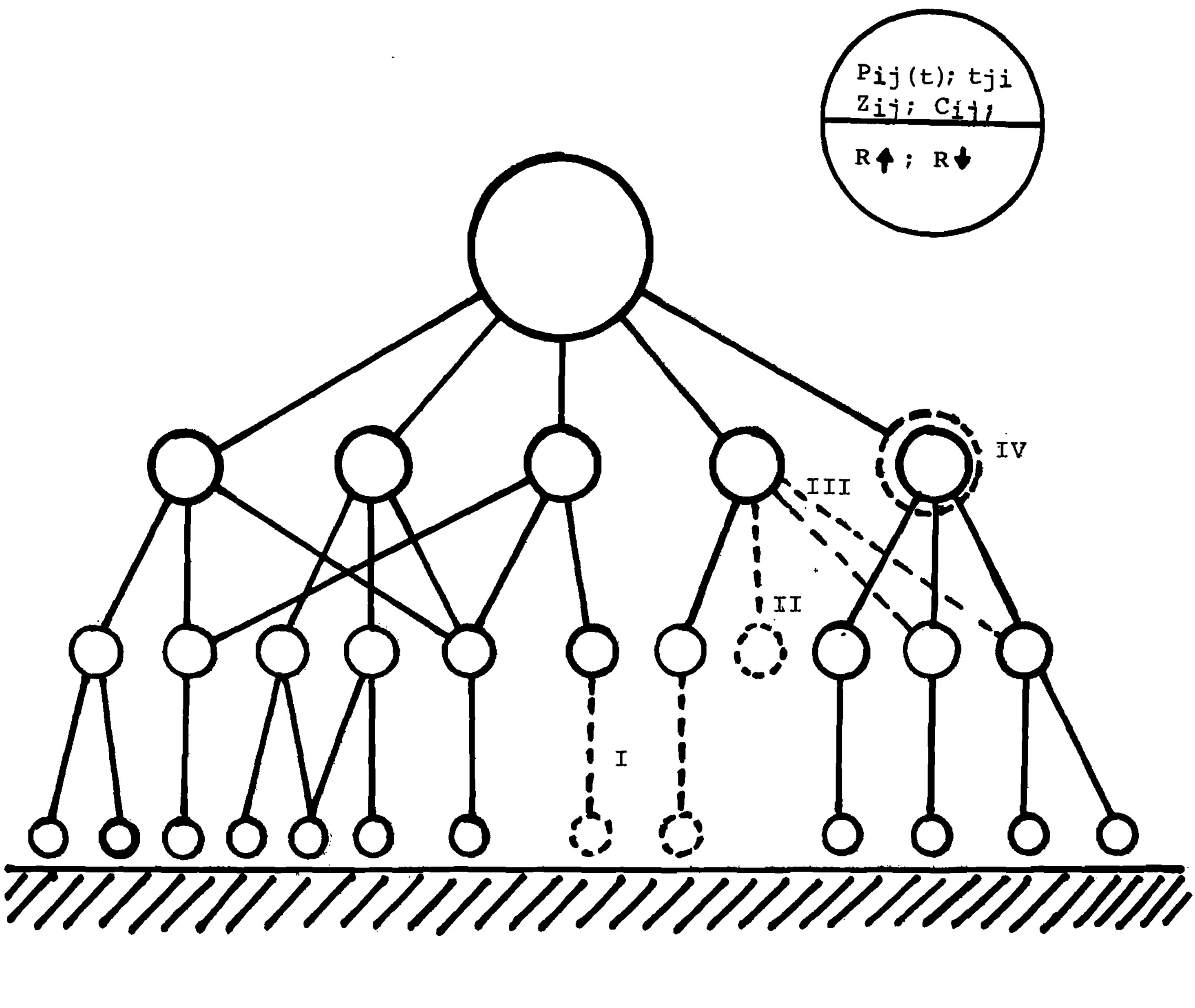
1 In working with experts, we take account of positive experience in the development and application of the Delphi method (see last presentation in [23]). At the same time we have tried to avoid a number of traditional weaknesses of this method. The procedure which we have constructed for permanently conducted expert estimations is an example of the "non-conventional Delphi" - see [24].

Figure 26

MODEL OF TECHNOLOGICAL CHANGE



III - reconstruction of the network of connections among the events (establishment of new ones or liquidation of existing ones);

IV - changes in the set of quantitative characteristics of the events in the graph.[1]

The methodology based on these ideas has received the name "Programmatic Methodology for Technological Forecasting." In 1971 it was approved by the collegium of the State Committee on Science and Technology of the USSR as the basic methodological instrument for SANT. Since 1975, the CMEA countries have had a Joint Methodology for Multinational Work in Technological Forecasting created on the basis of the "Programmatic Methodology" but utilizing the CMEA countries' experience with forecasting.

With the use of these methodologies, and in various technological areas, assessments are now being obtained which are practically related to all the elements of SANT: prognostic technological data; estimates of the possible influence of technical achievements; comparison of variants of technological policy; comparison and evaluation of R&D projects at the stage of their inclusion in plans and programs; and advance estimation of the ST potential which could be drawn in for performance of expedient efforts.

The practice of working with the model can be characterized in the following way.[2] A representative sample of experts, often numbering in the hundreds (with variable membership in each round of the inquiry), puts forward technological conditions for the achievement of a certain level of goals and subgoals.

1 An important element in the information included in this system of knowledge is data about specialists and organizations which are ready to perform different tasks or are relevant to such a type of planning activity.

2 This presentation is based on the monograph [22] cited earlier.

The procedure of expert estimation continues until it reaches such conditions as the use of already extant R&D results, the implementation of an already patented solution, the introduction of an innovation which can be bought on license, etc. This operation is known as "grounding" the graph.

The networks of hypotheses which are constructed in this way include thousands of events and serve to systematize a great deal of information about technological ideas and possibilities. Such a formalized presentation of the generalized opinion of specialists possesses a number of interesting and non-trivial properties.

First of all, the graph contains important information which no one specialist by himself possesses - not even the most highly qualified and erudite. This information is subject to structural analysis and calculations through the application of quantitative methods.

A program has been developed and implemented on computer which allows us to determine the optimal path for achievement of the final goal (optimal in terms of time, cost, etc.), and also the importance of various events and chains of events (variants) for solution of the initial problem. In addition, we can quantitatively evaluate such properties for technological policy alternatives. The computer also performs some rather cumbersome operations for putting the information in the graph into good order, such as liquidating "dead ends" and loops, and other operations necessary for the subsequent analysis and calculations.

Computations are carried out according to the formula:

$$q_{t_k}(j) = \Sigma \, q_{t_o}(i) \, P_{ij}(t),$$

where $q_{t_k}(j)$ is the absolute probability that at time t_k the system will be in condition j; $q_{t_o}(i)$ is the absolute probability that at time t_o the system will be in condition i; and $P_{ij}(t)$ is the relative probability that the system being forecasted will, by time t, move from condition i to condition j $(i,j = 0,1,\ldots,N;$ $K = 0,1,\ldots,n)$.

Conditional estimates of the probability of achievement of the subgoal S_i by the time t are calculated as proposed by V. Glushkov:

$$P_i(t) = \frac{1}{R_i} \sum_{E=1}^{E=l} R_{iE} \cdot P_{iE}(t-t_{iE}) \cdot P_{iE1}(t-t_{iE}) \cdot P_{iE2}(t-t_{iE}) \ldots P_{iEN}(t-t_{ie});$$

where P_{iE} is the probability of achievement of subgoal i estimated by expert number E; l is the total number of experts in the group; P_{iE1}, Pi_{E2} ... P_{iEN} are the probabilities of accomplishment of a chain of intermediate events (1,2...N) suggested by expert E as conditions for achievement of the subgoal i; R_{iE} is a weight coefficient for weighting an estimation made by the expert E about subgoal i; and R_i is the general weight coefficient of the expert group.

There are also other computational formulas and algorithms for different specific compositions of data and different functions of SANT. They make it possible to perform a qualitative analysis of the chains of interconnected events from a common viewpoint and to carry out quantitative computations of their characteristics with compatible estimates. This analysis embraces data about goals and subgoals, paths to their achievement, the resources required for this, and the existing ST potential. One of the most important properties of the model examined here is the possibility of working with the graph with the help of a new type of dialogue - a dialogue between "man, information system, and the community of specialists".

As a natural reflection of the logic of the process of technology creation, each event is connected not only with that nearest to it, but through that to the subsequent events. Thus the attainment of the final goal depends in various ways on the individual fates of the separate events. The graph allows the analysts to play out the situation and thus test a series of hypotheses of the type: what kind of consequences could be expected in the program from occurrence of event j in the period $\pm \Delta t$; or how does the absolute probability of achieving goal S change if the relative probability of transition from event i to event j turns out to equal zero (failure).

Owing to the specific character of technological change as an object of SANT, at any given moment there are a certain number of events in the graph for the realization of which none of the experts could suggest conditions. In the real course of performing ST work, possibilities for further development of the graph become clearer (both under the influence of world experience and on the basis of one's own R & D). These possibilities reveal the ways of completing ("grounding") those branches which could not previously be grounded. At the same time, ideas about structural connections and previously suggested quantitative estimates for other events are made more exact.

Under the influence of information newly entered into the system, periodic revision is performed on the previously made estimates, forecast variants, and decisions. The results of such an analysis can give the system "reason" for re-examining one or another part of the plan of practical actions and for discussing the newly formed situation on an informal level.

In every case, a valuable managerial possibility is the fact the agency responsible for decision making can know the "cost of error" or the "cost of nonoptimality" in decisions taken under the pressure of external circumstances.

Use of the model's indicated capability for "self-improvement" and "self-instruction" opens up especially favourable prospects for formation of a new methodology for the planning and management of ST changes. Its basic features are as follows:

- providing a single set of decisions, embracing research work on various levels, development work, and the technical improvement of production;
- making key management decisions under conditions of fuller knowledge and with the use of calculated analytic bases;
- carrying out planning as a permanent procedure, i.e. at any moment of the 15 year plan it will be possible to update current decisions in light of the long-range perspective;

- obtaining a single methodological substantiation for the choice of goals, for assessment of dynamics of technological change, for long-range program design, and for the distribution of resources;
- making it possible for a broad circle of specialists (people having concrete ideas and suggestions)to introduce their information into the bank of data used in SANT. The input of such data can change the previous estimates and can influence both the SANT and the decisions being made. We should emphasize that the most important influence which such new ideas exert in the model is not through statistically averaged numbers but through change in the set of events and the structure of their interconnections. Attention to individual judgements has a stimulating influence on the activeness of this process of "competition of ideas".

8. THE CASE STUDY OF THE SYSTEM-ENGINEERING OPTION

Democratic, flexible, and dynamic planning has naturally required the creation of a permanently operating system for SANT and it integration with automated management information systems.

One possible option for this kind of system is presented in Figure 27. The output of this INPROGS system is a flow of data containing the results of assessments, analysis, diagnosis, and forecasting of tendencies in the area of technological changes (surveys, comparative assessments, prognostic hypotheses, etc.). This data receives its final form from a team of highly qualified specialists who interact with INPROGS[1] through a dialogue routine (D-II) and can use both formalized and nonformalized data for SANT. (See "BD" - Bank of Data.)

The technical element (computer) included in the system can be completely specialized for the given system, or in other cases a universal computer is used in a time-sharing mode.

The software of the system includes a variety of standard and specially prepared programs (see "LP" - Library of Programs). These programs perform informational and computational procedures of information retrieval, statistical calculation, etc. As the system continues to develop, its software will include programs for choosing technological policy alternatives, programs for optimizing management decisions, etc.

We should note that the BD contains not only engineering information per se, but also the necessary data about experts, information about previously made science-policy decisions, conceptions of goals, various ST programs, catalogues of statistical and normative data, and so forth.

The input of fresh information into the system takes place along three channels. The central place in the information entering the system is occupied by data about ideas and assessments made by a pool of experts, with whom the system analysts are working in a dialogue mode (D-I). They constantly analyze the growth in

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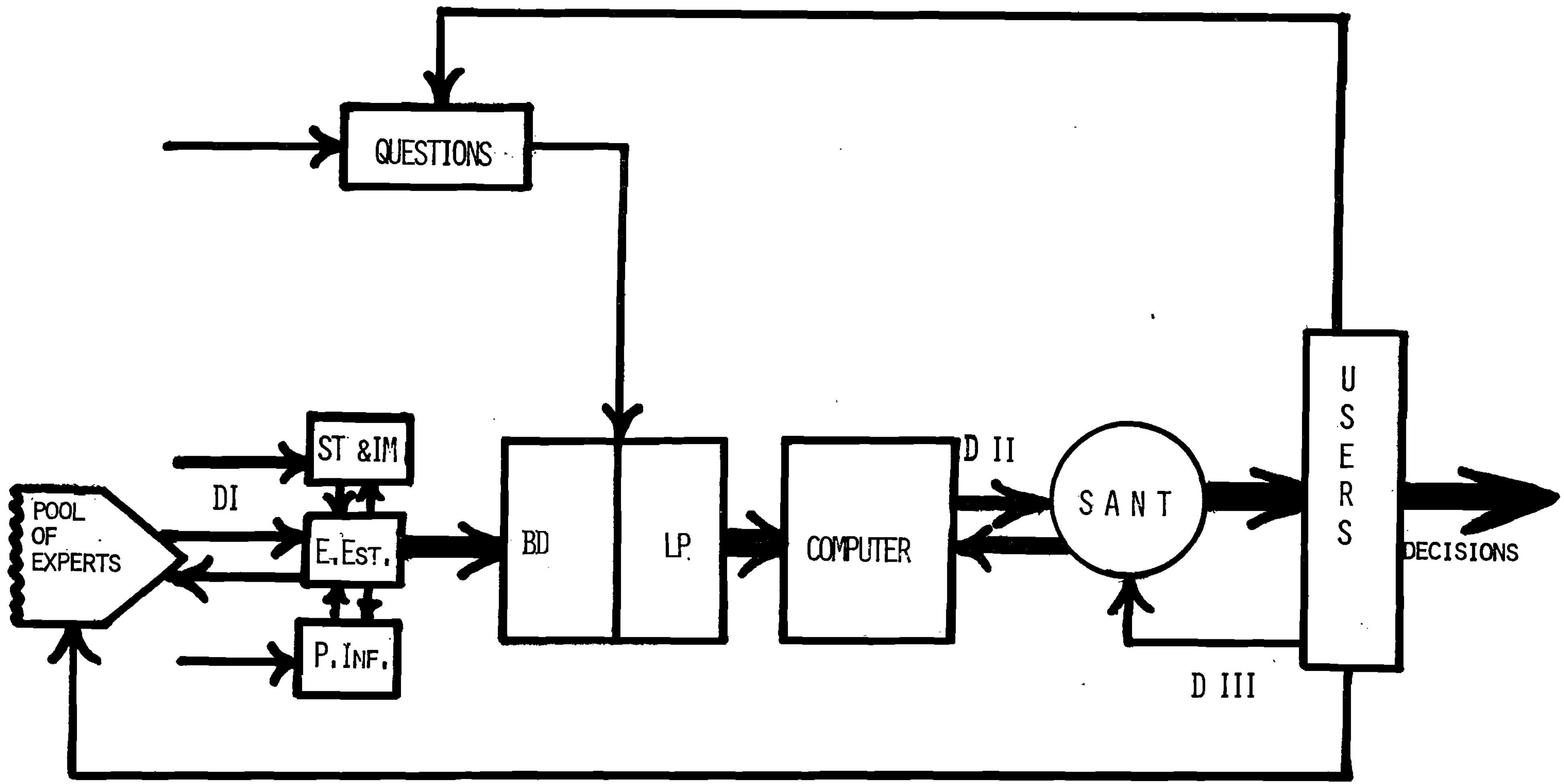
1 "INPROGS" - INformational-PROGnostic-System. Its description is in [25].



"INPROGS"

Figure 27 INFORMATION AND PROGNOSTIC SYSTEM the experts' competency, activity, and accuracy of intuition in order to up-date weight-coefficients which are applied to the assessments which the experts have put forward.

The second channel is the flow of patent-analysis data based on newly appearing documents of the world patent fund in classes relating to the object of the SANT. The results of the patent analysis are used by INPROGS in several forms: (1) as direct substantiation for changes in the graph, adding to the set of events, "grounding" the charted branches, or making more exact the previously made quantitative estimates; (2) as the basis for hypotheses which, after dialogue with the experts, are entered for further use in the BD; and (3) news for the experts about new technological solutions and possibilities.

The third channel is the flow of results from technological information analysis based on data surveys, estimates of levels, prognostic documents, experience and ideas about ST development extracted from the literature or contributed directly by the specialists. These data are utilized in the same ways as the results of the patent analysis.

In the course of the last few years, all indicated blocks of the system have undergone experimental testing. This experience, and also specially performed theoretical generalizations, allow us to assert that iterative SANT routines have several fundamental advantages: (i) they raise the usefulness which estimates have for management; (ii) the system integrates with the technological and patent information services; and (iii) it can be successfully integrated with the existing and newly forming services for scientific analytical support for the organs of management (D-III).

9. IIASA'S MISSION AND POSSIBILITIES

Here it is appropriate to recall that, in creating the International Institute for Applied Systems Analysis, the National Member Organizations did so: ...

> "Convinced that science and technology, if wisely directed, can benefit all mankind; and
> Believing that international cooperation between national institutions promotes cooperation between nations and so the economic and social progress of peoples ..."[26]

It is my profound conviction that the time has now come to make the problem of "wisely directing" technological development the subject of special applied systems analysis.

The very concept of IIASA included the idea of placing modern systems-analytic methods at the service of applied decision-making for management of complex systems on a global scale and/or of a universal character.

In their purpose, SANTs can be either "alarm-oriented" or "managerial-oriented". The first type of SANT is called upon to give objective information about possible negative consequences of the use of technical solutions. We do not agree with the opin opinion that "noise is made basically by those men and women who are unable to pay their bills on time or who do not know how to solve a quadratic equation".[27] World scientific community through an international and independent research organization, can promote objective and timely assessment of various technological options.

In spite of all this, our basic traditional orientation remains the application of systems analysis to the practice of managerial decision-making. In the experience of countries which regularly carry out analytically based decisions for the guidance of ST development, various kinds of decisions are known which use data from SANT (usually in combination with data about national and international needs, preference criteria, goals for system development etc.). Such decisions include: plans and programs for R & D; the choice of forms, methods and directions for international ST cooperation; distribution of resources; assessment of conditions and the level of ST development in various areas; etc.

We should emphasize here that SANT, like applied systems analysis as a whole, is not the same as either decision-making or management. SANT is only an important instrument for designing new, and analyzing existing, ST policy on all three levels of management defined earlier.

In this systems' instrumentation, the "WELMM approach" provides important professional (engineering, biological, ecological, etc.) data which the "STM approach" combines with more general economic, organizational, legal, socio-psychological and other systems of SANT data (TF + TA + AT + ERD + STP). In this way IIASA's M & T area can include its special methods in efforts joined with other areas and programmes to provide an ST policy design which is inter-disciplinary and intersectoral in character.

Because of the international qualities inherent in scientific knowledge and technology, we should especially emphasize the importance of the international aspects of ST policy and cooperation.

This systems practice is one of society's newest forms of activity. Its importance is rapidly growing for all countries without exception, and in some aspects for the fate of the world as a whole. The system of generally accepted concepts, comparable indicators, scientifically substantiated models and decision-making procedures here either is based on experience borrowed from international trade and diplomacy, or else is completely absent. This circumstance is standing out ever more clearly as an obstacle (not the only one, of course) on the path toward realization of one of mankind's greatest hopes - national development through mutually advantageous international scientific and technological cooperation. Hopes for the use of the possibilities which exist here are reflected in the Helsinki declaration, and in the conceptions of numerous specialized international organizations, and in the statements of practically all countries in the modern world. It is also the main goal of the next UN world conference on science and technology for development (August 1979).

IIASA, as an international, independent, non-profit scientific organization, has exceptionally favorable possibilities for providing the world a methodological, consulting, and research service in this area. The need for this is even pressing, and IIASA itself is its offspring.

Perhaps it will be interesting to recall that both the former and the present leaders of IIASA have understood its possible role in a similar way. Thus Dr. R. Levien has proposed that, "every nation should have at least one independent institution engaged in anticipation of the social consequences of scientific evolution and technical progress." He wrote nine years ago, "I hope the time is not distant when we shall see such institutions serving every nation--and the community of nations."[28]

Professor Howard Raiffa, in one of his latest articles devoted to the concept of the Institute, has suggested that the goal of the Institute is to improve the methods of systems analysis in order to make them more effective for "forecasting, assessment, and management of social and other consequences of scientific and technological development."[29]

Professor J. Gvishiani wrote in the last issue of Eastwest Markets: "The institute could also be a place for assessing the state of the art in various industries.... It can be a meeting place where people can exchange ideas on an informal basis and at the same time be exposed to a new 'technological culture'."[30]

In all areas and programmes within their specialization, IIASA has already started along this path. The discussion now is about systematic additions to the professional aspects of the scientific analysis which the Institute is carrying out in various fields, and about the special approaches to the design and analysis of technological development's managerial problems.

Our notion of the possible products of this integrated activity at IIASA and the various "consumers" of this scientific production is given in the following table.

"PRODUCTS" (Results of IIASA Activity)	"USERS"
1. Proposals, recommendations, and projects for improving the activity of international organizations for ST cooperation	International agencies which have the task of promoting ST exchange and cooperation. International program groups
2. Key concepts, measures, methods and models for analytic basing of one's own (and evaluation ot one's partners) decisions regarding ST cooperation and technology transfer	National agencies,institutions and industrial organizations on the international level
3. Organization of international problem-oriented scientific teams for applied systems analysis of concrete national problems and preparation of drafts for ST policies	Competent national organs and industrial organizations acting directly or through international agencies which provide financial support for national problem-solving
4. Generalization of existing analyses and systems assessments of new technology (SANT) and independent preparation of SANTs reflecting the viewpoint of the international scientific community	International and national agencies and scientific research organizations which are analyzing and designing ST policy
5. Scientific methods, models, and theoretical foundations for applied systems analysis of problems of managing ST change, advance and progress	The world community of scholars conducting investigations in corresponding problem areas
6. Strengthening of the scientific potential of national organizations by raising the qualifications of their personnel who are involved in IIASA research	Research institutions in IIASA's National Member Organizations

It is completely obvious that realization of the conception presented here is not a simple matter. We face many new and complex scientific problems and practical difficulties. But if IIASA does not undertake this task, who will? In this area of activity, the Institute has a unique mission not duplicated by any other organization in the world.

There are several important organizational and managerial conditions here which must be borne in mind:

- the problem demands a high degree of integration of efforts among all the existing subdivisions of the "IIASA matrix";
- the problem demands the organization of active cooperation between the IIASA staff core and the world community of scholars (see Figure 28);
- the problem demands strategic orientation toward IIASA's long-range plan of actions.

* * *

We ask colleagues to accept this report as an element of IIASA's own policy design.

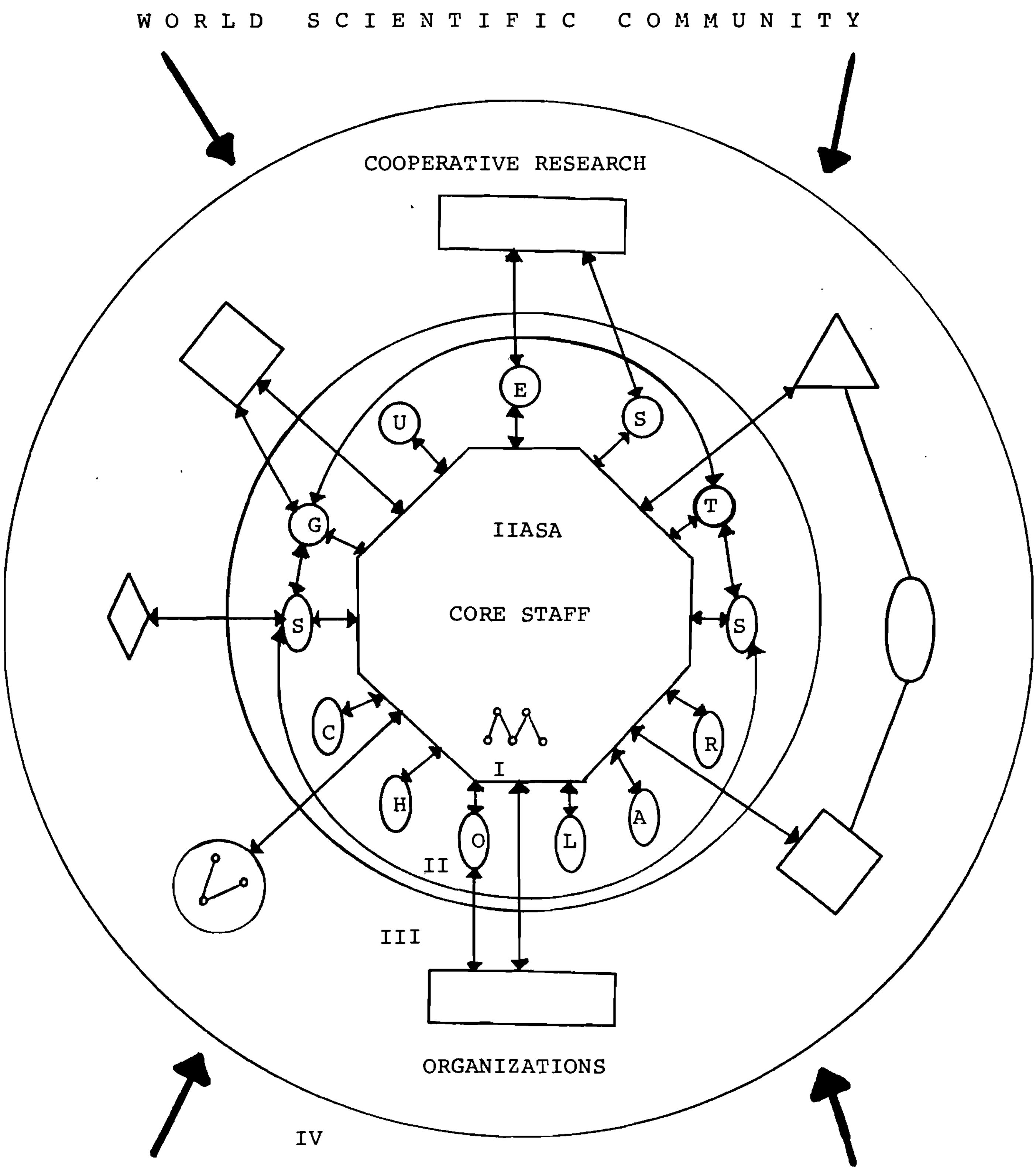


Figure 28 ORGANIZATION CHART

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