OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

18038-E

Distr.
LIMITED

IPCT.107(SPEC.)
1 February 1990

ENGLISH
ORIGINAL: FRENCH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

TECHNOLOGICAL FORECASTING: PRINCIPLES AND ANALYSIS OF METHODS*

by

Pierre F. Gonod
UNIDO Consultant

* The opinions expressed in this report are those of the author and do not necessarily reflect the opinions of the UNIDO Secretariat. This document has not been edited.

V.90 81053 7452e

CONTENTS

I. USEFULNESS OF TECHNOLOGICAL FORECASTING FOR UNIDO

The first function of technological forecasting from UNIDO's standpoint is to clarify strategy options for investments.

Ignorance of contemporary technological development has led many developing countries - and industrialized countries - to make massive investments that have rapidly become obsolete. These chance mistakes are clearly a function of the reliability of technological forecasting, the diffusion of its results and the constraints and degrees of freedom that accompanied the investments.

This is why the establishment of cumbersome and centralized data-processing systems might, at the time, have seemed to be a rational decision, before the advent of microprocessing, which is far more flexible and decentralized. Unfortunately, no one had envisaged the development of microprocessing. This immediately pinpoints the relative weakness of technological forecasting - a weakness for which it is advisable to understand the reasons.

Guesswork may also have disastrous repercussions. An example of this is the reliance placed by the USSR after the Second World War on advances in genetics, then dominated by the arguments of Lysenko, by which it was hoped that one could do without an expensive fertilizer industry. Forty years later, this view is no longer so unrealistic, considering the progress made in biology and genetic engineering. Similarly, new agronomic practices are likely to bring about extensive changes in agricultural equipment.

There are numerous examples of mismatching between technological development and investments.

The second function of technological forecasting is to envisage simultaneous developments in international economic competition.

This function no longer relates merely to the intrinsic development of technology and isolated decisions based on the prospects offered by such development but, in addition, evaluation of the potential for technological change among competitors, rival enterprises and adversary countries.

Before the economic crisis, the massive indebtedness of the developing countries and the policies of structural adjustment, this function might have seemed to be secondary in the eyes of many developing countries. This is no longer true of today when there is opening up to the international market and the dismantling of protective barriers for national industries, sometimes not without "shocks". Export growth is becoming a common imperative imposed by the need to balance foreign trade accounts. Since many developing countries occupy the same export niches *vis-à-vis* the strong-currency industrial countries with high product quality expectations, there is an ensuing standardization of technical norms, and a greater awareness, dependence and sensitivity on the part of developing countries with regard to technological developments and changes and, consequently, the need to play the role of partners who are aware of the future prospects for technology. Hence there is a new and important role to be played by UNIDO.

Furthermore, in the industries which have been able to introduce computerization and robotization, the movement towards a shift in the location of industries from the North to the South is now reversed and the comparative benefits of lower manpower cost are no longer attractive. For the "newly-industrialized countries", in particular, maintaining a foothold in the club of industrial countries requires the adoption of computerized production. In their case, the focus of forecasting is moving away from the technological prospects of developing robotics towards those of mastery of such technologies in the production processes.

Despite its current situation, technological forecasting is one of the essential instruments of industrial policy, since technology has become the decisive strategy variable.

II. FEATURES OF TECHNOLOGICAL FORECASTING

Explanation of the various methods of technological forecasting and evaluation of the results obtained require an understanding of the features of it, i.e. those of the technological system. This raises a number of questions regarding:

- The levels of technological forecasting;
- The stages of technological innovation and forecasting;
- Associated concepts and differences between technological forecasting, evaluation, watchfulness and long-range planning;
- Technology considered as an independent system or a social construct.

Levels of technological forecasting

Technological forecasting covers a very wide variety of levels. These levels correspond to the levels of the technology pyramid. This may be analysed using the following **model** 1/ (see diagram overleaf).

In this document we shall not deal with the construction of this model and shall merely enumerate the different levels of the technology "arch":

Technological principles derived from or prior to scientific laws;

Technological properties connected with the technological principles;

Processes which are "ways of doing things";

Elements which are the vectors of the technology: e.g., transistor, microprocessor, laser, etc.;

Technical objects which combine in specific forms the principles, properties, elements and processes;

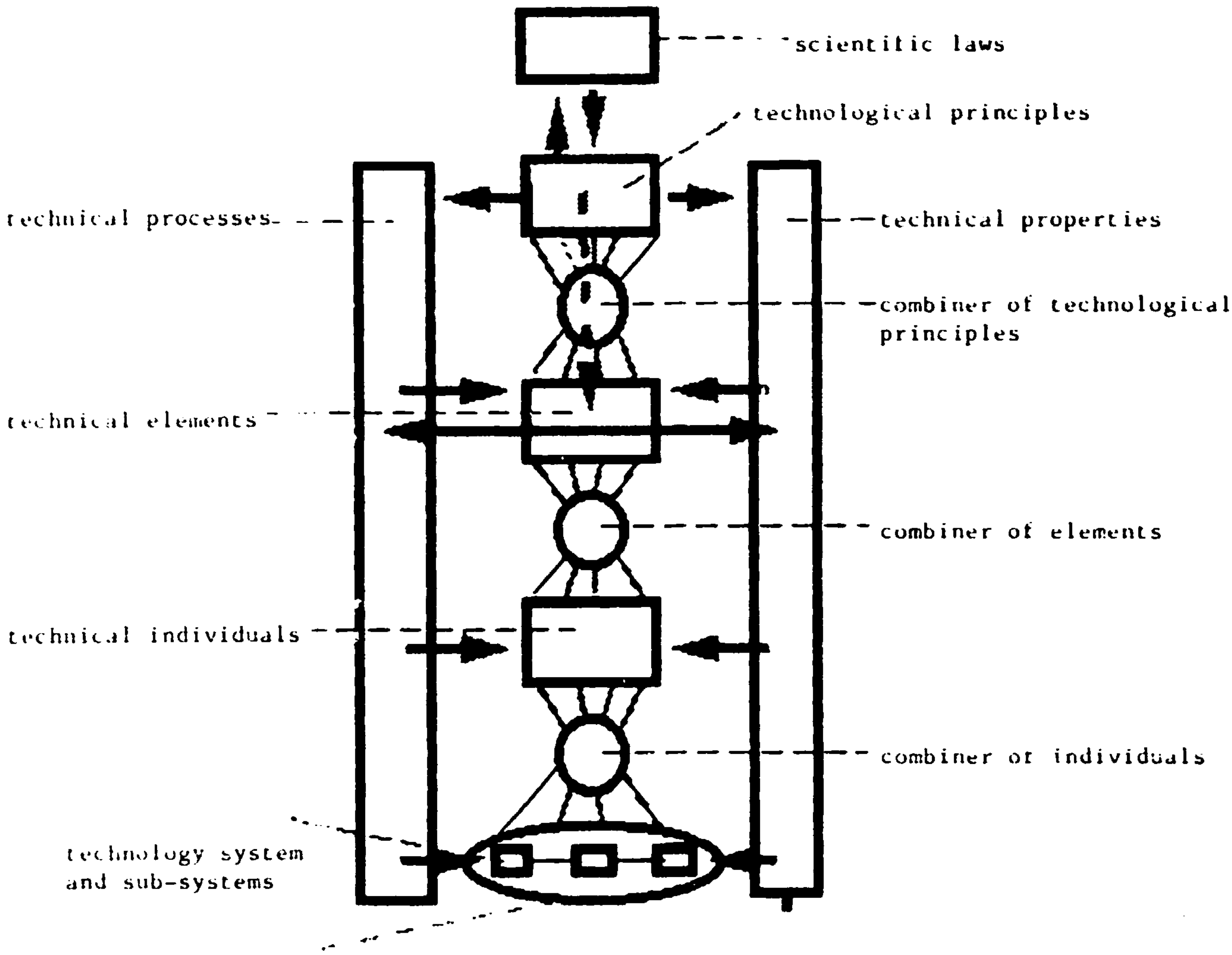
Transverse generic technologies and sub-systems, the system as a whole.

Technological forecastability varies depending on the levels of the system. This phenomenon has not yet been stressed and examination of it indeed assumes prior modelling of the technology system:

With reference to the **scientific laws**, the discovery of new principles cannot be forecast. The scientific laws and constants are limited in number: of the order of 10^2. The discovery of fundamental scientific laws, after a slow process of acknowledgement by the scientific community, is leading to the emergence of new paradigms.

1/ Pierre F. GONOD, "La technologie générale: projet d'encyclopédie systémique de la technologie", Analyse de systèmes (Systems analysis), Vol. XIV, No. 4, December 1988.

Model showing the structure of the technology system



__Technological principles__ are the result of centuries-old practices which have, more often than not, preceded scientific explanation and codification. However, today the majority of them are included in the body of scientific knowledge. They derive, for example, from fundamental notions of statics, dynamics, etc. and have their own calculation rules. Technological principles may or may not be interrelated; for example, combination of the principles of electrostatics and photoconductivity which brought about xenography, which is not just the sum of the two sets of principles, but possesses new properties. Technological principles are also limited in number, probably of the order of 10^2. None the less, although mankind has empirically discovered a large number of principles in its technical activity, the latter is enriched by other principles - such as superconductivity - which broaden the technology system and make it more complex. Technological principles are both the expression of the laws of nature and a means of acting thereupon. The degree to which technological principles can be forecast is linked to the extent to which they now derive from scientific activity.

__Technological properties__ and principles are closely linked and may sometimes be defined in mutual terms, one being the condition of the other. The example of superconductivity illustrates this dialectic:

"Hence the properties of certain materials and the principle of superconductivity go hand in hand and, in turn, the discovery of new superconductors questions the theory (incidentally, long-established). Following the technological breakthrough achieved in October 1986 by Alex Muller and Georg Bednorz of the IBM Zurich Research Centre, who discovered ceramics with previously unobtainable superconductivity transition temperatures, the obstacles met by physicists in bringing down these temperatures to levels at which they could be put to large-scale industrial use posed theoretical questions that had not been tackled until then. Although the date of the technological breakthrough was not predictable, the event was not improbable because of the existence of a known principle and catalogued research programmes. However, subsequently, the scientific impact, reflecting a degree of ignorance at a fundamental level, could clearly not have been foreseen. The mood of tremendous excitement among physicists which followed the Nobel prizewinners' discovery has subsided and, with it, the hasty extrapolations regarding the prospects for superconductivity applications."

This example illustrates the complexity of technological forecasting and its evaluation.

Furthermore, it is necessary to distinguish between "**natural properties**", which provide data for human activity, and "**artifical properties**", which are created as the outcome of a process of artificialization which characterizes the composition of the technosphere in which we live. While the table of chemical elements is limited, the technological properties do not constitute a closed system. As stated, the conjunction of two properties may generate a new property and, in addition, the malleability of the new technologies opens up the possibility of producing "tailor-made" (composite) materials with predetermined characteristics. This is a reversal of the situation in chemistry, for in that case, forecasting is essentially normative and knowledge of R&D programmes is an essential component of forecasting. There are plans to establish data banks of properties, of which there are probably of the order of 10^3.

By the very nature of technical progress, there are thus various theoretical forecasting cases:

A technology is made up of rigorous operating processes which are "ways of doing things". Each process is a specific combination of technological properties and principles implemented by humans equipped with tools, machines, energy, information, rules and programmes using non-arbitrary sequences or orders of operations. Each process is an organized configuration. Since each property may give rise to several alternative technical processes, these are clearly more numerous and, if we take a very broad mean estimate of 10 processes per property, we arrive at an order of magnitude of 10^4 and, taking account of finer ramifications of specific technological processes, certainly 10^5. The intrinsic development potential of the processes is very great and the combination of technological processes is vast. Hence, even if there is no scientific progress, the processes of the technology system could continue to develop themselves over a long period. This phenomenon often leads one to think of a technology system as being autonomous or semi-autonomous, as compared with a scientific system. It follows that the forecasting of the development of technological processes is less unpredictable than scientific development, leaving aside the appearance of those which stem directly from unforeseen scientific breakthroughs. However, this implies that technology develops only according to its own rationality. This is an untenable view at other levels in the technology system.

Surprising as it may seem, there is no classification of the elements that are the vectors of the transfer of the technology content. A limited number of common elements are the first materials of the technological edifice that has been constructed in the course of history. In all they probably number in the region of 10^3. The machinery, devices and appliances that are called "key devices" in English may be considered as elements. The same can be said in respect of the wheel, lever, wedge, wire, thread, cord, knot, chain, spring, bearing, gearing, valve, key, crank, pendulum, gyroscope, air pump, speed regulator, ball-bearing, electromagnet, photoelectric cell, optical and magnetic lenses and, more recently, aerosol, transistor, microprocessor, laser, etc. These elements are components of technical objects, of which there are millions, even thousands of millions of specimens. Most elements have been created empirically through human activity. One does not re-invent the wheel. Those which come into being subsequently are the result of a science-based activity. They have the same unforeseeable character and, indeed, the discovery of the major elements of our epoch, such as the transistor, microprocessor and laser, had not been foreseen.

Technical objects and individuals make up the familiar universe in which we live: objects that make up the household electrical systems, tools and machines, office equipment, means of transport and appliances of all kinds. In all they number in the region of 10^6. This estimate is correlated by the five to eight million types of machines and instruments, the probably similar number of consumer goods and the seven million molecules synthesized by chemists. Technical objects, which are a social creation, are subject not only to the laws of nature, but also those of society and the economy, as well as to the laws of psychosociology. The latter demonstrate the symbolic, cultural and even religious character with which the categories of objects are endowed. The history of the motor-car and the bicycle indicate how their conception was influenced by social signs and symbols before evolving towards marked technical rationality. The technological forecasting of "everyday things" is dependent on that of product innovation and "design" psychology. It is in this context that technological forecasting leads on to industrial strategies and marketing.

In extreme circumstances there is another force: technical rationality which gives objects their shape. Objects are not subject to symbolic influence - for instance, scientific instruments such as the microscope, instruments of modern medicine, the scanner, echographs and nuclear resonance spectroscopes.

Objects lie somewhere between these two extremes and their status evolves with the passage of time.

When dealing with technical objects, consideration must also be given both to **the complexity of their functions and that of their manufacture**. Objects may be mono- or multi-functional. They have different degrees of ease of use. The complexity of use has been reduced and transferred to the organs of the machine or its software (e.g. microcomputers). They are made up of a single part or a multitude of parts which may sometimes be expressed as a power of 10: 10^3 for a motor-car or 10^6 for a space-ship, undoubtedly the most complex technical unit. Their elements are relatively independent or, on the contrary, strictly interdependent. It would be advisable to classify them according to this criterion. There are scales to measure their performance levels. Consequently, a change from a precision mechanical engineering industry to mechatronics is also a change of scale of 1/10-1,000 mm to 1,000-10,000. A change from an optical microscope to an electron microscope involves an increase in the resolving power of 10^3, even 10^4.

These breaks are connected with changes in technological principles and the new lines of technology develop to saturation point in a space bounded by physical constraints: e.g. the electron microscope is now approaching the limits of saturation and progress is expected in another technological generation through the implementation of other principles - "the tunnel effect". Hence, the technological forecasting of objects is also that of breaks, changes and the appearance of new "lines of technology". Since these changes, likely to generate decisive competitive benefits, are the object of systematically-organized R&D activities, technological forecasting takes on a regulatory character for the desired objective.

Here again, technological forecasting has various basic features:

The **technological sub-systems** are technological combinations combining different properties. Consequently, mechatronics is the result of the merging of mechanics and electronics, whereas photonics brings together the latest technologies based on the interaction between light and material and includes lasers, optical fibres, data display, processing and acquisition systems and photovoltaic and solar systems. Office automation and genetic engineering may also be considered as technological sub-systems by virtue of their ability to integrate different technologies. Robotics also constitute a transverse system which brings together different technologies in a coherent combination. These sub-systems are sometimes looked upon as "**generic technologies**", characterized by their proximity to scientific principles.

The forecasting of these sub-systems is a difficult matter which must take account of the joint evolution of the technologies involved and limiting factors connected with the lesser development of one of the constituents. However, with regard to these combinations it is clear that forecasting can no longer merely cover the intrinsic development of the technologies and the coherence of their association, but must also be able to incorporate the economic and social factors which will play the part of motivating forces or conditions permitting the existence of foreseeable technical combinations.

Combination in a sub-system is an a posteriori mental operation. The same is true of the system. Nevertheless, these abstractions are fundamental for any understanding of the whole. The various technology systems that supersede one another have the common features of cohesion and coherence and a logic or a dominant paradigm. There has been a dominant machine logic and an electrotechnical logic which have marked all technical development in our era. We are now witnessing the emergence of computerization. In other words, technical principles have brought about sub-systems which have carried out the activities transversely, established themselves and had a linkage effect on the whole situation. This effect is the result of a complex process. The technical principles are not independent of existing paradigms but, mutually, are component parts of them. They exercise a dominant effect on the techniques derived from other principles and, reciprocally, they can only emerge through the existence of other technologies which provide the conditions that permit the constitution of the technologies they engender and which can only be disseminated through a set of socio-economic conditions. This interplay is guided by a paradigm, that is to say by the new principles which will govern the behaviour of the innovators and the decision-makers, i.e. the decisive social actors. Microcomputing and computing have a "revolutionary" content which shapes the current technological system. The following stage may be marked by biotechnology, that is to say the technologies permitted by the development of computing and the conquest of the infinitely small which, by mastering the complexity of the living organism, makes for a return to the "natural" through artificialization. The scope of the current transformation movement, which brings into play complementary or antagonistic forces, requires a complex dialectic.

At the level of the technology system(s), forecasting is thus considerably influenced by the dominant paradigm and, since technology is considered, if not the fundamental variable of contemporary society, then at least an indispensable variable, it follows that global studies of the future will in turn be subject to the influence of the technology paradigm.

Stages of technological innovation and forecasting

One source of confusion about forecasting relates to the imprecise nature of its very object. What is it all about? We need to consider not only the technology, but also the stages of its development. The technology system is a combination of techniques of different generations that co-exist in a more or less lasting manner and in which some are merely ideas, others have reached the laboratory or prototype testing stage and others are coming on to the market with commercial success - these are the real innovations and they arise out of incessant developments and improvements either in terms of the product or the process, or both. These achievements may be of considerable economic importance. The major innovations give rise to product lines whose improvement is continued until the development possibilities reach saturation point. An innovation has real impact only if it gives rise to a process of diffusion. Technology systems are only formed once technical innovations have become widespread in production systems. 2/ Diffusion has been defined as the process whereby an innovation is propagated as an idea, product or process. Their adoption involves a decision. There are various categories of adoption levels over a period of time, according to a curve which espouses that of the "life" of the product or process, its birth, growth, maturity, decline and death. There are discrepancies between enterprises, industries and countries. The concept of diffusion includes that of technology transfer in the sense that the transfer always occurs at one of the stages in the diffusion of the innovation. However, if we consider that transfer only occurs if there is assimilation of the technology by the recipient, the diffusion of products and processes does not mean that there has been transfer *ipso facto*. Since technology is power, its transfer will be more restrictive, in general, than the diffusion of the products. The "alienated", "incarnate" and "capitalized" forms of the technology cause the transfer to be a restricted diffusion process. It is the transfer mechanism that brings the technology system into concrete being and enables it to be powerfully utilized by the economic and political systems through the logic of composite exchange, conflict/co-operation and the balance of power between partners, suppliers and receivers of the technology. It is they who mark the division of the international technology system through national systems.

Consequently, technological forecasting could relate to "moments" in time that differ from the technology system:

- The probability of the appearance of inventions;
- The process of creating innovations;
- The process of developing existing innovations;
- The process of diffusion and transfer of innovations covering different stages ranging from their birth to their disappearance.

2/ P.F. GONOD: "Le système technologique" in *Traité d'économie industrielle* (Treatise on industrial economics), Economica, 1988.

These forecasts have deep-seated differences which are not sufficiently stressed in available literature.

Invention forecasting is impossible by its very nature. An invention introduces creative and unforeseeable disorder into technological order. However, great visionaries with a deep understanding of technological matters, such as Leonardo da Vinci or Jules Verne, had a remarkable gift for anticipating future developments. Today science fiction continues to play a useful role as the fruit of fantasy based on scientific premises and, in return, it stimulates the imagination. Creativity methods are designed to remove an existing mental block, not to forecast but to imagine and invent.

The **creation of innovations** is an organized activity in our day and age. An innovation is always a meeting between a feasible technique and a latent need. Although chance does play a part in the discovery, its role is less in the creation of new products or processes to fulfil a need, an expectation or a technical and industrial strategy. Whether the innovation belongs to the laboratory or the workshop, it is an explicit objective of the achievement to which specific activities relate. Consequently, the forecasting of technological innovation has three levels: (1) exploration of latent needs and their meaning for future technical changes; (2) exploration of technological development spaces and their meaning when defining other products or processes (it is this exploration that, as we shall see later, some American writers call "state of the art" of the technique, which measures its current development potential); (3). normative plan of action and organization of activities designed to achieve the desired result.

The first level corresponds to the "demand pull" approach, the second to the "technology push" approach and the third to planning. In practice, these three forms are generally found in association. In modern enterprises, they cover the activities of marketing, technology management and strategic management.

The **development of existing innovations** extends the preceding activities. Innovations reflect two main modalities: (1) the use of their own potentialities; (2) the incorporation of compatible elements, properties or processes which create around the initial innovation a process of budding or clustering that may, like modern technologies, lead to creation by merging new fields of technology.

The forecasting of the technological development space for an innovation is not clear, even though it relates in substance to the intrinsic logic of the technique, its parameters, their combinations and their saturation limits. It assumes instruments of analysis and information that are not always available.

The forecasting of elements that are likely to be associated with the inital innovation is also not evident. It assumes, firstly, mastery of the technical architecture of the original innovation and of its evolutionary capability and, secondly, knowledge of the existing or anticipated outside technical elements that are likely to be added to it.

The development of technological innovation is indeed a continuous process. The experience gained on the production lines is transferred to subsequent ones which also benefit from other inputs. The production of successive generations of Boeing aircraft, for instance, illustrates the way in which the programmes have incorporated the continuous flux of new technologies relating to aerodynamics, structures, navigation systems and propulsion systems.

Technological innovations also follow multiple trajectories. The trajectories are not determined merely by the logic of constitution and functioning of the technology, but also by their utilization logic. Since the general pattern is to simplify the utilisation for the users, the manufacturer must either simplify the product or incorporate as much complexity as possible into the organs that operate automatically - or both. The evolutionary logic of innovations will obviously depend on the nature of the market and the level of competition. Under conditions of cut-throat competition and faced with the vicissitudes of the economic war, the only sure way to survive is very frequently to implement an R&D programme. Hence the overriding need to be kept informed of competitors' preparations and progress. However, it is no longer really a matter of forecasting, but rather of technological watchfulness. 3/

The forecasting of the **diffusion of technological innovation** is the final stage of technological forecasting. Here the "socialization" of the technical process comes into its own. An invention or an innovation may be something remarkable, but it only becomes an event as far as society is concerned if it receives a significant degree of diffusion. Forward-looking market surveys are designed to envisage the market for new products, with their stages of growth, maturity and decline. What a hazardous exercise! Not only does the penetration of a product depend on the dynamics of the economy, but there are also many other factors with which to contend. The boom in microcomputing has provided us with a glimpse of considerable growth in "household computing" ("home electronics") - reality has outstripped the forecasts and the discrepancy has cost major enterprises dear. On the contrary, the development in France of electronic messenger services which extends the use of the telephone - five million users are now equipped with "minitel" - was not foreseen and is a sort of societal phenomenon. This is at the heart of the dialectic of the innovation process since R&D programmes to create or develop an innovation are often only undertaken if the prediction of the way in which it will spread indicates attractive propspects. Forecasting subordinates creation.

Organizational structures either promote or hinder diffusion. It is known that internal vertical divisions and an institutional vertical structure are serious obstacles to the diffusion of technical progress. Making discoveries in the laboratory or in the factory does not automatically mean that they are effectively transferred. On top of the risks connected with the innovation there are those connected with its adoption. Prevailing social structures and remuneration systems may have a powerful restraining effect.

An innovation is protected by legislation governing industrial property. Technology transfers thus do not constitute a "pure market", but rather a composite exchange, that is to say a mixture of free and reciprocal transfer and power relationships of conflict/co-operation or struggle/competition. The regulating of transfers is a weapon in the economic war - and in the armed peace - for the dominant countries and enterprises. The policy of keeping things for oneself may be overridden by economic problems or the reduction of markets that may lead to the sale of technologies. The licensing of advanced technologies may be weighed, firstly, against estimated progress in a given time-span by the licensed partner/competitor and, secondly, against progress made by the licensor himself. Hence the need for dual forecasts.

The **timescales for implementation of the stages** of the technological process are generally the weakest part of the forecasts. Thirty years ago they used to be over-estimated, but the current trend is to under-estimate them. Optimism is often due to the analyst s temptation to go along with his client's hopes. The research

---

3/ The French expression "veille" does not seem to have an exact equivalent in English. "Watchfulness" is an approximation which should be combined with the image of a sensitive antenna permanently deployed.

and development time is dependent on technical and scientific factors, to the extent that these have not been mastered. They are partially forecastable. However, the greatest difficulty lies in estimating the diffusion time. In this respect we are not only competing with nature, but also with society, so we need a broader approach.

The "life cycles" of the technology, industrial structure, market and strategic management are mutually integrated. There are close links at each stage between these and the scale of the technical process, required manpower level, production logistics, investment strategy, capital intensity, location of production facilities and their organization, nature and scale of barriers, price flexibility, strength of competition, etc. The logic of these links, which surround the technology, is not sufficiently borne in mind. Nevertheless, this is a decisive factor in industrial projections for developing countries. The "life cycles" should be used as a basis for forecasting and for industrial strategies.

In short, it is necessary to distinguish technological forecasts depending on the stages in the process of the innovation, which afford unequal opportunities for anticipating and implementing different methods. Unfortunately, the current literature does not provide an adequate analysis of these differences.

Technological forecasting, assessment, watchfulness and long-range planning

These connected notions must be made clear and their appearance and history form part of our understanding of the technology system. 4/

Once it had been realized that the forecasting techniques had failed to make the "expected" breakthrough, interest shifted in the 1970s to "**technological assessment**", that is to say the estimation of the potential impact of the new techniques on society. This movement required a renewed effort to consider matters in a socio-economic and geopolitical context. There are several reasons for this new focus: the economic and social crisis in the industrial countries, the job uncertainties caused by new technologies, the growing financial burden of large-scale technology programmes and disenchantment following a period of mythical growth in the ability of science and technology to transform society, coupled with awareness in certain circles of serious industrial risks and ecological disasters. With assessment, technological forecasting assumed a political dimension, in the broadest sense of the term. This provided an opportunity to acknowledge technology as a social construct and to facilitate the democratization of the decision-taking process. Without being negative, the margin here is also very slender, particularly since the infant "technology assessment" was quickly subjected to the distortions imposed by the political authorities and institutions for which its recovery justified the decisions taken or projects submitted for funding. In other periods, the manipulation of discounting rates fulfilled the same function as an alibi or strategem. The social interpretation of the emergence of assessment is eminently critical. It is no longer a question of referring to the "invisible hand" when deciding on major technology matters and R&D outlay - their implications and consequences have to be clarified. Assessment is ambivalent. It may also involve appreciation of the impact of past technical activities on planned activities. As far as links between technology and society are concerned, assessment embraces a far wider field than everyday forecasting. Insufficient

---

4/ According to the analysis by P.F. C[illegible] in "Prolégomènes à la prospective technologique", Analyse de systèmes (Systems [illegible]is), Vol. XV, No. 2, June 1989.

emphasis has been placed on the change in intellectual dimension connected with assessment in comparison with technological forecasting. Assessment raises questions of the choice of the reference theoretical model, the various ways of measuring technical progress, the taxonomy of technical change, the stability and regulation of industries, the linkage effect of innovation, the level of assessment and the choice, number and social significance of the criteria selected for assessment "ex-post" or "ex-ante". What is thus involved is a qualitative intellectual change in which previous ideas are superseded. However, for this to succeed it would have been necessary to establish a set of technological forecasting methods with a solid basis, as well as techniques permitting integration of the new dimensions and introduction of the greatest possible complexity. If this is not the case, the superseding becomes mere pursuit of an aim regardless of circumstances.

In this context, the practice of "**technological watchfulness**" is a realistic response and an acknowledgment of the failure of forecasting and assessment. Given the uncertainty of development, cutthroat international competition and the speed of technical change, the only certainty is the need to remain steadily and promptly abreast of the projects and achievements of others, whether in industry or in military matters. This has led to the formalization of management practices including technological watchfulness. An improvement on forecasting, the "four-speed system" is an approach in which technological watchfulness is part of a "business intelligence system" focused on the here and now. The other speeds are a three- to five-year span, ten- to fifteen-year scenarios, a will to exist and a very long-term enterprise project. Following a period of discredit which affected general forecasting that had been unable to anticipate the economic and social crisis, there will be a strong swing back to long-range planning, at least among large enterprises. This is explained by the duration of the crisis which is conducive to a search for ways out and other approaches. This has brought about "strategic enterprise planning".

Technological watchfulness, imposed by the pressure of the real possibilities and necessities, could be the logistic basis of a fresh appraisal of technological forecasting and long-range planning. How can forecasts be made without a systematic inventory of technological knowledge? How can long-range plans be made without identifying the development programmes that will reflect the strategy of the actors involved? The compulsory step back may prove to be salutory by providing the chance to gather essential information, provided, naturally, that this is not restricted to the large enterprises. 5/ The existence of an organized technology information base is a condition for forecasting.

Long-range planning is different from forecasting. The differences are summarized below:

Forecasting:

Vision: fragmented, "all other things being equal";
Variables: quantitative, objective and known;
Relations: static, constant structures;
Explanation: the past explains the future;
Future: unique and certain;
Methods: deterministic and quantitative models (econometric) (mathematical);
Attitude to the future: passive or adaptive (future to be accepted as it is).

5/ The United Nations system and UNIDO in particular have a role here.

Long-range planning:

Vision: global, "nothing else is equal";
Variables: qualitative, whether or not quantifiable, subjective, known or hidden;
Relations: dynamic, evolving structures;
Explanation: the future is the raison d'être of the present;
Future: multiple and uncertain;
Methods: intentional analysis, qualitative models (structural analysis) and stochastic (cross-impact);
Attitude to the future: active and creative (desired future). 6/

If we use these definitions as our reference point, we find that the definition of forecasting fits in well with the practice of technological forecasting. However, there seems less likelihood of technological long-range planning as reflected by the aforesaid criteria.

None the less, it is the latter, rather than technological forecasting alone, which is apparently needed once the level of technology aggregation rises and at the stages of the creation and diffusion of the technological innovation. The following tables summarize the necessary approaches.

Forecastability depending on the technological structure and stage

Structural level	Forecastability
Scientific laws	Cannot be forecast
Technological principles	Cannot be forecast
Properties	Known and normative
Processes	Can be forecast
Elements	Cannot be forecast
Sub-systems	Can be forecast using long-range planning
System	Can be forecast using long-range planning

Stage in process	Forecastability
Invention	Cannot be forecast
Creation of innovation	Cannot be forecast and normative
Development of innovation	Can be partly forecast; technological watchfulness
Diffusion and transfer of innovation	Long-range planning
Process time	Long-range planning

The judgements indicated in this table are cursory, which is the drawback of any categorization of complex phenomena. Reality is more subtle. Hence, a strong scientific and technological background, combined with a sound knowledge of research in progress, is conducive to envisaging the prospect of the discovery of new scientific and technological principles, which are axiomatically unforeseeable.

6/ Michel GODET, "Crise de la prévision, essor de la prospective", PUF, 1977.

The higher the level of technology aggregation and the greater the "socialization" of the stages in the process, the more urgent it becomes to adopt the long-range planning approach. This brings us back to evaluation of long-range planning methods, which are not the subject of this document. 7/ We shall merely stress that long-range planning is by its very nature dialectic and systemic. Progress in long-range planning is thus dependent on the transfer to the field in point of acquired dialectic and systemic information. The systemic approach has, however, only rarely been used by (forward) planners and the intellectual movement of complex thought and dialectics has not yet sufficiently impregnated the long-range planning approach. Moreover, systemics raise the important problem of their relationship with scientific theory in general, of which systemics are a product, but not a substitute. The picture of the technology is a fragment of the picture of the world and, therefore, of one or more theories that are more often than not implicit. It is advisable to make them explicit.

The "**recapitulation of groups of methods**" sums up the above analysis and compares the forecasting, assessment, watchfulness and long-range planning approaches.

- The choice of approach depends on the **representation and understanding of the technology system.**

Consequently, if we consider technology as an autonomized phenomenon, this will lead us to envisage a determinist universe in which technology shapes society and to favour the forecasting approach based on the inherent rationality of technology.

If we consider it as a social construct, this will lead us to think in terms of an open system in which technology is shaped by society. This view involves two variants. In the first variant, we do not envisage a self-organized physical subsystem. In the second, the technology system has physical and social interfaces, with the ensuing need to take simultaneous account of the laws of nature and those of society.

Furthermore, a "new wave" of sociologists considers technology and society as a "seamless web" which, a priori, seems to exclude any possibility of forecasting.

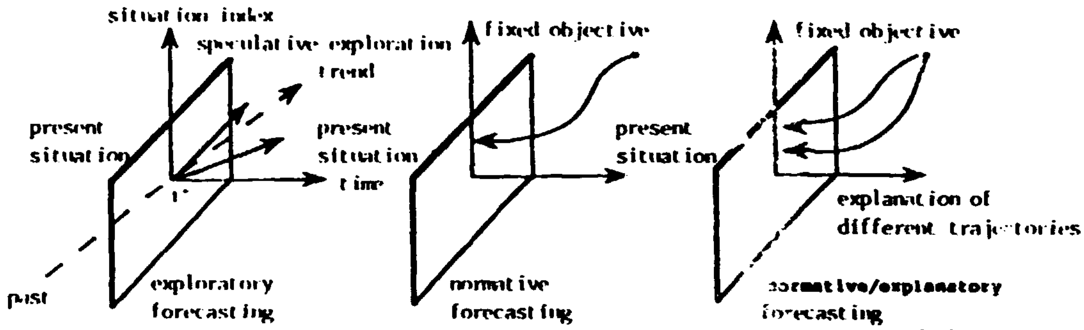
The **outline "understanding of technology"** summarizes its influence on forecasting approaches.

7/ Interested readers may refer to "Prolégomènes à la prospective technologique", already mentioned, ref. 2, and the coming study by the author of this document "Dynamique de la prospective".

Recapitulation of groups of methods

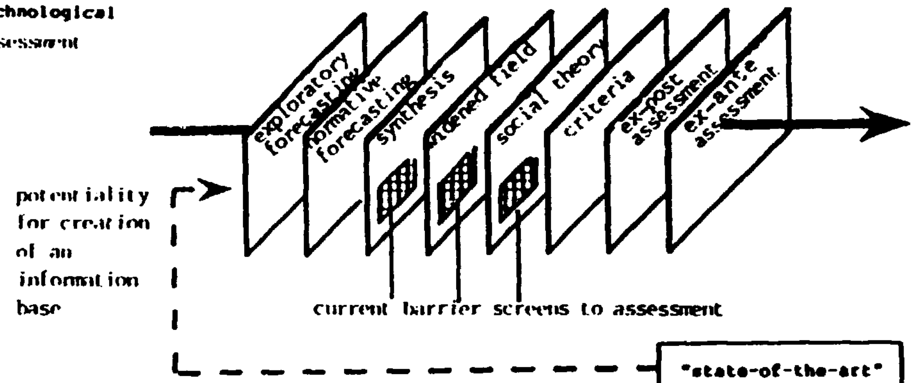
Order of appearance

1. **Technological** forecasting

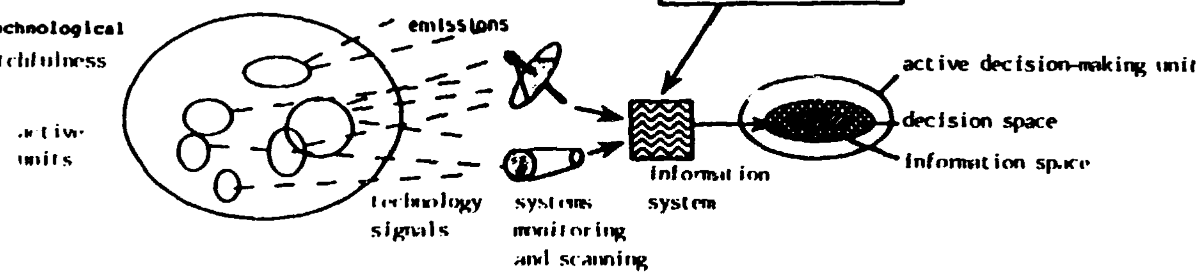


* Source: Saint-Paul and Ténière-Buchot

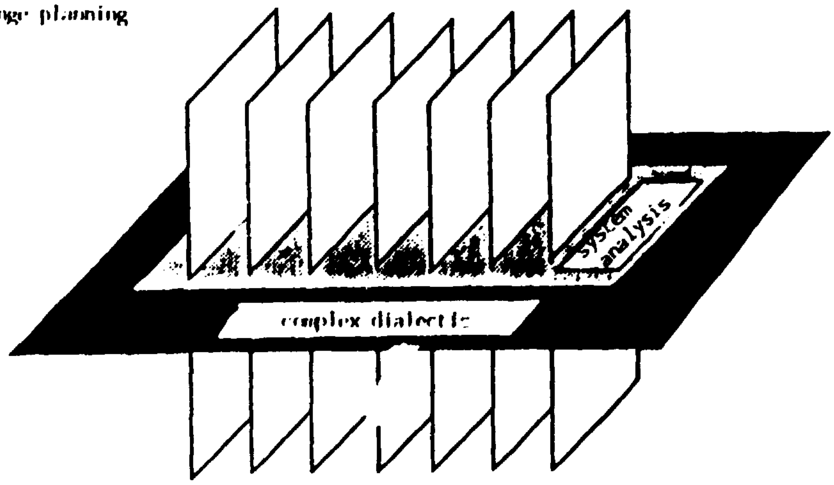
2. **Technological** assessment



3. **Technological** watchfulness



Necessary conditions for long-range planning



P.F.G.89

Understanding of technology

Autonomized phenomenon technology shapes society	Social construct technology shaped by society		
Deterministic universe	Technology as an open system		Technology and society form a seamless web
□ Technology develops according to its own rationale, consequently society becomes a technicist system	□ System with "physical" and "social" interfaces □ Hypothesis of a self-organized physical system Existence of internally-composed physical laws □ Structured technical edifice	□ System with physical and social variables □ Failure to consider a self-organized physical sub-system □ Distinction between internal and external variables □ Actors operating the technical system and its socio-economic environment	□ Technology and society one and the same □ Absence of a particular self-organized physical system □ Absence of distinction between internal and external variables □ Network of actors made up of heterogeneous associations of material factors and agents considered jointly
Forecasting approach □ Deductive and continuous: extrapolations; exploratory forecasting; normative, explanatory or correlative forecasting □ Synthesis □ Inductive and discontinuous; morphological analysis	Long-range planning approach Explicit or implicit economic and social theory Possibilities for the building of technological scenarios		Sociological approach Social construction of technology Empirical analysis Unknown use for long-range planning

P.F.G.89

III. PRINCIPAL TECHNOLOGICAL FORECASTING METHODS

The preceding "features" section indicates that the methods of technological forecasting form part of the general understanding of the technology system and are a reflection of it. The forecasting possibilities vary with the levels of the structure of the technology edifice and the stages in its process. There are thus objective limits to the methods and also a need depending on the object of the forecast (level and stage), to use the appropriate methodological instrument. Many failures in the field of forecasting are caused by the use of an inappropriate methodology and indiscriminate use of methods that are not an "open sesame" and far less multi-purpose prescriptions.

This chapter summarizes the essential aspects of the methods which have practical scope and relate to technological forecasting proper, as set out and defined in the "features" section.

The outline below indicates the "technological forecasting methods". 8/

This classification is made according to three criteria: the forecasting focus, the intellectual approach and their logic.

Forecasting focus: it is necessary to distinguish between exploratory forecasting and normative forecasting.

- Exploratory forecasting can also be divided into two categories: the tendential approach and speculative exploration.

The **tendential approach** is conventional forecasting, which consists in pursuing past observations into the future. It postulates the permanancy of laws, structures and linear developments; though without theoretical foundation it is the most widespread approach. It gives rise to simplistic extrapolations and optimistic or catastrophic visions postulating that the future will be an e tension of the past.

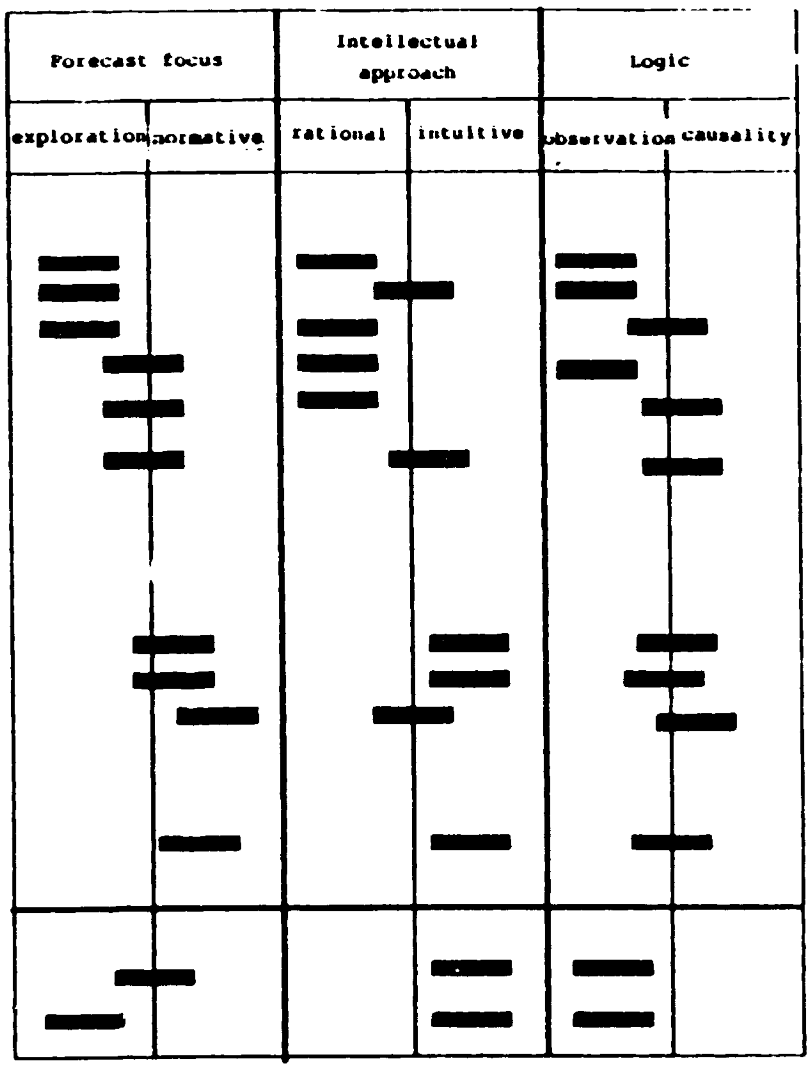
Speculative exploration is a variant of the tendential approach. Around the mean resulting from the trend, one modulates an "upper hypothesis" and a "lower hypothesis", which form a kind of top and bottom boundary. Such speculations hardly clarify possible future situations, since the sweeps made around the mean are intellectually very superficial.

The motto which could be used to sum up this approach is "to foresee is to know". However, the quality of the knowing is debatable. There is thus no reason a priori that the structure should remain unchanged as time goes by and that changes or breaks should not occur in the developments.

- Normative forecasting operates in a totally different spirit. The fixed objective in the future is used as the basis for reasoning, rather than the present situation. One goes back in time from the objective to the present situation. The motto that may be used to illustrate this approach is "to foresee is to be able". However, commitment is not always enough, far from it. The objectives may be unattainable. Starting from the objective one cannot use recurrent reasoning to return to the starting point. If this is lower than the arrival point, it means that the normative forecast is too high or, if it is higher, that the normative forecast could be higher.

8/ The basic literature in this field is the book by R. U. AYRES, "Technological Forecasting and Long-range Planning", MacGraw-Hill, 1969, and, in French, R. SAINT-PAUL and F. P. TENIERE-BUCHOT, "Innovation et évaluation technologiques", Entreprise Moderne d'Edition, 1974.

Technological forecasting methods



Continuous methods

1. Individual

Trend extrapolation
Envelope curves
Precursor analysis
Learning curves
S curves and analog, heuristic and phenomenological models
Statistical methods: variance analysis, simulation, *a priori* probability, plausibility

2. Collective

Scenarios
DELPHI
Cross impact matrix

Discontinuous methods

Morphological analysis

(for information)

Science fiction
Creativity methods, brainstorming, buzz-groups forecasting games, synectics

based on R. SAINT PAUL and P.F. TENIERE BUCHOT

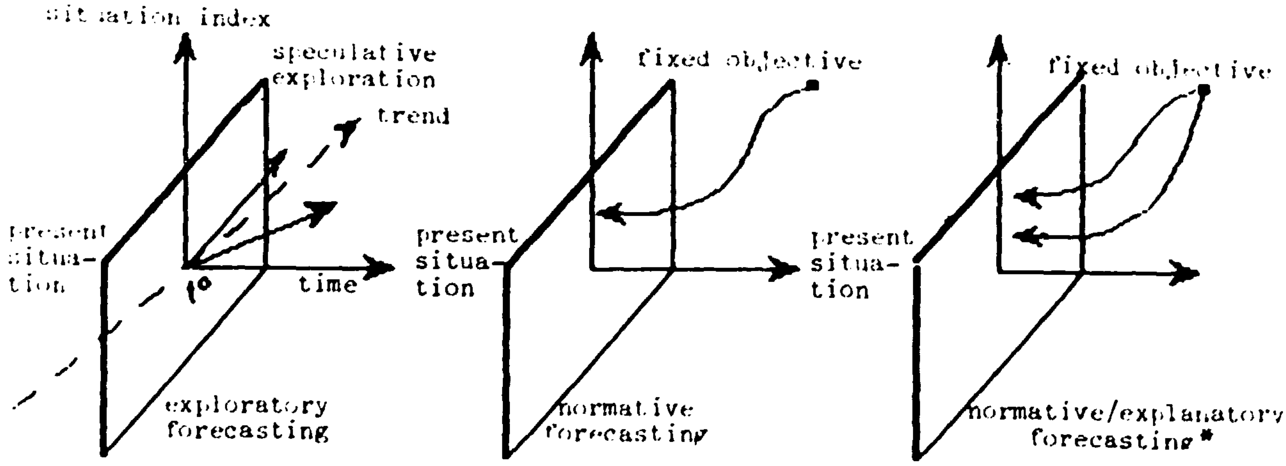
- Normative forecasting leads to an <u>explanatory approach</u> and a <u>correlative approach</u>.

<u>The explanatory approach</u> is the consequence of normative forecasting. The aim is to find out why certain objectives are attainable and others not. The causes are analysed on the basis of the effects they engender along trajectories running in a recurrent fashion from the objectives to the present situation. Phenomena are no longer envisaged with reference to their effects, a characteristic of tendential forecasting, but rather to their causes. Since these are generally varied, the effectiveness of the method depends on the quality of the tools used for the causal analysis. The problem is displaced without thereby being solved.

<u>The correlative approach</u> is a more highly developed form of the explanatory approach. The objective is considered in its environment. The environment is made up of constraints and factors that are favourable or unfavourable to the attainment of the objective. The links between these factors and the objective make it possible to establish correlations. However, as in statistical theory, there should be no confusion between correlation and explanation. Correlation is a presumption. The approach may give the impression of false security, which makes it dangerous. Once again, one cannot do without causal analysis and consideration of the impact of the environmental variables on the structure of the system considered. Nevertheless, the approach is a sort of transition towards systems analysis.

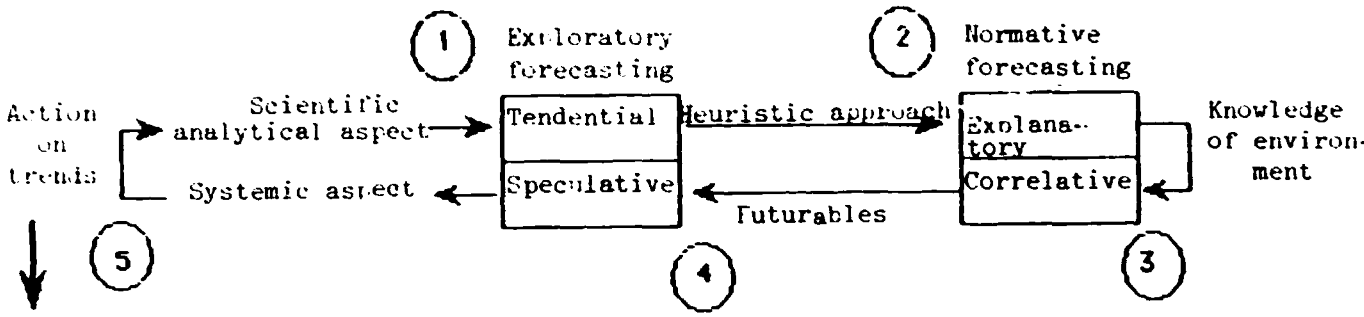
In short, the normative approach is more interesting and action-oriented than the tendential approach, but there is a trap: the planner may mistake what he wants for reality. One cannot be normative if one discards all the devices for verification.

The following <u>outline</u> summarizes the <u>tendential and normative approaches</u>.



* <u>Source</u>: Saint-Paul and Tenière-Buchot.

The two approaches, tendential and normative, are useful and even necessary. However, they have their limits. They provide glimpses into the future(s). They may supplement and fertilize each other. They need to be synthesized. This requires a more complicated machinery which brings together both types of methodology. The following <u>outline</u> describes this:



The synthesis of the two approaches furnishes exploratory forecasting with the ideas it lacked and normative forecasting with the theoretical guarantees of verification which a priori make it possible to eliminate utopian attitudes. The synthesis provides a way to progress from the observation of trends (marked (1) in the outline) to explanations (2) in the form of causality relationships by means of a "heuristic" approach that involves moving from effects to causes. The systemic approach begins at stage (3). It involves acquisition of a thorough knowledge of the correlations between the result to be obtained and its environment and speculating on possible futures, the "futurables". In other words, the short- and medium-term future is deemed to be determined by a sought after and feasible, long-term future. These speculations, variants around the trend, may then, in the light of the possible futures, be interpreted in concrete terms (4). The system loop is completed by acting upon the trends selected in order to respond to the choices determined by the speculative approach (5). Implementation of this outline would open up vast possibilities for the forecaster, as regards both conception and action. 9/

It may be interpreted as the search for a system that combines different methodologies that are indispensable but, when taken separately, are reductionist in relation to a more complex reality. In other words, the "variety" (cybernetic notion which expresses the number of states that a system may assume) of separate methodologies is too weak to apply to the technology system. The synthesis and the approach embodied in the outline may indeed be considered as a path towards systems analysis which is the outcome and the synthesis of numerous disciplines and a starting point for technological forecasting. It is a third path towards the methodological approach, alongside that indicated by Descartes (evidence, breakdown into elementary parts, synthesis and order, generalization in law) or that indicated by Claude Bernard (observation, hypotheses, testing, postulation of a law, verification). This leads us into a tangle of language and structure, particularly with regard to data processing and logic. Such research gives rise to considerable difficulties: for example, the question of mutations or creations among the elements of a system is one that has been hardly dealt with. 6/

9/ It is 15 years since SAINT-PAUL and TENIERE-BUCHOT formulated this view (see reference 6) which is definitely feasible. It does not appear that an approach of this nature, combining the two foci of forecasting, has been implemented.

Intellectual approaches

The above outline of "technological forecasting methods" contains a second column entitled "intellectual approaches", which is a supplementary classification. Even though the principal classification criteria is the exploratory/normative duality, in reality no method is completely exploratory or normative, but a mixture of different proportions of these extremes, depending on the forecaster's inclinations. Certain methods will be more rational, others more intuitive. Rational methods are usually exploratory, whereas intuitive methods are generally normative. The two classifications overlap, but should not be confused.

Logic

The third column of the outline is entitled "logic". This refers to the logic used in the forecasting - ontological or causal.

Ontological logic (or observation logic) considers the subject studied as a whole and indicates its evolution according to observation of the whole. There are numerous exploratory techniques based on this logic in which the causes will not be investigated.

Teleological logic (or causality logic), however, considers the constituents and explains the evolution and the purpose of the whole through a modelized representation of varying complexity. The correlative, econometric, experimental, phenomenological, dynamic, learning and other models are based on this logic.

A **synthesis** of these two logics remains to be made. One may conceive of a richer and more systemic ontological logic relating to understanding of the structure, relations and interactions between the parts themselves and with the whole. These interactions, whose configuration constitutes the organization of the system, may be a source of contradictions, be mutually over-determined or have weak or strong links or degrees of cohesion and coherence making the whole more or less stable or unstable. This brings us into the field which is beginning to emerge from the complex thought and dialectic. It is in this intellectual field that we will, from now on, find the true responses to questions of long-range planning, in general, and technological forecasting, in particular, and not in the improvement of such or such a technique.

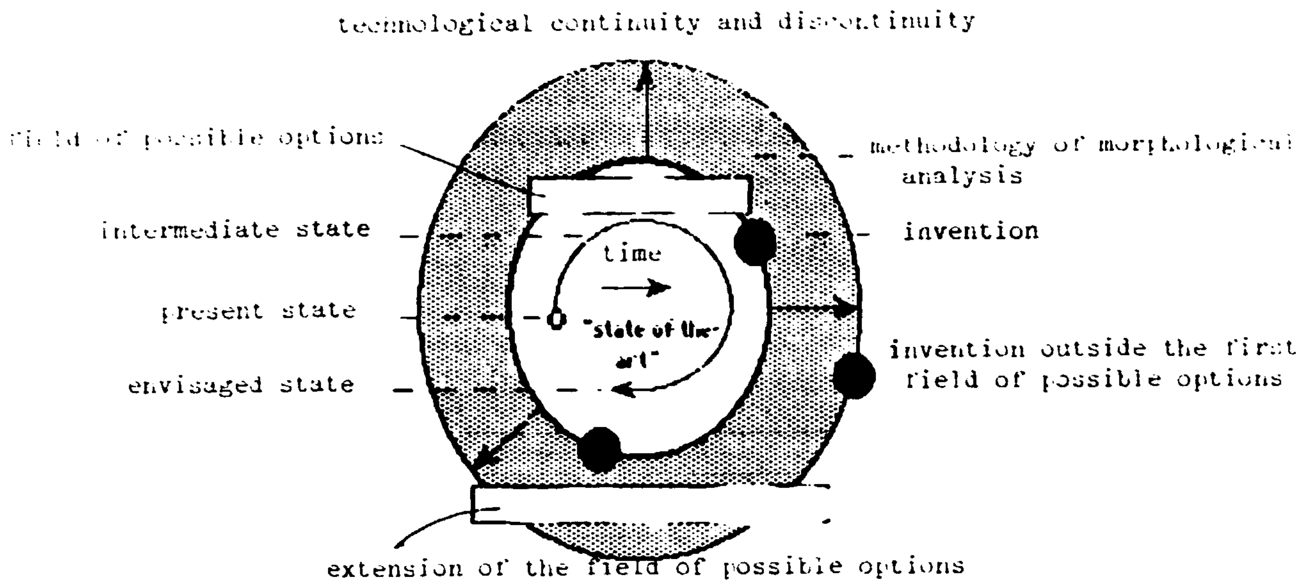
Continuity and discontinuity

Forecasting methods may also be classified as "continuous" and "discontinuous".

Most forecasts are continuous. In the field of possible options, a trajectory makes it possible to move regularly from what exists to what is foreseen. An interesting method involves measuring this field of possible options (called "state of the art" by American writers 10/) and studying the solutions within it. However, technological jumps may occur outside this field as a result of the appearance of inventions or innovations, rather akin to particles jumping from one orbit to another in quantum mechanics. These are often major innovations like the transistor, polaroid materials, freeze-drying or the laser. The methods, morphological analyses in particular, then act act as discovery matrices.

The following **outline** summarizes the differences of approach.

10/ For example, E. N. DODSON "Measurement of state of the art and technological advance", J. P. MARTINO "Measurement of technology using trade-off surfaces", Technological Forecasting and Social Change, 27, 1985.



Overview of the principal methods used in technological forecasting

Following the presentation of the typology of forecasting methods, focus, intellectual approach and logic, it is useful to look more closely, not at all forecasting methods, but rather at those which may be applied to technology. We shall therefore analyse the "envelope curves" in the trend extrapolation family and, in the mixed extrapolation and normative family, the S curves and analog models, statistical methods and state of the art and, in the predominantly normative family, scenarios and cross-impact matrices, the DELPHI method and morphological analysis.

Envelope curves

Extrapolation is a mediocre forecasting tool. It postulates the continuity of phenomena over a period of time. What we want to know is whether there are any points of inflection, indicating changes in orientation of the curvature of the trend. If this is the case, it goes without saying that extrapolation is inoperative for forecasting purposes. Phenomena may also be cyclical or periodic and have several inflection points. Extrapolation of the trend postulates in addition that "all other things are equal" (ceteri paribus). This amounts to believing in a "certain" future. Statistical series may indicate remarkable linear progressions, such as the rates of electricity consumption or the power of automotive vehicles, which doubled every 20 years between 1900 and 1970. In the context of the continuous growth of the world economy over the 30 years following the Second World War, there were numerous series of this kind. The difficulty for impetuous forecasters lies in the fact that the world economy is governed by cycles, no doubt long-term cycles, and that it has inflection points and critical breaks. Consequently, the environment surrounding technological forecasting in the past 15 years has been considerably altered. The oil crises have brought about unitary energy savings and slowed down the race for more powerful motor cars. Awareness of the dangers involved for the planet in the development of industrial activity creates a new situation, this time in terms of the constraints imposed by the societal and political environment.

The envelope curves are a way of taking into account the different constraints. It is necessary to distinguish between absolute constraints, relative constraints and economic constraints.

Absolute constraints relate to the laws of nature, physical constants or physiological limits. Examples of such constraints are the theoretical limit on the efficiency of a propeller, the resolving power of generations of microscopes built according to successive scientific and technical principles, the number of fleas per unit of surface area, the G force that can be tolerated by the human body during acceleration, and so on. These are essential parameters for assessing qualitative barriers, the saturation point of technologies and the corresponding industries.

Relative constraints are generally process-specific. They correspond to the state of the art. These are provisional limits. They are more extensive and quantitative. Hence, the measurement of the critical temperatures of materials with superconducting properties concerns a relative constraint. The techniques permitting the creation of a new generation of supercomputers working in parallel also belong to this category of constraints.

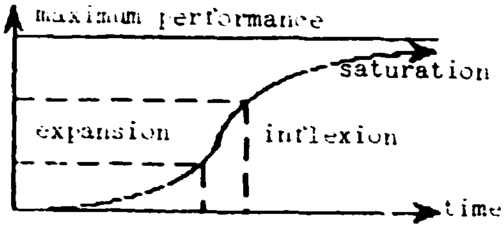
Economic constraints represent the third type of constraint. It is not enough to envisage technical development with remarkable performance levels - it also has to be acceptable in terms of requirements and costs. A major innovation, even at initially high cost, may have a destabilizing effect on the sector in question. Ensuring a monopoly of innovation on the market may accelerate the obsolescence of competing processes or products. Technology policy now spearheads strategic management. The data it requires are the economic constraints and the limits of ability, but it can act upon them, at least in respect of the "active units" capable of influencing their own environment.

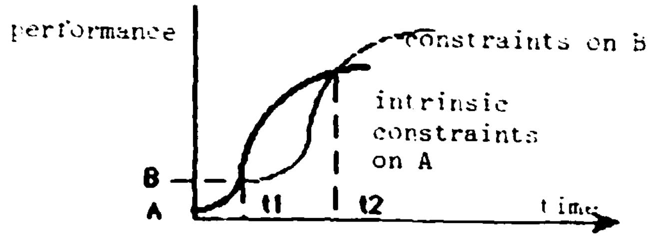
When constructing an envelope curve we need to take into account these elements and this is why its construction is problematic and more complicated than the simple mathematical curve would suggest. However, the by-product of its creation, namely the mass of necessary details, is perhaps more important than the envelope curve itself. Its interest lies in the fact that it places the problems in a more general context, but does not make it possible to forecast any breakthrough in processes.

S curves and analog models

S curves are an analog transfer in the field of innovation of biological growth in a closed environment. This is because the latter may be represented by a curve with three distinct parts: initial expansion (rising curve), transition zone (inflexion point) and saturation (falling curve). Several equations may be used to represent this pattern (e.g. the Pearl equation, Gompertz equation or von Bertalanffy equation). The usefulness of S curves in technological forecasting is twofold. Firstly, they make it possible to use a series of statistical points to draw a more realistic curve than a uniform, logarithmic or exponential straight line. They also make it possible - at least in theory - to link forecasts over a period of time, as the forecasters successively correct the projections corresponding to the three stages. Secondly, most importantly, they may be used as a guide to decision-making by identifying the intrinsic constraints in the stages of technology.

The following outline summarizes the form and use of S curves:





Statistical methods

The notion of probability clearly forms part of the conceptual arsenal available for forecasting purposes. What distinguishes the notion of probability from expectation is an indication of the likelihood of success. However, it is necessary to make a distinction between "probabilisable" future and uncertain future. The calculation of probabilities only applies to the former. In this case, a mathematical expectation and a variance may be calculated, tests may be made and confidence intervals may be deduced therefrom. With regard to the uncertain future, none of this may be done. It would be assumed that all events have the same probability of occurrence. One can go no further.

In the probabilisable future, the establishment of "ranges" around the trend may give rise to statistical calculations. In order to make the latter, it is necessary to have a sufficient quantity of information from which one deduces the confidence intervals based on the residues resulting from processing using the least squares method. None the less, practice shows that, in long-term projections, the breadth of the "ranges" increases greatly. The ranges are well-suited to short-term forecasting, but are practically useless for technological forecasting.

In uncertain forecasting, there are several techniques available. There is the Monte Carlo method, which is based on random probabilities and, along the same lines, the Markov models do not correct random probabilities, but transform them gradually by means of transition matrices made up of probabilities. The theory of games has also been tested in technological forecasting, apparently without promising results.

State of the art (SOA)

The expression "state of the art" is here taken to mean level of the technology. 10/ Modern technology, particularly military and space technology, is highly complex and develops very rapidly. It is therefore a matter of assessing the benefits of new systems. A technology may be described by one or more parameters that measure its features. Sometimes the performance of the parameters is dominated by a single parameter which is sufficient to characterize the SOA. In most cases, a technology has a set of technical parameters which measure its features. A family of similar technologies at the same SOA level may have different values for each parameter. These technologies, objects or processes may be equivalent for the designer because each represents a different balance (trade-off) between parameters which the designer is free to modify. In fact, at a given moment, there is a fixed amount of technological performance available for a class of technology. If the designer wishes to increase the value of a technical parameter he must sacrifice one or more other parameters.

Conceptually, the SOA may be seen as a surface in a space of multi-dimensional parameters. Designers are free to move over this surface by creating alternative designs. There are limits to this freedom. They may not move to a "lower" surface, which would be inefficient. They may not move to a "higher" surface unless there is an advance in the SOA. This echoes the notion of maximum operating surface developed in political economics. 11/

The precise point on the "trade-off" surface selected by a designer depends on the users' requirements and this point is at a tangent to the "trade-off" surface of usefulness for the user and the accessible surface for the designer. It is the determination of this last surface which has been the subject of recent research. To clarify this abstract representation of a "surface" we shall use the example of the parameters considered which interact within a technology:

> Designing a sailing boat involves a number of "trade-offs". A boat must transport the greatest possible load within its size constraints. This means that, for a given length, it must have an appropriate beam and draught. Furthermore, it must transport this load at the highest possible speed. In addition, the boat must be able to gather speed both into the wind and with the wind behind it. When gathering speed with a tailwind, it requires a narrow beam and slight draught, whereas a headwind requires a deep draught. For a given boat size, an economic and efficient design requires careful juggling with the different dimensions under the supervision of a naval architect. This poses many problems.

Any technology involves correlated variables with frequently contradictory effects. The freedom of design is therefore within the "surface" bounded by the state of the technology and tends to optimize the compromises made in the selection of variables.

Mathematically, the "surface" is an ellipsoid of the order of 2, that is to say a convex surface with three planes of symmetry, two to three orthogonals and three axes of symmetry with two orthogonals, with these three planes and these three axes intersecting at a single point which is the centre of the ellipsoid. The parameters of the ellipsoid are those obtained by SOA analysis.

Hence, it is possible to compare different generations of technology (e.g. propulsion engines or transistors), to measure the evolution of their "surfaces", identify the points of intersection and overlap of surfaces between generations and assess to what extent use was made of the technological potentialities available at a given time. It appears that such research has not been applied to technological forecasting and it is uncertain whether it would be possible to anticipate future SOA changes, but it does seem to provide food for thought. Such research makes it possible to break down the technology and to go into the logic and coherence of the association of its parameters.

The DELPHI method

This is probably the most widely used method and it has given rise to thousands of applications. It is based on the principle of the convergence of opinions, a consensus which is generated by successive iterations within a group of carefully-chosen persons individually answering the questions asked.

11/ See F. PERROUX, "Unités actives et mathématiques nouvelles", Dunod, 1975.

There are three essential stages:

- Formation of a group of experts;
- Preparation of a questionnaire;
- Consultation and processing of information gathered.

The establishment of a group of experts is a prerequisite of all the activities. The term "expert" is understood, not in the sense of a specialist in a narrow discipline or a holder of prestigious titles, functions or rank. A DELPHI expert will be chosen for competence, naturally, but also breadth of vision and forward-looking approach. On important matters, the organizers of DELPHI must therefore draw up a list of 100 or so names so that the final team participating right up to the end of the investigation is not too small.

We should say right at the start that there is some "bias" inherent in the establishment of the group. The method is based strictly on the principle of the participants' independence and their separation when formulating their answers. This essential condition can only rarely be fulfilled. The experts generally know each other and move in circles in which they have many occasions to meet. Even though an expert is independent and separate, he or she is still liable to the "effects of fashion" which give rise to convergence of opinion and conformist attitudes in a given situation.

The preparation of the questionnaire is the responsibility of the organizers of the investigation. The questionnaire must be precise and the questions must be quantifiable and mutually independent, which is not always an easy task. Independence is taken to mean a situation in which the supposed realization of one of the questions at a given date has no influence on the realization of another question. A thorough study of the questionnaire is thus necessary in order to eliminate, as far as possible, any mutual dependence between questions. As in the case of an opinion poll, the questionnaire is tested on a limited number of individuals.

Sectoral or specialized questionnaires are the most difficult to prepare because the links between the parameters are numerous. The general questionnaires which relate more to the future than to a particular field contain more diversified questions with a fortiori fewer links between them. As in any opinion poll, the initial formulation of the questions inevitably has an impact on replies, despite the special arrangements for DELPHI. The questionnaire unavoidably provides an initial framework which reflects one representation of the problem.

The survey and its utilization. The operations involved have five stages: four investigation stages and one stage in which the findings are processed.

Stage No. 1: despatch of the first questionnaire.

The questionnaire is posted to 100 recipients in order to allow for drop-outs during the investigation. Statistical theory shows that a sample is not only significant by virtue of the percentage of representativeness, but also by virtue of its absolute size. In this case, a minimum of 25 questionnaires is needed.

An introductory note explains the aims and spirit of DELPHI and gives assurance that all replies will be treated anonymously. Each expert must indicate his name at the bottom of the introductory note in order to guarantee authenticity and to facilitate processing.

A special feature of the first questionnaire is that each expert must give a notation for each question. The scale of values generally used is as follows: 1 = very competent (specialist), 2 = competent, 3 = abreast of the subject, 4 = unfamiliar with the subject, 5 = incompetent (the expert must nevertheless give one answer).

This self-notation will make it possible to sort the answers which are deemed to be the best and to facilitate their subsequent interpretation.

<u>Stage No. 2</u>: processing of the first questionnaire and despatch of the second.

The organizers eliminate the answers by the experts which they do not wish to pursue. They deal with each question according to the rules of descriptive statistics. A distribution is constructed and a median and an interquartile difference are calculated.

Let us assume that the question concerned the possibility of a manned flight to the planet Mars. If the distribution median falls at the year 2010, this means that 50 per cent think that the flight could occur before the year 2010 and 50 per cent afterwards. Also let us assume that 25 per cent of the experts think that the journey will be possible before 2005 and 75 per cent think otherwise. This is the first quartile Q1. Another assumption: 75 per cent of the experts think that the journey will take place before 2015 and 25 per cent think otherwise. This is the final quartile Q3. The interquartile space IQS is defined by the two dates 2005 and 2015 and 50 per cent of the experts think that the event will occur within this range, whereas 25 per cent of "optimists" think that it will occur before and 25 per cent of "pessimists" that it will occur after. <u>The objective of the DELPHI method is to reduce the interquartile space while establishing the median more exactly</u>.

The second questionnaire sent to the experts will inform them of the results of the first by indicating the year of the median M (2010) and the interquartile space (2005-2015). The expert's answer in questionnaire No. 1 will be recalled and his or her new answer and the reasons which place it above or below the interquartile space (IQS) will be requested.

This second round contains a certain bias. If the first response falls within the IQS, the expert may be encouraged to repeat it and to enjoy "majority satisfaction" and it is unusual for the expert to change his or her opinion. If the first answer deviates from that of the majority, the expert must justify it. An expert who is undecided or has no real preference may be tempted to side with the majority view.

<u>Stage No. 3</u>: processing of the second questionnaire and despatch of the third.

The approach is the same as in Stage No. 2. The processing of the second questionnaire indicates a narrower distribution than the first. The new values for the median and interquartile space are, for example, 2009 and 2006-2012. In the third questionnaire the new values are indicated, as well as the views of the "extremists". The experts will be required to give their opinion on whether to join the "majority" or, on the contrary, to stay out of the majority. They are also required to back up their views in the form of counter-arguments against the allegations put forward.

The organizers thus form a channel for debate among the participants in the survey. However, it should be noted that the debate only concerns the deviant attitudes and not to those of the majority. We can understand straight away why the method is well suited to decision-making: it encourages successive consensus to narrow the choices and it is less effective for exploratory applications.

The method followed to reduce the IQS gives rise to predominantly centrist views.

Stage No. 4: processing of the third questionnaire and despatch of the fourth.

The preceding process is repeated. Questionnaire No. 3 will give, for instance, 2008 as the median and 2006-2010 for the IQS.

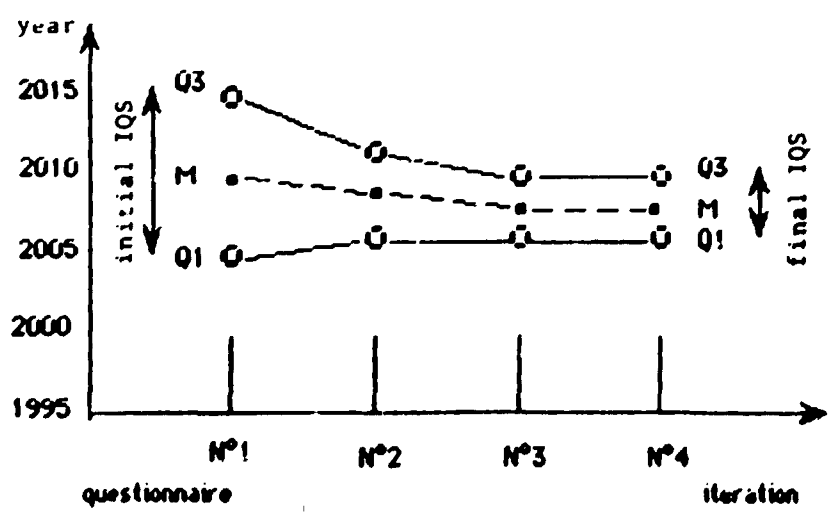
As before, Questionnaire No. 4 will indicate the values for M, Q1 and Q3, as well as the counter-arguments put forward by those favouring one or other end of the histogram.

The experts will be asked for a final answer in the light of the latest exchanges of views.

Let us take the arguments put forward by those in favour of an earlier event: for example, the wealth of information collected by unmanned space probes has considerably enriched knowledge of Mars for the purpose of sending human beings there, the technology of rockets and recoverable space vehicles has made great leaps forward, the cold war has ended and disarmament has taken place - all this facilitates co-operation between the USA and USSR in sharing the costs. The arguments put forward against this venture could be the following: the end of the cold war has introduced other priorities in international co-operation, such as assistance to the third world, protection of the biosphere and biomedical research; the scientific information to be collected does not require the presence of a human being on board the space vehicle, knowledge regarding the adaptability of the human body to manned flight remains inadequate to justify the risk, and so on.

Stage No. 5: processing of the last questionnaire and final results.

The investigation is now finished and the distribution of answers shows no significant variation. The IQS is stabilized and the attitudes of the experts have crystallized. All the answers are recorded on a table which separates the average response of the specialists, for example the year 2009. In short, during the investigation convergence has occurred, as indicated by the following graph:



The narrowing of the spread of opinions is reassuring, particularly when the majority position is supported by the experts. This is an advantage when taking a decision, as well as a risk. In science and in technology, a deviant or marginal view may prove to be right in the face of the "establishment". The "majority" may also be more sensitive to fashion. Hence, it is probable that, if a DELPHI survey had been organized on the prospects for superconductivity immediately after the discovery by the IBM Zurich researchers, the prognosis on application to loss-free electricity transmission, levitation of trains and other technological and industrial breakthroughs would have been extremely over-optimistic.

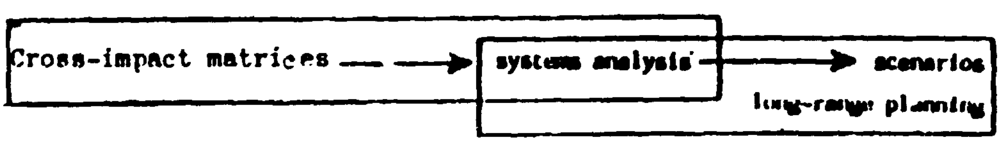
There are computerized procedures for the rapid processing of information generated by questionnaires and the automatic preparation of the subsequent questionnaire on the basis of the answers to the preceding one. It is thus possible to obtain the final results in a few hours, provided that the participants possess remote data-processing equipment. This advantage is offset by the shorter time for reflection, though such might be useful when dealing with complex problems.

Cross-impact matrices have been designed as a critical extension of the DELPHI method. The main criticism made was that the forecasts generated were isolated points in space and that this isolation greatly weakened confidence in and the value of such forecasts. A refinement was thus introduced to avoid bias through the non-independence of the questions posed. This refinement brought about a veritable qualitative change in relation to DELPHI. By considering cross-impact relationships, it is possible to strengthen or weaken the importance of certain questions by extracting the essential variables which affect all the questions posed. The results obtained at the end of the consultation will be modified.

The refinement takes the form of "cross-impact matrices".

The principle is simple. It is restricted to a systematic study of all of the relationships which may exist between the different parameters by examining them two by two. In this way, it is possible to draw up a list of all the parameters connected with a given problem. This exercise may be individual or collective. However, with regard to important problems which require considerable competence and have a social dimension, the exercise is generally collective. Identification of the variables is an aid to understanding. The establishment of cross-impact matrices - also known as structural matrices - already forms part of systems analysis, the basis of scientific long-range planning, of which the scenarios are one of the forms.

The methodological part is therefore the following:



The obvious direct influences between variables are classified by using a binary notation in the intersecting boxes of the matrix square. Either they exist and a sign is used to denote this or they do not exist and no sign is used.

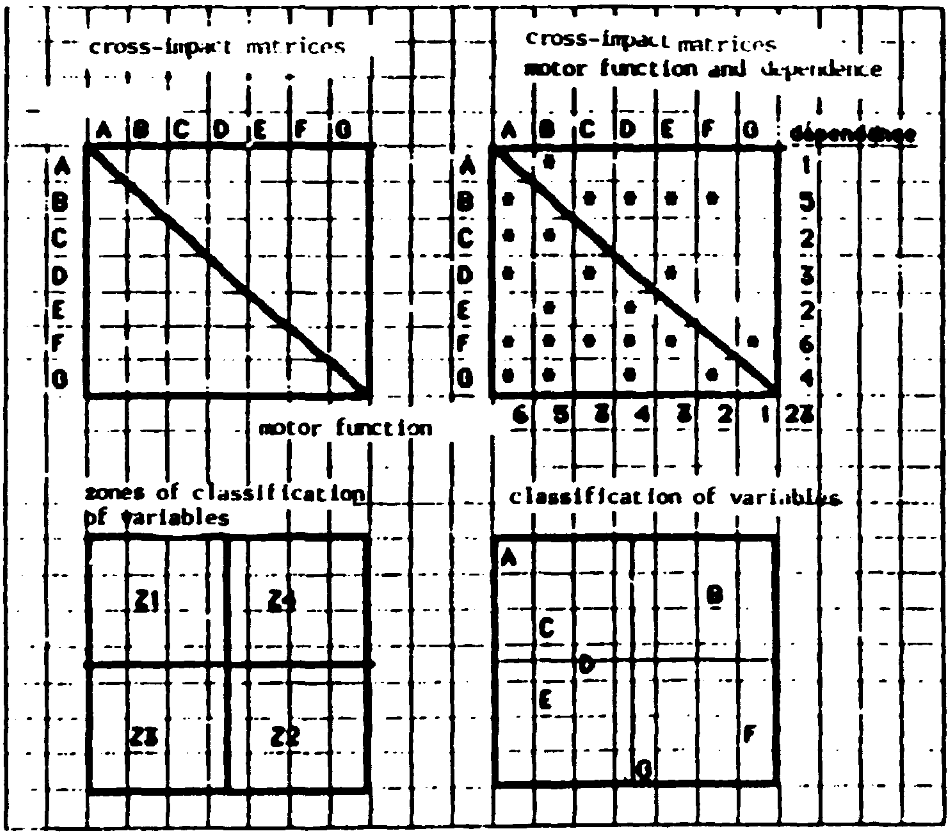
Counting of the column intersections reflects the global influence of one parameter on the others. Reciprocally, line counting expresses its dependence. This double counting generates two notions:

- **Motor function**, indicating the number of times a parameter may influence a system in different ways;

- **Dependence**, indicating the variety of the influences to which a variable may be subjected by a system.

The following graphs illustrate cross-impact matrices. The cluster of parameters may be divided into four zones: a zone in which the variables are a strong motor function and are scarcely dependent (Z1), a zone in which they have a weak motor function and are highly dependent (Z2), a zone in which they have a weak motor function and a low level of dependence (Z3) and a zone in which they have a strong motor function and are highly dependent.

Structural matrices



Motor function and dependence are measurements of frequency and not intensity. It is true that, in the case of complex social systems, the greatest difficulty is experienced initially in assessing the existence of relationships and, at best, the direction of such relationships. Under such conditions, it may seem unfeasible to quantify their intensity. Econometricians do not always have these scruples. However, in many cases, it is possible to establish a scale of intensity. This does not alter the principle, as one calculates the "weight" of the influence of the motor variables on the others and, reciprocally, the "weight" of the influences felt.

In the event that the matrix contains numerous variables, a refinement might involve seeking the indirect relationships between them which may not be detected, for example, in the analysis of graphs. This is because, apart from the direct relationships, they are also indirect relationships through chains of influence and reaction loops (feedbacks). A commonplace matrix with several dozen variables may comprise several million interactions in the form of chains and loops which it is impossible for the human mind to represent. The MICMAC method 6/ makes it possible to study these paths and loops. The principle is based on the conventional properties of Boolean matrices. A program of matrix multiplication applied to this structural matrix permits deduction at each iteration of a new hierarchy or variables classified this time in relation to the indirect action they exert on the others. From a certain power level, the hierarchy remains stable and it is the hierarchy that is included in the classification of the variables.

Common structural matrices (CSM) are an essential aid to understanding. Nevertheless, they do have serious limitations. Since they do not record the direction of the relationships, they do not permit examination of the contradictions and regulations within the systems. These are essential phenomena governing development. It is thus necessary to supplement the CSM by other tools to take account of the positive and negative influences of a system and to provide separate pictures of them. Negative-positive-neutral (NPN) matrices represent a step forward in this connection. 11/ Another possibility is to calculate the positive and negative "varieties" with a contradictory effect on the system. 7/ These additions are not mere details. It is not without interest to know whether a variable has an effect on other elements in a positive or negative fashion. Indeed, it is known that the cumulative total of positive relationships (of the exponential growth law type) gives rise, when "plus" generates "plus", to explosive effects, whereas the cumulative total of negative relationships gives rise to blocking effects when "minus" generates "minus". When any variation towards "plus" generates a correction towards "minus", the negative feedback to the positive relationships may be used for regulation and establishment of balances. This gives one an inkling of the implications of taking account of the quality of the relationships. It then becomes possible to identify the contradictions in the influence and dependence of each of the variables and the system as a whole. It is thus necessary to incorporate an analysis of the contributions into the analysis of the dynamics of the system evacuated by the CSM. This is because the contradiction is at the heart of understanding of the system and its development. Nevertheless, this has not been put into practice in forecasting and long-range planning.

Scenarios are the development of the current state of the common structural matrices (CSM).

We have already seen how it is always possible to split the joint-impact matrix into four zones, whether by ranking of the variables or with regard to the average levels of motor effect and dependence. This thus provides an initial basis for extracting the essential variables from the system in question for use in establishing senarios.

The zones have a meaning. The "strong" variables, with a powerful motor effect and low dependence (Z1), have relative independence. The "weak" variables, which are strongly dependent and have a low motor effect (Z2), are to some extent the results of the system. The variables which score low both in dependence and motor effect (Z3) are virtually autonomous. However, the variables which are both

---

11/ ZHANG W. R. et al.; "Pool 2, a generic system for cognitive map development and decision analysis", IIEE Transactions on System, Man and Cybernetics, January February 1989.

strongly influenced and have a strong motor effect are sensitive elements of the system, which may be called "relay variables". It is the strong variables and the relay variables which will play the principal role in the development of the system considered. They will form the basis for formulating evolution hypotheses.

Evolution hypotheses are formulated in view of the strategy of the actors operating the essential variables. The world of scenarios is not a shadow theatre or an economy governed by an "invisible hand". It explicitly incorporates power relationships into an understanding of the past and the present and into thoughts about the future. The basic construction of a scenario thus comprises: establishing the limits of the system and, if appropriate, its division into sub-systems; analysis of its past development and its present state; identification of its development factors; the actors' projects.

The sets of hypotheses may then be probabilized using different techniques. The most important step is to put these hypotheses together into a coherent whole. The scenarios differ fundamentally in principle from the DELPHI method: whereas the DELPHI method is concerned with the convergence of opinions, the scenarios are concerned with the coherence of the resultant images of the future.

DELPHI starts from a hypothesis and obtains an image of the future with an implementation date, whereas scenarios are constructed from hypotheses deduced by analysis and their coherent combination gives images of alternative futures. Not all futures are envisaged, only those which appear to be possible. One technique involves producing a tendential scenario and contrasting scenarios leading to different futures. An attempt is then made to identify, within the possible scenarios, the most probable one. This is then compared with the desirable scenario. Comparison of these two scenarios provides an indication of the measures to be adopted to ensure that future reality is as close as possible to the desired future. Between the scenario(s) envisaged and the current situation it is possible to map out one or more paths, i.e. itineraries by which to arrive at the desired goal. Envisaged in this way, a scenario is no longer merely a descriptive and passive instrument, but an active and anti-fatalistic instrument in the service of projects and hopes.

It must be said that few scenarios obey these construction rules and that the inaccurate term "scenario" is used to cover what is very often no more than the extrapolation of a trend. However, despite its interest, the scenario method does have weaknesses. Consequently, the number of theoretically conceivable scenarios rises with the number of hypotheses considered at a rate of 2^n. With six hypotheses there are 64 envisageable scenarios. As a result, the trend is to reduce the number of hypotheses, often at the cost of an aggregation of variables whose theoretical justification is not always clear and which, in any event, may contain disguised contradictions. An intellectual effort is therefore made in two opposing directions: firstly, an attempt is made to gain the most thorough knowledge of the system through cross-impact matrices and their treatment; secondly, a drastic reduction is made in the information by a non-demonstrated compression of the variables and the developments of the system. It is undoubtedly necessary to implement an R&D programme for this essential long-range planning tool. None the less, despite their limits, scenarios are a collective way of considering and gaining awareness of problems which has positive effects, more through the process of its elaboration than through its results and more through the anti-fatalistic attitude it engenders than through the decisions it suggests.

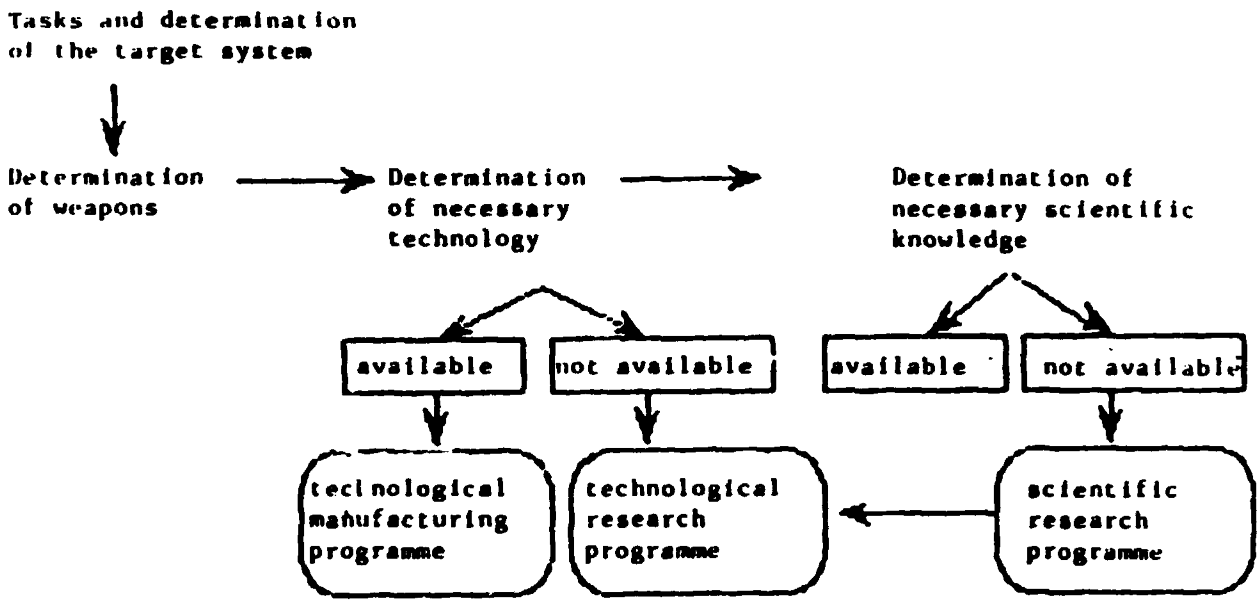
In the more specific field of technology, the method also stimulates deeper systemic analysis of the "physical" and "social" realities which condition the creation and evolution of innovation and its diffusion. 4/

Iterative "task-technology-science" matrix method

Operational methods have been developed by the armed forces for technological forecasting on the basis of the tasks in hand, particularly in the definition of new weapons.

The approach may be summarized in the following way. Given a task to be accomplished, one determines the appropriate weapon(s). One then asks whether the technology exists to produce the weapon. If it does exist, there is no problem. If it does not exist, the next question is whether the knowledge exists to create the technology. If it exists, the corresponding technological programme may be established. If it does not exist and if the relevant scientific knowledge proves to be lacking or insufficient, it is advisable to organize an appropriate scientific research programme.

This gives the following sequences:



The tasks are determined using a relevance tree (apparently used for the first time by the Honeywell Company in military and space matters and then in the Apollo Programme by NASA). The passage from one sequence to the other is then effected by project/technology, technology/fundamental science and fundamental science/project matrices. These techniques are evidently perfectly transposable to civilian life and would be particularly useful in developing countries for the organization of scientific and technological research for the implementation of projects connected with their specific requirements.

The method is <u>teleological</u> and starts from the goal to be achieved before returning, as applicable, to the fundamental science to be mobilized. It therefore moves from the future towards the present and from the base of the technological edifice towards its summit.

Morphological analysis is a method that differs from all the others. 12/

12/ The method was designed by the famous astronomer ZWICKY who discovered the existence of black holes in space; see "Morphology and Nomenclature of Jet Engines", Aeronautical Engineering Review, 1947.

Here it is not a matter of developing situations or systems over a period of time or even of forecasting the occurrence or appearance of a specific event, but rather of <u>imagining</u> what this still unknown event could be, thereby extending forecasting towards the area of <u>invention</u>.

The procedure is an inductive one. However, this approach is based on the <u>analysis of the structure</u> of the technology system in question. In biology, <u>morphology</u> is the science which studies the form and structure of living beings. "Morphological" analysis begins with the technological structure and goes on to imagine other internal combinations of the technical being and other arrangements leading to changes in the form thereof.

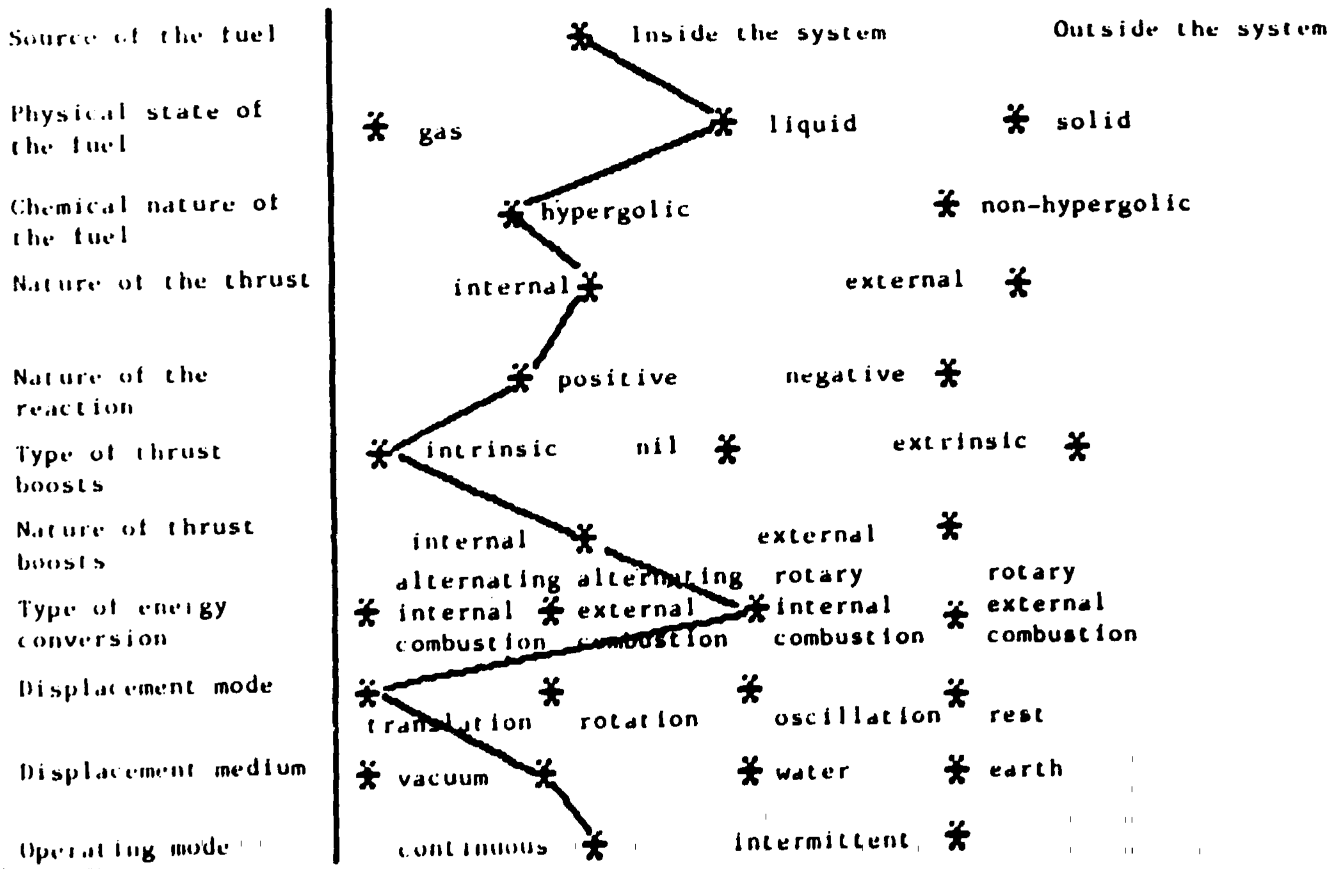
The morphological analysis method is thus <u>essentially systemic</u>. Its aim is basically exploratory. The end result sought is an overall vision revealed in a single glimpse and not a gradual approximation subject to probabilities.

There are two stages in the anlysis: breakdown of the structures into levels and search for solutions.

- <u>Breakdown of the structure into levels and search for solutions</u>.

- <u>Breakdown of the structure into levels</u>.

The diagram below gives a practical illustration of the analysis through the example of the breakdown of the structure of a chemical propellent considered as a propulsion structure which may be represented by several levels (left-hand column of the diagram). This analysis poses problems. Naturally, it requires technical competence, but also an ability to select the levels to be retained: an excessive proliferation of levels would make them impossible to analyse and too small a number of levels would be liable to impoverish the analysis and deprive it of any significance. The resultant compromise has considerable scope: it makes it possible to distinguish the structure of the system. <u>With the identification of the structure it becomes possible to reveal all possible combinations generated by the process of combining its constituents and their relationships, in a systematic fashion</u>.



There is an analogy with the "state of the art" method, but in this case the world is not governed by continuity, but by discontinuities, breaks and mutations. Morphological analysis becomes a discovery matrix. Here imagination has the sound basis of analysis of the structure and what it implies, with the simultaneous and global vision of the relationships between the whole and the parts.

Morphological analysis, which is essentially exploratory, none the less contains an element of scientific normativity on the part of the operator, a guideline and a will to succeed.

The search for solutions is effected by selecting modalities which satisfy each level. In this way one obtains a tree in which each path will be determined by a modality at each level which will represent an imaginable solution. This representation is reminiscent of the "relevance trees" and the "support graphs" used in the decision-taking methodology of choosing research projects. However, it differs in that the latter always have the same levels, whereas the levels of morphological analysis vary depending on the system studied. There is no standard framework, each structure has its specific features and must be dealt with as such. On a case-by-case basis, it is thus necessary not only to find the "nodes" of the system - its modalities - but also to reconstitute the characteristic levels. The analysis effort is therefore double since it is necessary on each occasion to reconstruct a method without predetermined elements.

The set of modalities chosen form what is known as the "morphological space or box" and the known solutions are represented by joining the different points of the tree by means of a continuous line. The above diagram relates to a turbo reactor. 13/ This is only one solution from among the 36,864 imaginable solutions (this is because multiplication of the modalities at each step is as follows: 2x3x2x2x2x3x2x4x4x4x2 = 36,864). Among these imaginable solutions, some will be very close to the known solution and may differ from it (for example) by only one modality. We then say that they have a "morphological distance" of one unit. The full set of close solutions will form a "morphological neighbourhood". This notion is very interesting and it could be used in developing countries, particularly in the effort to adapt to imported technology. It may also be transposed, in more general terms, for use in technological education to establish new curricula and new teaching approaches. The method is not easy to develop but it is a formidable intellectual machine which mobilizes not only the left hand side of the brain (analysis and rationality), but also the right hand side (imagination and creativity).

IV. THE FUTURE OF TECHNOLOGICAL FORECASTING

Emphasis must be placed on one interesting, but worrying, phenomenon at the end of this review of technological forecasting methods: the essential aspects were described and written up 20 years ago - Jantsch in 1967, Ayres in 1969, Saint-Paul and Tenière-Buchot in 1974 and Godet as regards Micmac in 1975. Without dismissing more recent important contributions, such as those by Martino in 1985 (analysed in this study) it must be said that no spectacular breakthrough has been made. Could it be that everything has already been said? This is doubtful. None the less, the technology variable has perhaps never before been of such importance among not only in mankind's societal decisions, but also in the strategic choices to be made by States and enterprises. This is a paradoxical situation. However, it is no more paradoxical than the fact that there is no taxonomy of technology.

13/ From E. JANSTCH, "La prévision technologique", OECD, 1969.

One might initially seek an explanation for this in the general conditions of the economy and forecasting during the period. The period of strong growth in the post-war cycle and the euphoria following the wave of innovations resulting from the scientific and technical revolution did not encourage strict forecasting. Reality was moving faster. The economic crisis in the early 1970s, its persistence, its extension with a vengeance to the developing countries and the economic, and the social and political crisis affecting Eastern Europe at the end of the 1980s have put an end to the "time of certainties and felicitous paradigms". The crisis has taken by surprise generations of economists in the West who dropped the concept from their vocabulary and were intellectually ill-prepared to grasp its meaning. For years they have had to navigate by sight and to practise crisis management. This has discredited forecasting in general, without sparing long-range planning, although it is not the same thing as forecasting. The clearest outcome has been the halt in appreciable research in these fields. However, the enduring crisis and growing uncertainty have made it necessary, particularly for multinational enterprises, to rethink the future. The body of analytical techniques known as "strategic enterprise planning" is the organizers' response to this demand, which constitutes a new market. It is a hasty attempt to transpose the long-range planning approach to the enterprise. However, since this approach has not meanwhile developed a new generation of instruments, it must be applied with the instruments already available and those which it remains to develop. In short, the impact of the crisis and the absence of R&D programmes in long-range planning partially explain the state of virtual methodological stagnation.

Another explanation might entail the internal conditions of technological forecasting during the period. It leads us to ask the question: "who has been the active focus of technological forecasting?" Without doubt it is the armed forces who have engendered the methods mentioned in this study. However, confidentiality must prevail. If a methodological breakthrough has occurred, it is a weapon and about which nothing should be said. The major enterprises have probably also developed their own methods under the threat of competition. That, too is a kind of war which, albeit only economic, cloaks advances made in secrecy. Work has indeed gone on, particularly in the petroleum sector, as well as in data processing, biotechnology etc., whether directly through the companies, through banking study subsidiaries or through companies setting up "risk capital" - enterprises in which the exploration of uncertain futures is an essential part of decision-making. However, it goes without saying that information regarding such activities is not public property. In short, military secrecy and business secrecy could veil progress in technological forecasting. Given this reservation, it would be very surprising if the methods likely to be used mark a decisive conceptual breakthrough. Since it would not then remain hidden.

It does not seem that the above reasons are the principal explanation, although they definitely play a role. The cause must be sought in the intellectual stagnation of long-range thought itself.

This is a conclusion reached by one of the men who has contributed most to the methodology and practice of technological forecasting and agrees fully with the views developed by the writer of this study. 4/ In an important article, R. U. Ayres, 14/ 20 years after having written the book which remains the most important work on the subject, reviews the situation and envisages the future of technological forecasting.

14/ R.U. Ayres, "The future of technological forecasting", Technological Forecasting and Social Change, 36, 1989.

To begin with, he poses a number of issues for which we require better forecasting methods such as: "Are the rate and direction of technical change foreseen with sufficient accuracy to provide a decision-making guide for investment and disinvestment? Is it now the time to push synthetic fuels? Photovoltaic cells? Superconductors? Fusion? Is there a rational way to reach a decision on these matters? Is there a long wave or a long cycle in the world economy? If so, is it correlated with a clustering of major innovations during the period? Where does this clustering happen? Is it happening now? Does the answer help to light the way for technology planners in the current situation?" Other questions have been better treated, partly because the data for analytical purposes already existed: e.g. an estimate of the relative importance as dominant features of technology change of the "push" force versus the "pull" force; measurement of the return on R&D investment; change in the effects on innovation of the costs relating to employment, capital and energy; determination of the relative innovation efficiency of small enterprises versus large companies. However, there are large and embarrassing gaps in our knowledge. This is particularly true of engineering data. This gap cannot be filled by economists. In the present context (the remark) is simply that economics is too narrow a discipline to deal with the question of technological change. The measurement of technological change is needed for a number of political decisions and implies an interdisciplinary approach, a better theory of technical change and new methodological approaches.

R. AYRES noted the bias introduced by the extrapolation methods and the weakness of the theory: "The relative rarity of the 'time series' available has obscured the fact that there is, in theory, an enormous possible choice of variables for extrapolation or modelling and that there is scarcely any theory to assist in their selection. In fact, the choice may affect the forecast in a subtle way. It is vitally important to acknowledge that the choice of the variables is a potential source of bias and to develop a systematic approach to offset this. (Incidentally, this choice may only be made by an analyst who possesses technological knowledge - one of the arguments for interdisciplinary efforts involving engineers and economists)." In short, the future of technological forecasting depends, firstly, on methodological breakthroughs and, secondly, on the elimination of certain bottlenecks.

The essential breakthrough is as follows: "We need better causal models, based on more sophisticated economic theories ... and, in order to develop better causal forecasting models, there is need to develop better explanations of technological change at the micro-economic level."

The bottlenecks to be eliminated are: "information overload, the need for filters, the linguistic tower of Babel in data processing which prevents inter-computer communication, the complexity of machines and systems and non-polluting renewable energy".

On top of all this, without doubt the methods reviewed in this document are, from different angles, useful and, in the absence of anything better, they may partly clarify technological forecasting. However, it is not clear whether, after 20 years of expensive practice, improvement is subject to enhanced understanding of the technical system and its evolution. **Technology is a social creation. It is therefore the matrical product of the laws of nature and the laws of society.** Any attempt to examine its future by looking at only one of its sides is doomed to failure. Any approach based on an intrinsic conception of technology as a closed system is to ignore what is frequently the essence: the power induction effect of society and its requirements, regulations and power relationships on technological creation and its diffusion. To envisage technology merely as the product of economic thought is to make a rationalization that is a postiori unreal, to reduce the laws of society merely to economic levels and to remove physical laws therefrom, with their constraints, cohesion and coherence. The future of technological forecasting depends on its capacity to link these laws of nature and society. Once we acknowledge the need to incorporate the latter, the real crux of technological forecasting is systemic and interdisciplinary long-range planning. The multitude of variables to be considered also requires data processing, in the awareness that data processing, however powerful it may be, is merely a medium. When all is said and done, the most important thing remains the conceptual breakthrough to be made.