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METHODS OF TECHNOLOGICAL FORECASTING, (U)
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Methods of Technological Forecasting

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
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AGARD Report No.655

6 METHODS OF TECHNOLOGICAL FORECASTING,

by

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- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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PREFACE

In response to a request by the NATO Military Committee to undertake a technology forecasting effort in the field of aerospace, AGARD first entered an initial phase during which it strove to improve its understanding of technology forecasting in order to possibly provide a more useful product to the Military Committee. One aspect of this was to examine if there were formal technology forecasting methodologies which could be applied beneficially to an AGARD exercise. Thus, during the initial phase, AGARD commissioned a well-known expert in the field of technology forecasting methodology, Mr. Francois Hetman*, to prepare a report on this subject for the benefit of those studying the overall AGARD task. His report contained seven chapters, six of which provided an introduction to the various methodologies; in the seventh chapter he offered his thoughts on the particular exercise which AGARD had been requested to do by the Military Committee. The first six chapters by themselves proved to be an excellent summary of technology forecasting methodology and thus are reproduced here as a general reference document.

*The views expressed by the author do not commit the organization to which he belongs.

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CHAPTER I

BASIC MODES OF APPREHENDING THE FUTURE

Man has two basic attitudes in his effort to apprehend the future:

- (a) To foresee or to forecast the future course of events or future situations at a given point of time.
- (b) To bend the future to the image or scheme of some desirable state of affairs.

In the first case, the intention to influence the future course of affairs is not stated explicitly. Nevertheless, it may be admitted that forecasts are being made in view of some further decision which will be taken in order to react to the forecast, either to make it self-fulfilling or self-defeating.

In the second case, the will to make the future different from the past is stressed from the beginning and is consciously intended to orient future research activity towards some previously defined objectives or specific priorities.

Any attempt to study the future implies a process of inference which relates some factual experience or some point of ascertained or desired attribute or value to the researched factors, relationships or events. In a sense, futures research is a process of inference searching for significant correlations between rapidly changing or changeable phenomena and elements or segments of societal activity which move more slowly or show some particular kind of inertia.

The reason for this search for a workable hierarchy of change is that human and social behaviour cannot be mechanically deduced from archetype fundamentals or purely mathematical models.

Although specific forecasting techniques may be counted in dozens and even in hundreds – if proliferating variants are taken into account – the fundamental methodological approaches may be grouped into five broad categories, representing the basic modes of apprehending the future. The two distinguishing criteria adopted are (a) the logical approach and (b) underlying or explicit assumptions concerning the basis of inference. (Table I.)

Obviously *prediction* can hardly be considered as an approach founded on scientifically acceptable premises and procedure. It is merely an apodictic statement or verbal revelation without indication of either the sources of information or the utilised tools of analysis. Such a prediction or guesswork must be distinguished from intuitive judgements such as opinions of experts which, although not always explicitly described, are nevertheless based on previously ascertained knowledge.

Projection or forecast is an attempt to outline a course of future events along a tendency of development which appears the most probable. Most often it consists of an extrapolation of past trends or statistically observed relationships between two or more variables. Sometimes it is done without an analysis of underlying assumptions. In other cases, the framework of assumptions is explicit and the results are considered as conditional statements about the future, dependent on the inertia of the so-called exogenous or parametric factors.

The main feature of projection or forecasting techniques is to maintain an identifiable relationship between the future and the past, assuming that the structural framework experienced in the past will continue practically unchanged to the limits of the chosen time horizon.

This is a serious limitation because it implies a fundamental hypothesis of continuity which is, in particular, hardly justifiable in the field of social phenomena. As a matter of fact, this assumption of continuity tends to privilege the past in attributing to it, tacitly or implicitly, both a regulative function and an overrating influence upon the future.

To avoid, or at least to diminish, such a one-sided influence of the past, *prospective analysis* is an attempt to search for images of the future by starting from some future time horizon and working back to the present, in order to find suitable ways and means for establishing operational ties with the present situation and conditions. This is also called imaginative exploration or looking at the future from the future. This involves a pluralistic exploration of future states without other constraints than a set of values upon which more imaginative futures can be built.

However, the past cannot be just exorcised: its weight is shifted from facts to valuations. Prospective analysis frequently discards the past factual experience but extrapolates the present values in order to deduce from them the future chain of desirable facts or actions. The problem is not resolved nor abolished – only reversed. The basic

uncertainty concentrates on the question of future values from which significant filiations between things to come and men of the present time are supposed to be deduced.

TABLE I

Basic Modes of Apprehending the Future

| <i>Mode of apprehending the future</i> | <i>Logical approach</i> | <i>Underlying or explicit assumptions</i> |
|--|------------------------------|---|
| Prediction | Subjective | Non-specified and non-explicated |
| Projection | Probabilistic or conditional | Constant contextual situation or constant socio-economic impact |
| Prospective investigation | Imaginative or combinatory | Constant or presumed set of values |
| Authoritarian planning | Coercitive | Single and constant socio-economic system |
| Programming by objectives | Decisional | Constant or system-determined relationships |

All uncertainty cannot be eliminated but it can be compressed by a "fiat" of an *authoritarian planning*. This singles out a privileged image of the future which is imposed by a policy of distinct priorities in order to push the present towards it. It delineates the image of a single future and strives then to determine ways and means of adjusting facts and actions to this image. Authoritarian planning is an instrument of deliberate policy to arrive at a given socio-economic pattern of society through the shifting of emphasis on to sectors which appear as the most promising for the achievement of the "planned future".

In privileging such a coercitively determined image of the future, normative elements tend to cover over the seeds of change and favour the sectors of the greatest inertia, in which routine solutions prevail in the long run. An authoritarian choice of one single model of the future may thus lead to a rigidifying attitude towards the future and finally to a mere projection of the most easily identifiable trends of the present.

To avoid the danger of an inadvertent pre-empting of the future, *programming by objectives* is an effort to keep the future as open as possible, as a reservoir of desirable futures. Futures are studied and formulated as an array of alternatives. This can be based on systems-analysis thinking and methods derived from operational research and decision models.

The main characteristic of this approach is to consider the future as a spectrum of virtualities which can be usefully apprehended by a thorough analysis of desirable futures and an assessment of possible futures consistent with a set of given objectives.

The systems-analysis thinking is not exclusive of other modes of apprehending the future. It can be considered rather as a general methodological framework within which the different forms and techniques of forecasting are used side by side, depending on their suitability for tackling particular problems and generating useful information.

CHAPTER II

FUTURES RESEARCH AND TECHNOLOGICAL FORECASTING

Leaving aside predictions, futures research may be considered as a systematic effort to analyse trends and components of societal change, the term "societal" covering all fundamental functions of society. Its first task is to examine the direction and scope of change. In the second place, it is expected to shed light on the opportuneness and desirability of tendencies perceived. It is supposed also to formulate criteria for choice of the most suitable or promising alternatives and to point out possible action options.

This links futures research closely to planning, in other words, to policy measures most likely to contribute to the achievement of the selected objectives.

Since futures research cannot be a science of facts, it is an endeavour which adopts scientific method and rigour to study significant interactions between the various social phenomena, assuming that men are able to act on the future and that the future is thus to a large extent dependent on the wisdom and relevance of their choice and political decisions.

All methods of futures research are founded on basic heuristic notions derived from the fundamental categories of human mind and experience, such as structure, causality, continuity of time and space, constraints to growth and change. These notions make it possible to attempt a classification of the different techniques.

These notions may be used to examine the theoretical legitimacy of techniques used in futures research. However, such a preoccupation can be rejected as a futile exercise by those who look for practical utility. Now this can also mean many things to different people. "There is no correlation between 'the value' of any method and the amount of paper we use to describe it."*

Despite this statement, a frequent tendency (often implicit) among students of techniques used in futures research is to attribute more credit to methods which include an increasing degree of sophistication, both in number of variables and in their mathematical or graphical manipulation. Unwarranted as it may be, this attitude seems to reflect the growing concern for more comprehensive analyses and more formalised forecasts.

Few techniques are specific to the field of technology. Most of them have been developed and adapted from standard scientific methods, usually in response to the need to tackle a particular problem. However, they have known intensive applications and interesting extensions in technology. This development has been stimulated in particular by anticipatory activities in the military field, often combining forecasting and decisional research.

In comparison with social phenomena the technology area may appear as relatively more tangible, more easily identifiable and quantifiable. However, there is still much confusion about the spectrum covered by technology. Among many definitions, we may prefer that according to which technology is defined as knowledge of physical relationships systematically applied to the useful arts.

The first difficulty of technological forecasting is that this knowledge varies with time. Technological change has become one of the major societal concerns, perhaps the most important one.

Another difficulty is that technology is applied to a large variety of things, ranging from basic breakthroughs to individual devices. (Table II.)

There are still other difficulties. If technology is understood as a generic term for a group of particular techniques, then a given technology generally includes a variety of competing devices, each with distinctive balance of performance and economic characteristics. At the same time, these various devices may also fulfil quite different needs and perform different functions.

Not surprisingly, definitions of technological forecasting reflect these difficulties, as can be seen from the following examples.

Technological forecasting is:

- The forecasting of technological change, which divides into three stages: invention, innovation and diffusion.

*Europe Plus Thirty Report, Part I, p. 12, Brussels, 1975.

- Systems of logical analysis that lead to common quantitative conclusions (or a limited range of possibilities) about technological attributes and parameters as well as technical-economic attributes.
- Prediction or determination of the feasible or desirable characteristics of performance parameters in future technologies.
- The process of generating a quantified prediction of a technological capability and its timing.
- The prediction of the invention, characteristics, dimensions or performance of a machine serving some useful purpose for society.
- The judgement of future changes in technology on a probabilistic basis.
- A formalised process for the study and prediction of the likely future state of technology, the interaction of technology with social and economic developments and the consequent effects on industrial activity.

TABLE II*

Levels of Causality to which a Forecast may be Addressed

One reason why so much confusion exists about technology is that anticipations about scientific findings, engineering developments, technological diffusion, economic results and social impacts are loosely and thoughtlessly intermingled.

Therefore, the analysts should first clarify those levels of causality to which their forecasting activity is to be addressed:

Level 1 – That a certain *knowledge of nature* or level of scientific understanding will be acquired.

Level 2 – That it will be possible to *demonstrate a new technological capability* (on a laboratory basis).

Level 3 – That the new technical capability will be *applied to a full-scale prototype* (field trial).

Level 4 – That the new technology will be put to first *operational use* (commercial introduction).

Level 5 – That the new technology will be *widely adopted* (as measured by such things as number of units in use, output, sales, etc.).

Level 6 – That certain *social (and economic) consequences* will follow the use of the new technology.

Level 7 – That future economic, political, social and technical conditions will *require the creation* of certain new technical capability.

These examples of definition do not make the subject of technological forecasting any easier. They show the need to define adequately the terms on the one hand and the area to be studied on the other.

This applies as well to forecasting techniques. During the last two decades many new techniques have been put forward. However, this proliferation is also at least partly due to differing terminologies. It happens often that a new problem or the same problem studied by another research team requires some modification of the technique, which is then given a new name.

The field of technological forecasting has been compared with a "forecasting jungle". To penetrate it, different groupings of techniques have been suggested. Since the extensive review of the art by E. Jantsch, many such classification schemes have been outlined. (Table III.)

Most of these schemes are based on the motivations and mental orientations of those undertaking forecasting activities. The basic dichotomy corresponding to the two fundamental attitudes towards the future can be traced in many of these groupings.

This gives primary distinctions such as subjective-objective, qualitative-quantitative or exploratory-normative. More

*Adapted from *Technological Forecasting for Industry and Government*, edited by James R. Bright, Prentice Hall, Englewood Cliffs, 1968.

sophisticated groupings are made by logical generation of forecasts, fields of application, degree of modelling, conceptual or procedural manipulating.

TABLE III

Classifications of Technological Forecasting Methods

| <i>Classification of techniques</i> | <i>Author and source</i> |
|--|---|
| Exploratory, normative | Jantsch, OECD (1967) |
| Prophecy, projection or extrapolation, programme, propaganda, parrotry, dynamic modelling, need interaction | J.R.Bright, Prentice Hall (1968) |
| Retrospection, diagnosis, prognosis with sub-unit forecasts subject to various checks | Lisichkin, Technological Forecasting and Social Change (1969) |
| Synthesis-analysis, collection-diffusion, application | Vogel, Technological Forecasting and Social Change (1970) |
| Three states of mind: subjective, objective, systemic. Two directions: exploratory, normative. | E.Jantsch, Technological Forecasting and Social Change (1970) |
| Four classes of methods based on trend analysis, intuitive analysis, systems analysis and analysis of objectives | J.Wautrequin, Industrie (1970) |
| Intuitive, trend extrapolation, ideal state, dynamic models | Eldredge, Technological Forecasting and Social Change (1970) |
| Qualitative-exploratory, qualitative-normative, quantitative-exploratory, quantitative-normative | Johnston, Technological Forecasting and Social Change (1970) |
| Exploratory, speculative, explicative correlative | Pyke, Futures (1970) |
| Genius forecasting, trend extrapolation, consensus, simulation, cross-impact, scenarios, decision trees, input-output analysis | Gordon, Inst. for the Future (1971) |
| Qualitative methods, time-series analysis, projection, causal methods | Chambers et al., Harvard Business Review (1971) |
| Techniques for acquiring information/data, techniques for manipulating information/data, techniques for evaluating information/data | EIRMA, (1972) |
| Visionary (integrative and strategic) analytical (multi-disciplinary and methodological) participatory (problem and implementation-oriented) | R.Amara, Futures (1974) |
| Comprehensive Technological forecasting: Four basic elements: qualitative, quantitative, time, probability | H.Jones, R & D Management (1975) |

Whatever the set of criteria adopted there is no absolutely clear-cut classification scheme and many of the general techniques can be included in one or several categories.

The primary schemes do not seem very helpful. To facilitate the choice of an appropriate methodology it is suggested that the various forecasting techniques can be usefully categorised in terms of the purposes they serve.

Technological forecasting is not an end in itself. To be fully meaningful it must be considered within the framework of the decision-making process. Two examples are given: one illustrates the basic functions of the futures research (Figure 1) and the other shows the roles for technological forecasting in the strategic planning process (Figure 2).

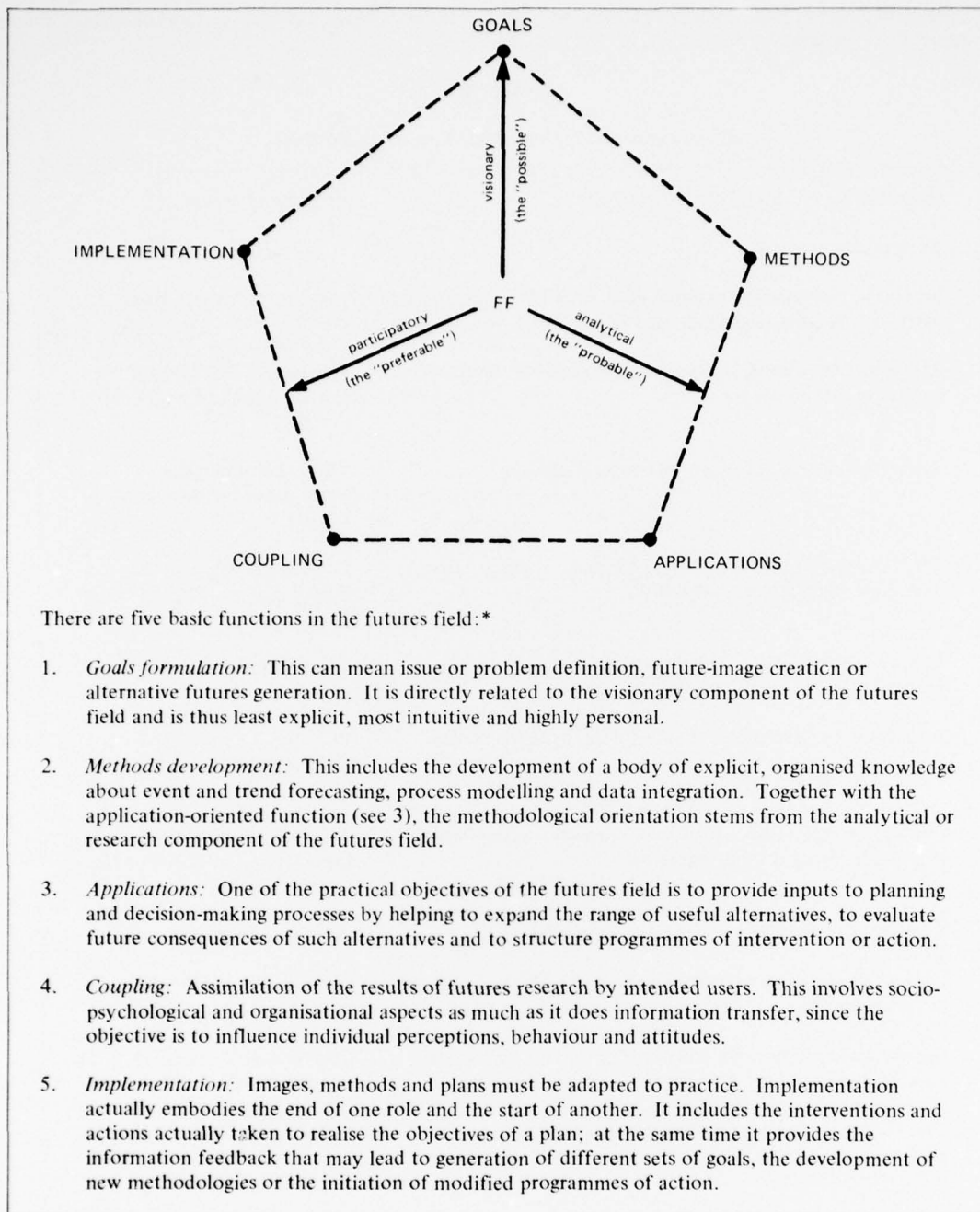


Fig.1 Basic functions or roles of the futures field

Combining purpose and basic categories of logical investigation, it is possible to devise a classification scheme in four parts:

- projective research
- prospective research
- decisional research
- planning

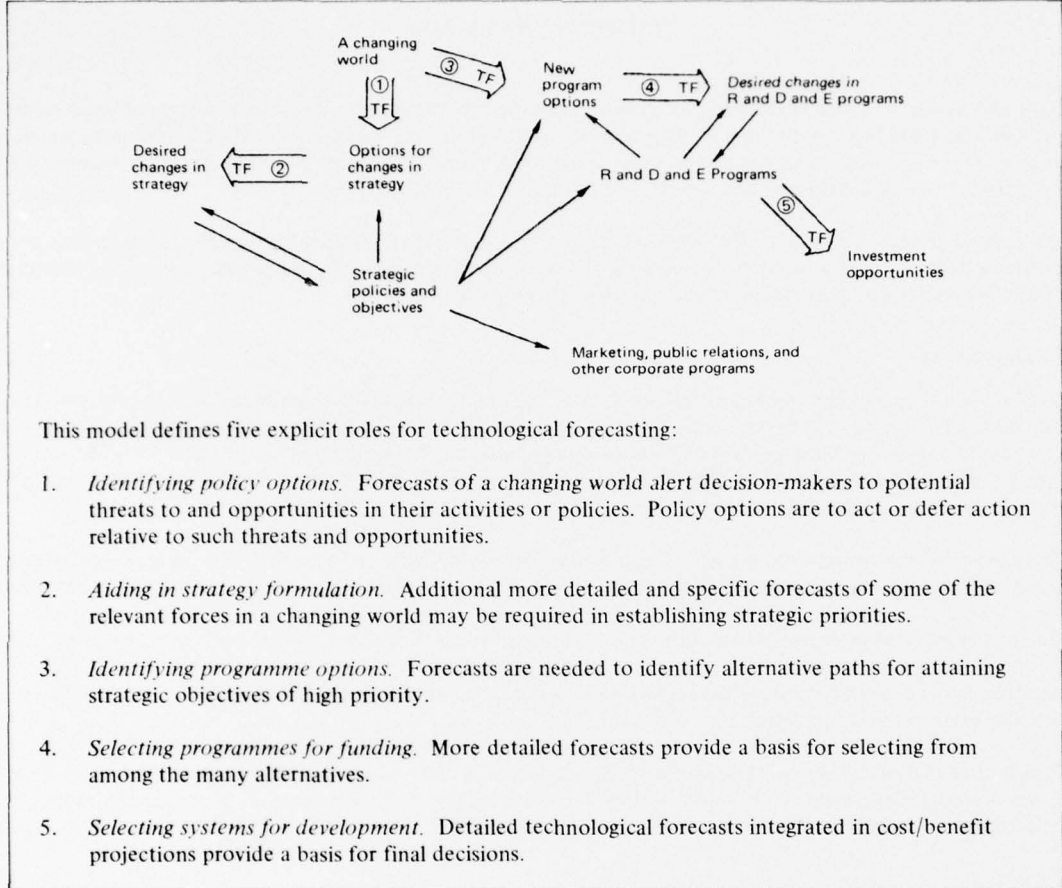
These four parts are complementary since each covers a distinct part of the "futures field":

- (i) Projective research casts forward past and present knowledge about facts and events.

*Adapted from Roy Amara "The Futures Field: Functions, Forms and Critical Issues", *Futures*, August 1974.

- (ii) Prospective research looks for desirable alternatives and futures which could influence the present.
- (iii) Decisional research clarifies possible futures in formulating action options.
- (iv) Planning consists in determining the ways and means of attaining the goals and objectives chosen from the array of alternatives.

There is both a logical and sequential link among these four areas, although each can serve as a starting point, depending on the problem to be dealt with or the responsibility and objectives of the sponsoring institution.



This model defines five explicit roles for technological forecasting:

1. *Identifying policy options.* Forecasts of a changing world alert decision-makers to potential threats to and opportunities in their activities or policies. Policy options are to act or defer action relative to such threats and opportunities.
2. *Aiding in strategy formulation.* Additional more detailed and specific forecasts of some of the relevant forces in a changing world may be required in establishing strategic priorities.
3. *Identifying programme options.* Forecasts are needed to identify alternative paths for attaining strategic objectives of high priority.
4. *Selecting programmes for funding.* More detailed forecasts provide a basis for selecting from among the many alternatives.
5. *Selecting systems for development.* Detailed technological forecasts integrated in cost/benefit projections provide a basis for final decisions.

Fig.2 Conceptual model of the strategic planning process*

From the analyst's point of view only the first two categories include forecasting techniques in the strictest sense. However, more and more often, decisional research is called upon both to structure and to organise information obtained through projective or/and prospective research and to evaluate alternative courses of action.

Planning is, by definition, the prerogative and the responsibility of decision-makers. Therefore, planning techniques are considered as being outside the scope of technological forecasting *per se*.

Hereafter the main techniques of use in technological forecasting are grouped according to the classification just given. Several techniques are more or less universal and can serve more than one purpose.

*Adapted from William L. Swager "Strategic Planning: The Role of Technological Forecasting". *Technological Forecasting and Social Change*, No.4, 1972.

CHAPTER III

PROJECTIVE RESEARCH

Projective research consists principally of carrying forward, into some future horizon, elements of knowledge obtained from past and present experience. In a sense it is conditional, since it implies a set of assumptions which determine its scope and extent. In some cases these assumptions are only implicit. Nevertheless, most analysts now use them to state the basic conditions within which the forecast is considered as valid.

Methods of projective research are mostly "inductive" in nature: they proceed from some known factors or data and extrapolate or explore, on this basis, the future path of a given phenomenon. They range from a simple extension of a single variable curve to complex mathematical models with many variables.

Trend Extrapolation

On the basis of time-series analysis of historical data, a particular variable is extrapolated into the future. This is generally done with the aid of statistical techniques of "curve fitting" using linear, exponential, logistic and other mathematical functions to obtain the best "fit" to the historical data. The underlying assumption is that factors influencing the past development of a technique will continue, with only slight or negligible changes in their nature and influence.

The validity of this assumption beyond a certain time horizon is highly controversial. This is why this technique is sometimes qualified as a "naive" one. However, it remains the most popular and the most used method of forecasting.

One of the essential problems is to identify the parameters which characterise best the progress of a given technology.

Another one is to limit the extrapolation to a point which is reasonably reconcilable with the historical series and the most suitable mathematical function.

Finally, the analyst should "get behind the trend" and identify the major factors which interacted to produce the trend. Any sign of a change in one or several of these factors should be taken into account or should accompany the extrapolation as a warning signal.

Progress Curve

Instead of plotting a technical parameter against time another method consists in plotting technical parameters against cumulative production quantities.

This relationship takes the form $T_i = a(i)^b$, where T_i is the value of the parameter at the i^{th} unit, i is a cumulative production quantity and a and b are constants.

This dependence of a technical value upon production quantities gives a technological progress curve. The form of this curve is similar to that of the industrial *learning curve* relating the cost C of the i^{th} unit to the cumulative production.

The rationale of this method is that technological progress is analogous to the learning curve and thus equates improvement in the learning process with improvement in technology through repetitive production.

Although learning curves are used in many fields, it may not always be obvious that the correlation between production quantities and behaviour of technical parameters in the past is a suitable method of forecasting future developments of this parameter.

Analogy

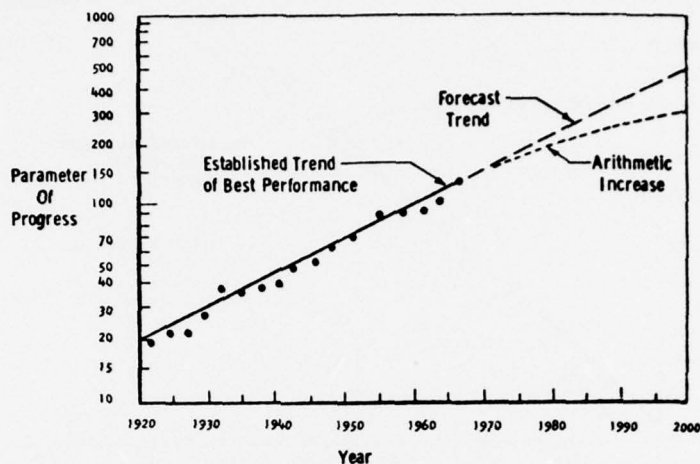
Analogy can be considered as an implicit correlation between two developments whose behaviour is thought to be analogous and is also expected to stay analogous in the future.

The examples given in the literature are mainly historical analogies and growth or biological analogies. (For example,

analogy to biological growth or Pearl's law, analogy to economic growth or Gompertz law, cellular analogy, reproduction or imitation analogy.)

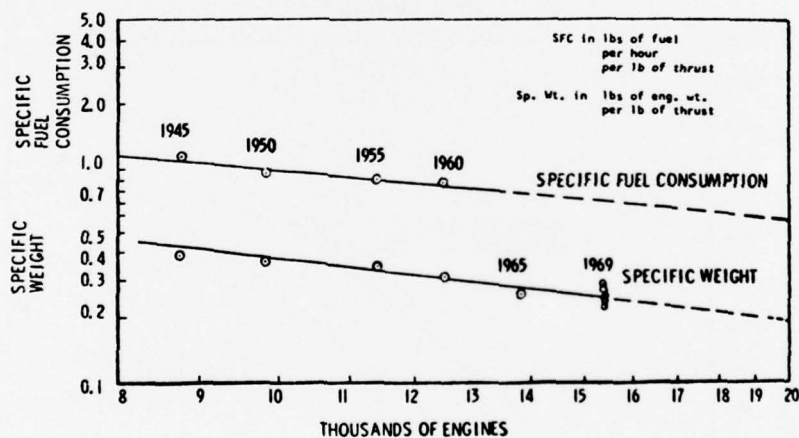
Some of these analogies, and particularly the biological ones, seem to be far-fetched. They may be useful in reminding the analysts of the fact that there are natural stages of development which must be taken into account. However, the biological analogy carries with it the erroneous implication that each technology has a life of its own, governed by some internal dynamic law expressing itself in relatively regular growth stages.

Trend extrapolation



Elements of exponential trend forecasting of technological progress.

Progress curve



Correlation of turbojet engine performance with cumulative production quantities.

Figure 3

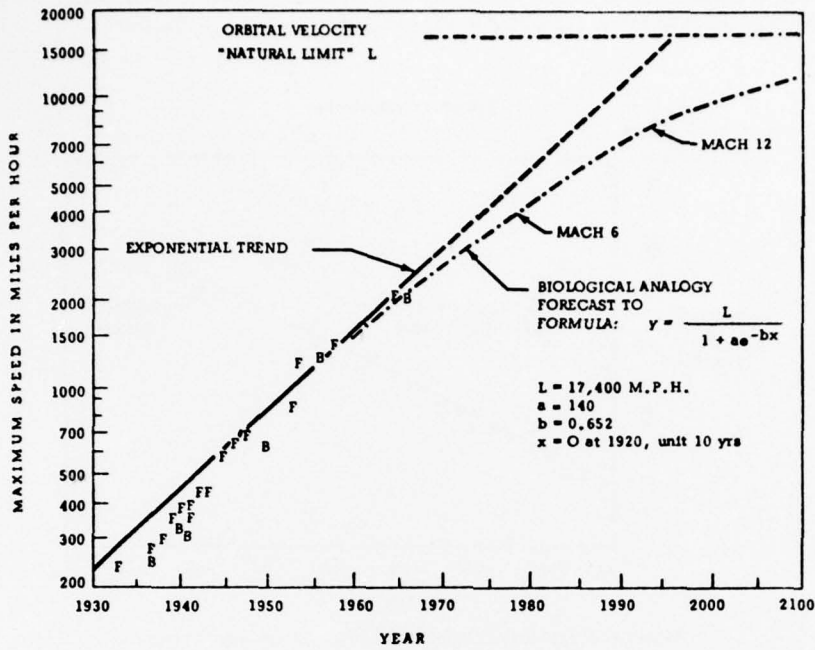
Trend Correlation

There are cases where one technology appears to be a precursor to another. This happens when the advances of one technology can be applied to the next one. Thus it seems possible to forecast the successor on the basis of the achievements of the precursor and the observed time lag. This method is also called forecasting by *precursive events* or by *precursive indicators*.

If the time lag between the two technologies is sufficiently long, useful long-range forecasts may be possible. The

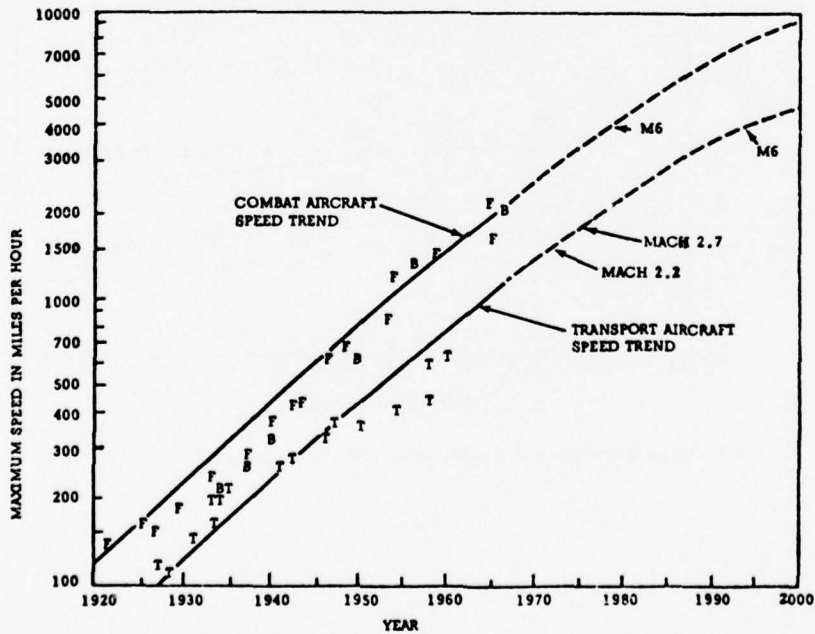
data yielded by the development of the first technology up to its present state can be used to forecast the development of the second one, up to the term corresponding to the time elapsed between the development of the two technologies.

Analogy



Speed trends of U.S. combat aircraft.

Trend correlation

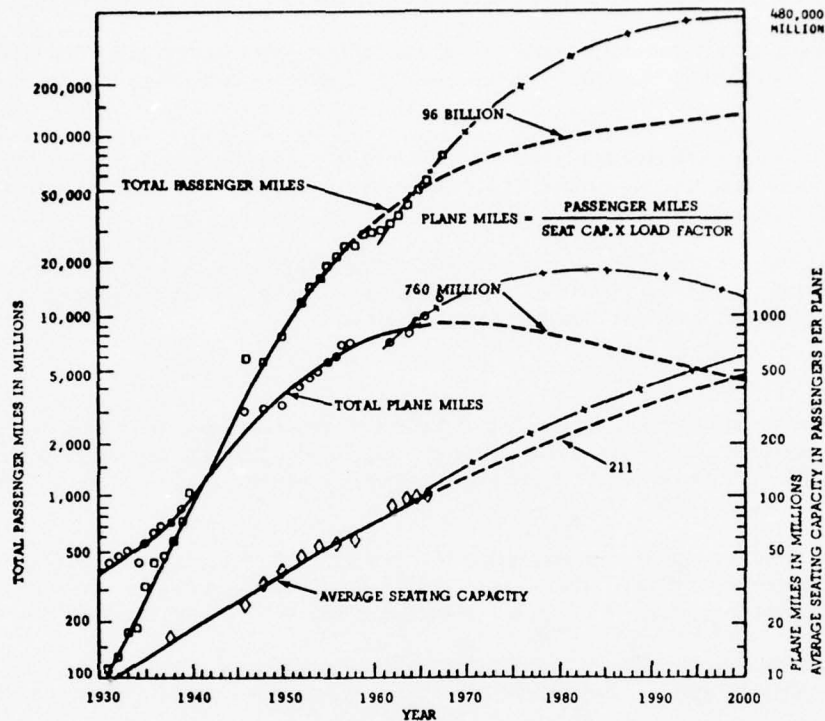


Speed trends of combat versus transport aircraft, showing lead trend effects.

Figure 4

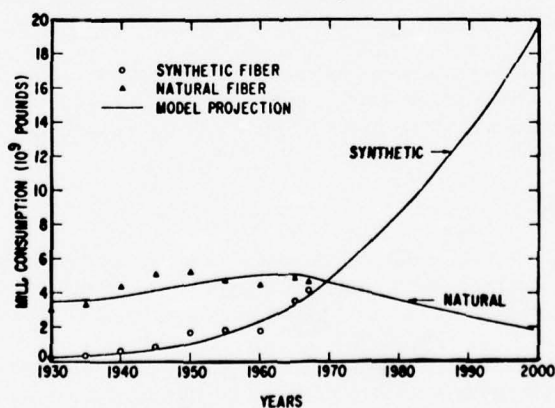
The major difficulty in using this method is to identify the time lag. Devices of the precursor and follower technologies rarely exhibit the same level of functional capability. This makes it difficult to determine the lag in years between achievement of the same level. It is thus necessary to interpolate between the values of either precursor or follower and this is not without risk.

Multiple-trend correlation



Domestic trunk airlines – multiple-trend forecast.

Substitution analysis



U.S. fiber consumption versus years – data and projection using the substitution model.

Figure 5

Strictly speaking, the use of this method seems justified in cases where the assumption that the two phenomena will pursue parallel paths of development, one following the other after a fixed time, is based on a causal relationship between them, or a common cause of their advances.

A specific type of trend correlation is the *multiple trend forecast*, based not on technological transference but on direct algebraic relations between variables. The fundamental notion is that if $Z = YX$ then one can forecast Z by forecasting X and Y separately.

Substitution Analysis or Substitution Growth Curves

Substitution analysis can be considered as a concept relevant to trend extrapolation. The substitution phenomenon or effect is premised on the observation or belief that a technology that exhibits a relative increase in performance over the older or established or conventional technology will eventually substitute for the technology of lesser performance.

This method implies that the substitution of one technology for another tends to follow the familiar S-shaped curve of the life cycle. Substitution increases slowly at first, faster as acceptance grows, and more slowly again as saturation is reached.

To use substitution analysis realistically, the substitution must have actually begun, the beginning of the upturn in its S-curve must be visible, continued substitution for the existing technology must appear technically feasible and the eventual degree of potential substitution must be calculable.

From the analysis of past substitution patterns, mathematical functions can be derived to forecast the form of the S-shaped curve for a new technology. This may be less applicable to military devices, since the rate of change is very rapid in this field and can be further accelerated by external threats.

Envelope Curve

This technique can be considered as a branching-out of the concept of trend extrapolation. It consists of plotting against time a set of curves of the form of the life cycle, each representing successive technical systems which fulfil a certain function. The individual curves are joined to give a family of overlapping curves from which the envelope curve — tangential to and connecting the set of curves — is drawn.

The envelope curves are based on the assumptions that the rate of development of a technology develops a kind of inertia through the various stages of its growth. The technological change is a continuous substitution process. The latest and most efficient system takes over even before the former system has used all its possibilities.

The main advantage of this method is that it avoids the saturation effect of more straightforward forecasts restricted to a single technology only. It is used to forecast possible future substitution by other emerging or unknown technologies.

A specific application of it is the *functional capability curve* which presents the maximum capability of any sub-system that can perform the desired function. The capability is independent of any particular technique. The functional capability curve is the envelope of the maximum development levels taken from all specific techniques which can perform the function.

In many examples given the envelope curve plots as a straight line (exponential growth) on a semilog graph. In the long term, however, one expects the envelope to tend to become, in its turn, a logistic curve.

The extrapolation of envelope curves is considered by most authors as one of the tools particularly suitable for technological forecasting. Some consider it even as having potential for discerning technological breakthroughs. In the available literature, however, the same examples have been mentioned for a decade, so that there can be some doubt as to the progress made in this direction.

Advances in the State of the Art

This extrapolative technique uses the concept of the state of the art, which is defined as the highest degree of technical accomplishment that could be achieved at a given time. The state of the art is represented in terms of selected physical and performance characteristics and advances are measured in relation to identified state-of-the-art "surfaces".

This representation reflects the best implemented technology during the time period in question. This differs from technological capability. Implemented technology implies not only technical feasibility but also economic or market feasibility. Thus advances in the state of the art may be stimulated by improvement in technology or by changes in the market or both.

The difficulty of defining implemented technology, on the one hand, and of identifying implications of the interdependence between the technology and the market, on the other, throws some doubts on any extensive practicability of this method.

Technological Mapping

This can be considered as a combination of monitoring and gaming: its main objective is to evaluate the competitor's

or adversary's strength. This can be done with the aid of network techniques visualising all significant approaches to a desired end result.

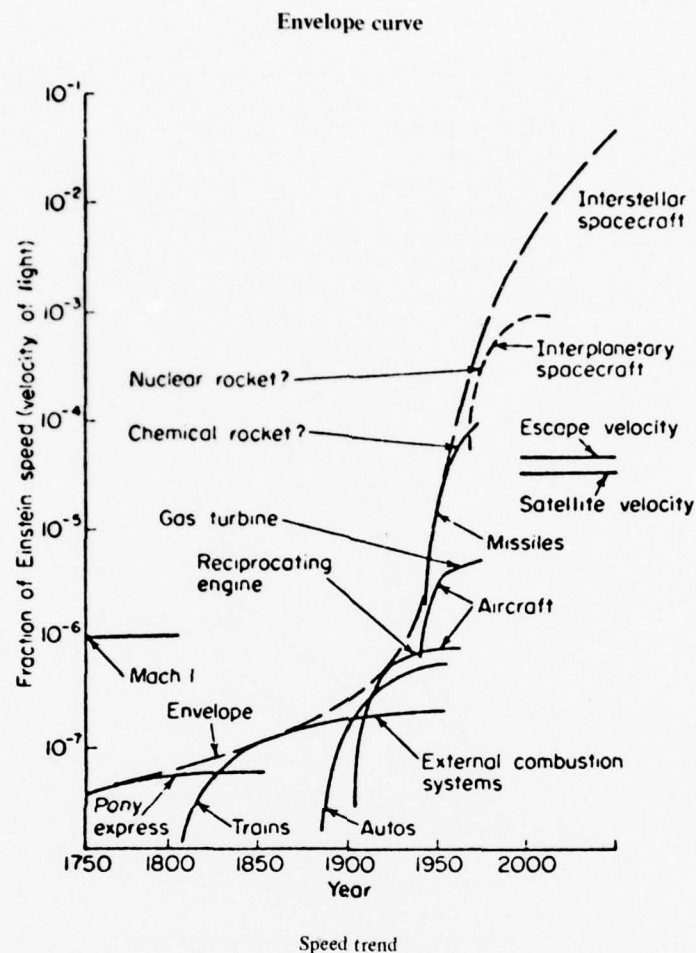


Figure 6 Part 1

Publications, patents and all available intelligence sources are used to lay out the technological capability of the adversary. The various techniques of rating or numerical graphs can then indicate the degree to which each path is invaded, dominated or avoided by the other party. The resulting map serves as a basis for estimating the future performance capabilities, directions of R & D efforts and main approaches.

Technological monitoring is probably an indispensable part of data collection and is widely practised in most countries. Technological mapping is somewhat more ambitious. It is an attempt to design and partly quantify known facts and projective insights – a designed scenario rather than a written one.

In this case technological forecasting is considered as a kind of information system on science and technology which shows, through continuing analysis, the need for changes, responses to threats, new developments and initiatives.

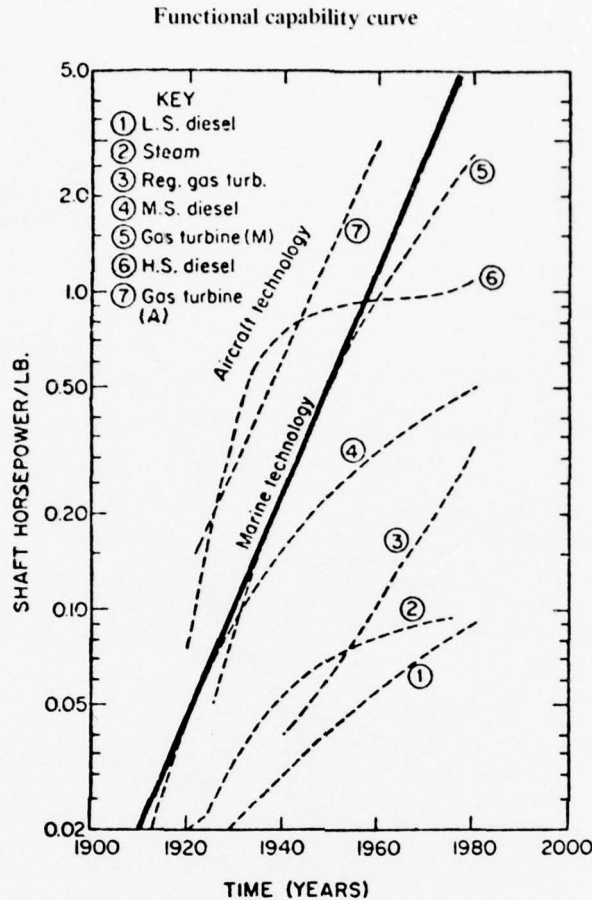
Contextual Mapping

This is a graphic display of the relationships among and between the developments/inventions/processes, during a period of time, that have, or do, or will contribute to the achievement of the desired performance of the parameter under investigation.

Matrix

This is a method of structuring the problem under study, using a tabular combination of system parameters to explore possible interactions.

There are many variations, depending on the horizontal and vertical parameters used. The most commonly used types are needs/resources tables and product/customer (or market) tables.



Functional Capability Energy Converters (Specific Weight).

Figure 6 Part 2

Input-Output Analysis

The input-output method is based on the neo-classical concept of quantitative interdependence between interrelated elements of a given system. The form of representation is a matrix connecting the various producing and consuming sectors. The interdependence between the individual sectors of the given system is described by a set of linear equations; its specific structural characteristics are thus reflected in the numerical magnitude of the coefficients of these equations. These coefficients are determined empirically.

The method is mostly a static one but several attempts have been made to transform it into a dynamic one. The coefficients can be made time-dependent, which allows technological change to be taken into account.

Input-output tables are widely used in economics, both as an accounting framework and a device for evaluation of changes in final demand or in supply needs. Even with the aid of computers, manipulation of input-output tables is far from easy. Calculation of technical coefficients, in particular, seems to be possible only for years relatively remote in the past. Application of the method to technological forecasting is therefore limited.

Mathematical Models

Mathematical models aim at representing in an abstract form the determinant variables of a system and their interactions. On the basis of observed data, a set of variables is selected which is supposed to be the best approximation to the real-world system. The relationships between the variables are expressed usually as connected linear equations.

If a mathematical model is to be useful in forecasting, the analyst has to be sure that there is a reasonable

probability that the relationships connecting the variables will hold during the period of forecast or he must have some clues as to the rate and direction of possible change.

Simulation Models

Simulation models are usually constructed for exploratory purposes where the theories are rather weak or the calculations are so highly complex that simple algebraic solutions cannot be obtained.

Models can be deterministic, and contain optimising or other control devices, or they can be stochastic. Relationships between variables are specified individually, either algebraically or directly into a computer simulation language, and the consequences of their interactions, which may have time lags, are then projected.

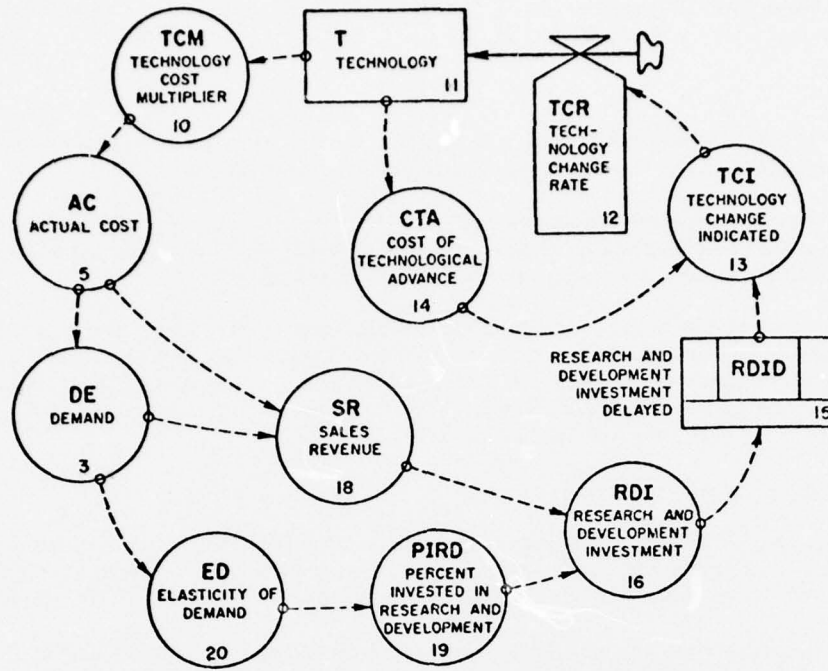
Stochastic methods include the *Monte Carlo technique* which permits simulation of processes in which probability cannot be expressed by standard distribution functions. It is used in probabilistic forecasting and consists in running repeatedly a sequence of events with random combinations of probability values, until sufficient statistical material is accumulated to determine the probability distribution of the outcome. This technique can be applied wherever random factors are involved that would make mathematical treatment difficult.

Dynamic Modelling

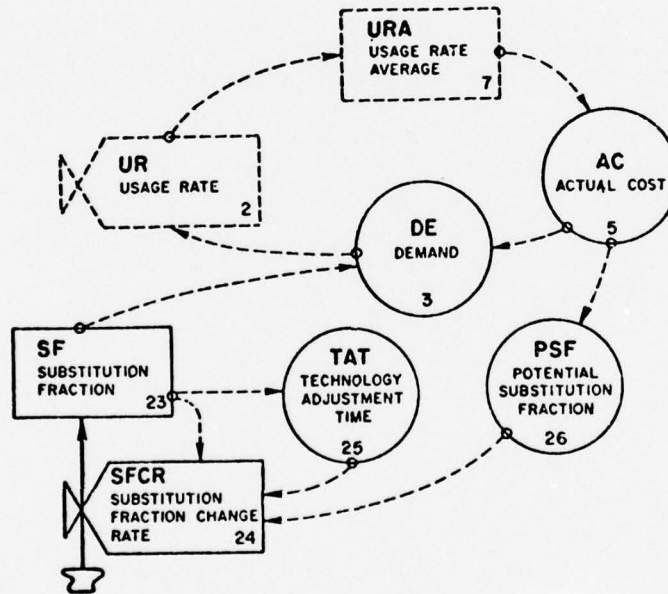
Dynamic modelling is based on the concept of industrial dynamics or system dynamics, elaborated by Jay Forrester. It consists of a set of quantitative relationships which together represent a model of a system, enabling the dynamic reaction of the system to the variations of parameters to be studied under the constraints of the system.

System dynamics is based on servomechanism theory and other techniques of systems analysis and is predicated on the ability of high-speed digital computers to solve large numbers of equations in short periods of time. The equations are mathematical descriptions of the operation of the system being simulated, applied for levels of various types which change at rates controlled by decision functions. The level equations represent accumulations within the system of such variables as funds, personnel, facilities, etc., and the rate equations govern the change of the levels with time.

Mathematical simulation of the system can only represent a real system to the extent that the set of equations describes adequately the operation of the real-system components. This is an important difficulty, since the choice of variables is based mainly on judgement and assumptions regarding the controlling components of the system.



Extraction technology loop



Substitution technology loop

Fig.7 Dynamic modelling

CHAPTER IV

PROSPECTIVE RESEARCH

The methods of projective research, reviewed in the last chapter, imply, if they are to be used in a meaningful way, constant or probabilistic relationships between and among the relevant variables. However, this condition hardly applies in studies of the long-range future or when deep changes are expected or pursued as a consequence of new social attitudes or new policies.

To study futures for which there are no clear terms of continuity or comparison in the past or in the present, it is appropriate to resort to prospective research. Methods in this category help to imagine and explore desirable, possible or alternative futures. Prospective research is thus the domain of creative or imaginative analysis where imagination, judgement, insight and scientific conceptualisation play a decisive role.

The methods of prospective research can be divided into two groups:

- (i) Imaginative techniques: expert opinion, brain-storming, synectics, paradigms, scenarios, event generation, Delphi.
- (ii) Combinatory techniques: interaction needs/possibilities, mapping technological alternatives, cross-impact analysis, discovery matrix, morphological analysis, contingency and perspective tree.

Expert Opinion or Genius Forecasting

This is an unstructured technique of eliciting the current state of the art and its likely developments. Reliance on the intuitive judgement of experts is not just a temporary expedient but a necessary ingredient of futures research.

The simplest technique is one-man or genius forecasting. At first glance if we want to know about the future of aerospace technology it seems reasonable to ask an expert in this field. However, such a forecast may prove quite unilateral and frequently even highly controversial.

To overcome the difficulties inherent in a single estimate, a poll of the judgements of several individuals active in the field may be tried. The hope is to cancel out the individual errors.

Another common practice is to bring together individual experts in a panel, to provide a desirable interaction among their opinions. However, if not handled properly, the panel may suffer from leader effects which may generate a bandwagon majority opinion.

Brainstorming or Image Creation

This is a way of obtaining new insights into a problem through intensive talking. Participants are asked to contribute ideas, even if they do not seem to be directly relevant: there is some evidence that more "good" ideas are produced by this means than if only "good" ideas are sought. No attempt is made to criticise, discuss or explore the ideas which come up in the brainstorming session, since this might inhibit it, thus negating the purpose. If desired, order can be introduced later.

Synectics

Like brainstorming, synectics is basically an aid to creativity. This is a group method of finding new solutions to a problem. The basic idea is to make the strange familiar and the familiar strange.

The method is practised in a group of four to six persons, plus a moderator and plus an expert. The main steps in a synectics session are: definition of the problem, generating ideas for solution, generating analogies, return to the problem to generate new ideas.

It is mandatory to avoid any criticism and to free the minds of participants from the usual constraints with the aid of analogies.

Paradigm

A paradigm is an explicitly structured set of questions, assumptions, typologies, concepts and outlines which attempts to provide a general pattern for considering a given issue.

Conceptually, it can be situated between a metaphor and a model. More rigorous, more complex and more relevant than a metaphor, it does not attempt to be as complete and rigorous as an analytical model.

Scenario

Scenario writing describes, in words, possible future events and the forces giving rise to them. It is in broad use, both as a tool for generating alternative futures and for demonstrating the possibility of a certain state of affairs by constructing a reasonable chain of affairs which might lead to it.

It may also combine the two approaches, that is (i) a description of the future at a given time with a verification of its internal consistency, (ii) an exploratory description of the events which link the present to the future taking into account the trends and the effects of policy decisions.

Scenario writing can resort to structural analysis to provide a qualitative model. Given the reference point in the future, it must then be decided which, among the system's structural parameters, are those which relate to this reference point. Based on the present conditions, a set of indicators is defined and an indicators profile constructed which characterises the system under study. The comparison of indicators at time t and at time $t + 1$ shows whether the initial internal consistency is maintained or if discrepancies have appeared. In the latter case, a judgement on evaluation is made, on the basis of which policy action can be decided.

Delphi Method

The Delphi method, developed initially by the Rand Corporation, has been viewed by many analysts as a complete forecasting method in itself. This is due to its versatility and flexibility of use.

Delphi is a technique for obtaining from a group of individuals (most often experts in a given field) a consensus on some topic or event, usually a forecast when an event will occur or when a scientific breakthrough will be realisable.

The main feature of the method is that the person-to-person interaction between experts is avoided. The basic tool is a questionnaire sent by the moderator to respondents. This questionnaire is circulated to experts, asking for estimates of when, for example, a given technological development will occur. The replies are analysed, the experts are informed of the "spread" of estimated dates and of the arguments put forward by the other participants and they are invited to revise their estimates. The process is repeated several times.

Delphi has been extensively used to forecast technical change. The advantages claimed are that participants can freely express their opinion, that the exercise is not time-consuming for the experts and that the results are presented in a way easily understandable by decision-makers.

On the other hand, Delphi has also been widely criticised. It is pointed out that the choice of experts and the way the questionnaire is drafted are important and can influence the results. Some critics see no evidence that group expert opinion is any better than the less prestigious, but informed, group opinion and suggest that Delphi should be used only for the forecasting of the elements of quantity and time whenever systematic means for the assessment of these factors is absent.

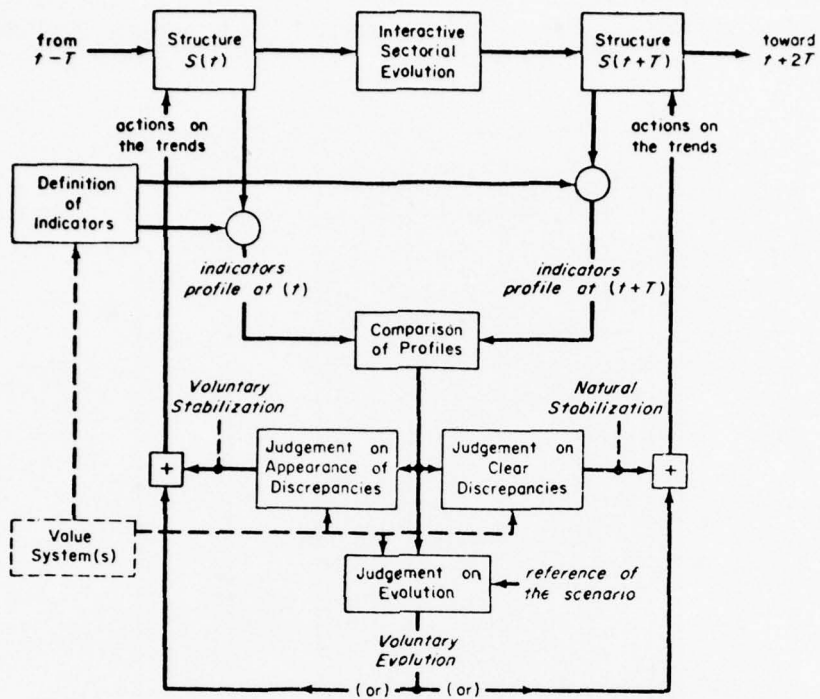
Event Generation

Event generation is a technique which has some similitude to Delphi. It consists of four phases: event generation, event cross-linking, evaluation, incorporation into the research programme.

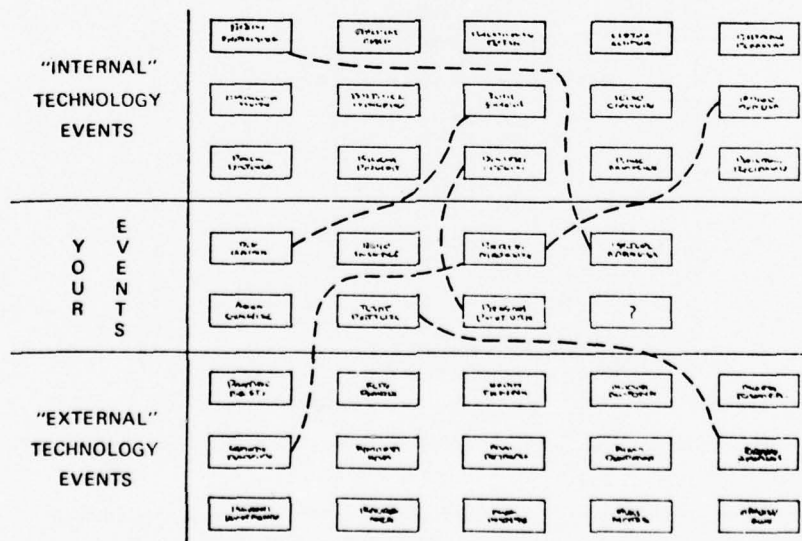
The participants come from three different groups. The "internal" technology experts are individuals whose proficiency is in the field of the organisation's activity. The "external" experts are those whose areas of technology lie outside the organisation's operations but are relevant to the overall technological environment. The "business" experts are those who deal mainly in marketing, economics, government relations, etc.

These experts forecast events which, if they occur, will represent a significant change in comparison to the current situation. Each expert is then asked to consider his own forecast in relation to the events forecast by other experts, in order to identify possible linkages which could produce a viable chain of events having some likelihood of future occurrence. Finally, evaluation is performed on an individual basis by experts selected for their judgement in technical or business area.

Scenario writing



Event generation



Event cross-linking

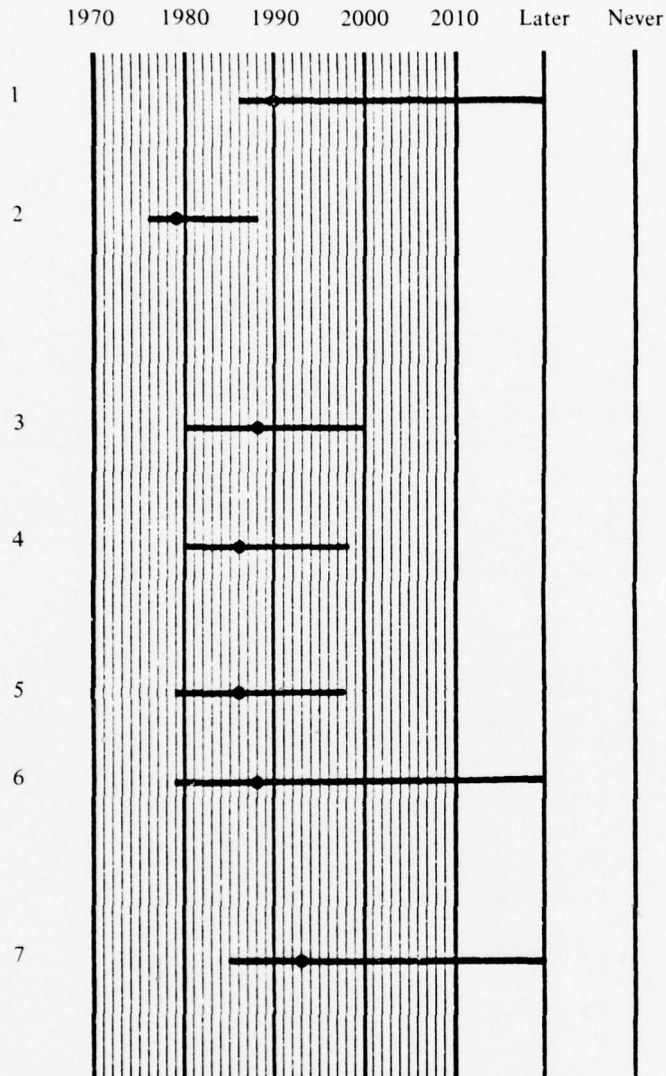
Figure 8

Interaction between Needs and Possibilities

Various approaches to a "dynamic visualising", rather than dynamic modelling, of interactions between needs and possibilities fall in this category. This special form of scenarios has been often employed by the military to determine threats, responses, possible capabilities, their constraints and impacts and thus to identify needs.

Delphi forecasts

Shown, in each case, are the medians of the respondents' estimates of the time by which the event was judged to have a 10%, 50%, and 90% probability of occurrence. (The dot indicates the 50% value, and the ends of the bar indicate the 10% and 90% values.)



- 1 Production of commercial energy through controlled thermonuclear fusion.
- 2 Development of mass-administrable fertility-reducing agents, economical enough for use by the less-developed countries, through such techniques as seeding the water supplies.
- 3 Manipulability of human genetic structure, permitting correction of hereditary defects.
- 4 Conquest of some major diseases, leading to 50% increase in life expectancy at birth for children in poorer countries.
- 5 Immunization against most bacterial and viral diseases.
- 6 Development of computer programs which simulate complex social systems adequately enough to permit prediction of the implications of alternative policies.
- 7 Feasibility of using drugs (as opposed to nutritional supplements) to raise the level of intelligence (not just temporarily raise the level of apperception).

Figure 9

If the identification is followed by action, it leads to a programme to achieve those needs. Hence the scenario becomes a form of forecast of technical needs or capabilities, although not necessarily of precise technical devices or configurations of techniques.

From several scenarios the relative usefulness of various technical capabilities and devices for the more likely future conditions can be estimated. This estimate can serve as a preliminary basis for outlining R & D programmes.

Map of the Technological Future

This technique is a structuring device which utilises available forecasting techniques to generate a map of the technological future. The map is designed to provide the planner with a tool similar to that available to the traveller. It displays technological alternatives and their environmental consequences in such a way as to enable the coupling of near-term technical activities to long-range forecasts. The analogy extends to the way in which both types of maps are prepared, the main stages being the following:

- (i) Selection of the area to be mapped and the establishment of an appropriate coordinate system.
- (ii) Detailed reconnaissance of the area.
- (iii) Transfer of reconnaissance data to the coordinate system.
- (iv) Topography to provide details of the "terrain" and the relationships between features of the map.

One axis of the coordinate system is time and the other is the category under investigation, such as environment, technology and applications. From the forecasting point of view the central part of the coordinate system consists of establishing "triangulation points" which are anticipations developed during the phase of reconnaissance and related to the various categories or fields of the map.

As the end result, the map is expected to consist of a computer-based data bank from which the decision-maker can draw an array of alternative options, the sequence of scientific discoveries and technological developments prerequisite to each alternative, the environmental precursors which may influence the choice among alternatives and the consequences of each choice in terms of its impact on the rest of the environment.

Cross-Impact Matrix

The cross-impact technique is an aid to forecasting frequently used as a complementary tool to the Delphi approach. This latter has been criticised because it yields a set of linearly independent estimates of the future, with the probability or date of each item estimated independently of the others.

The rationale of the cross-impact matrix is to find the conditional probabilities of forecasted items in full consideration of the potential interactions among them. A matrix is constructed with forecasted developments in rows and the associated probabilities in columns. The question is then how the probability of the individual items will vary with the occurrence or non-occurrence of other items.

There are at least three modes of connection between events: unrelated, enhancing and inhibiting. Enhancing linkages are those in which the probability of the second event is improved by the occurrence of the first. The reverse is true for inhibiting linkages.

The technique has been adapted to enable mathematical calculations to be carried out on a computer, with a view to showing or testing possible future developments of the variables selected. The effects of government or organisation policies can be included at the outset or during the computer run.

Discovery Matrix

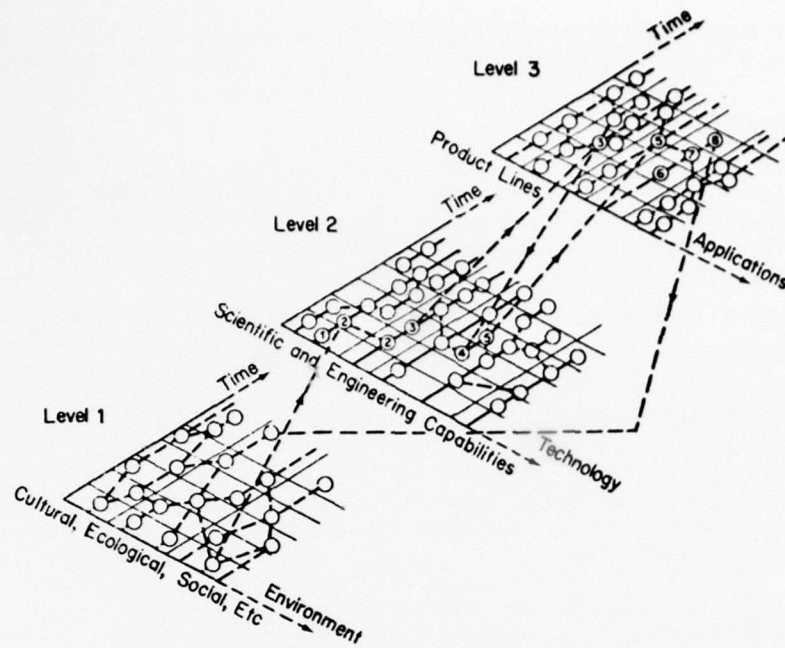
The discovery matrix is an aid to creativity very similar in principle to the morphological analysis; it is oriented towards exploration of possible combinations which have not previously been thought of.

The method is based on the construction of a matrix which represents the area under investigation. Two lists of parameters or characteristics are established. The rows correspond to items of one list and the columns to items on the other one. The lists must satisfy the following criteria:

- (i) It must be internally consistent, i.e. the parameters in it must be of the same type;
- (ii) each list must be exhaustive;
- (iii) the point of view adopted for the two lists must be independent and the combination of the two must be meaningful for the area under investigation.

New ideas can be discovered by combining one item from the first list with one item from the second. All possible combinations of items in rows and columns can thus be examined systematically.

Map of the technological future



Cross-impact matrix

| If this development were to occur: | Then Probability of | | | |
|------------------------------------|---------------------|----------------|----------------|----------------|
| | D ₁ | D ₂ | D ₃ | D ₄ |
| D ₁ | X | — | — | ↑ |
| D ₂ | ↑ | X | — | ↑ |
| D ₃ | — | — | X | — |
| D ₄ | — | — | — | X |

Figure 10

Morphological Analysis

This technique is an aid to creativity which tends to apprehend a whole range of possible solutions to a given problem by means of a systematic exploration of all significant parameters and basic principles.

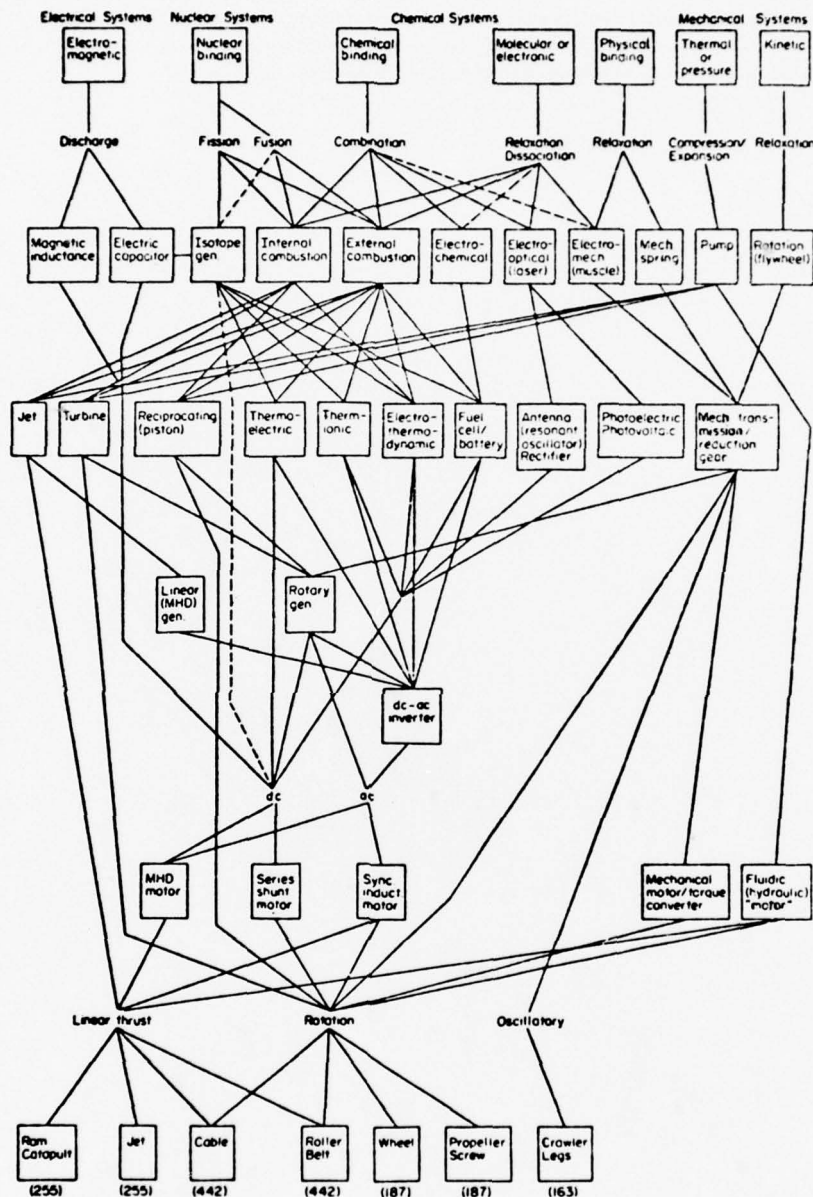
The steps involved in the method are the following:

- (i) Exact formulation of the problem to be studied.
- (ii) Problem structuring through identification of important parameters. Each parameter possesses a number of independent irreducible values which have to be determined and linked in a complete matrix form which is called a "morphological box".
- (iii) Enumeration of all possible combinations of the different values of the various parameters. It is convenient to use a computer, since the number of alternative combinations is very important. Concepts or random selection

can be used to select solutions which are closest either to known solutions or to the most strange ones.

(iv) Examination of the usefulness of solutions.

Morphological analysis is principally used to discover as many options as might exist and to provide a framework for thought. Its main advantage is to suggest new or unsuspected technological possibilities. However, the amount of work needed to consider the various combinations and to exploit the new ideas is considerable.



Sources of propulsive work. (Figures in parentheses below some items refer to the number of possibilities.)

Fig.11 Morphological analysis

Perspective Tree

Perspective tree is a structuring method of using forecasts in a planning process. This diagram links graphically relevant factors through three domains of concern:

- (i) The environmental domain is external to the organisation and is the one which includes changes and events of economic, social, political and broad technological nature.

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- (ii) Technology is the domain of technical changes available, or potentially available, to the organisation or company, or its competitors, for accomplishing technical advances in the technology under study.
- (iii) Between the two domains of environment and technology is a domain of utilities and functions. It is essential to define these utilities and functions explicitly in order to discover potential avenues of technology transfer. A function is an attribute of a physical system subject to change or improvement through one or more technologies. A utility is an attribute of a system deemed of value by the user of the system.

A set of perceived changes in the environment linked with a set of possible changes in the technology through one or more of the functions and/or utilities depicts a tree. Each tree represents a set of related changes – the impact of which could threaten present products or could provide a foundation for building a new area of interest. In other words, each tree represents a partially defined threat or opportunity to be considered further.

Discovery matrix

| Rotor \ Stator | Passive | Permanent magnet 2-pole | Electro-magnet dc, 1-pole | Electro-magnet dc, 2(N)-pole | Electro-magnet ac, 1-pole | Electro-magnet ac, 2(N)-pole |
|------------------------------|---------------------------|--------------------------|---------------------------|-------------------------------------|---------------------------|-----------------------------------|
| Passive | X | X | X | X | X | Inductive conjugate? |
| Permanent magnet 2-pole | X | X | Homopolar (PM) | X | X | dc (PM) (with commutator) |
| Electro-magnet dc, 1-pole | X | Homopolar conjugate (PM) | X | Homopolar conjugate (EM) | X | X |
| Electro-magnet dc, 2(N)-pole | X | X | Homopolar (EM) | X | X | dc series/shunt (with commutator) |
| Electro-magnet ac, 1-pole | X | X | X | X | X | ac homopolar conjugate? |
| Electro-magnet ac, 2(N)-pole | Inductive (squirrel cage) | Inductive synchro (PM) | X | Inductive synchro (EM) (slip rings) | ac Homopolar | X |

Morphological summary of electrical torque-producing devices.

Perspective tree

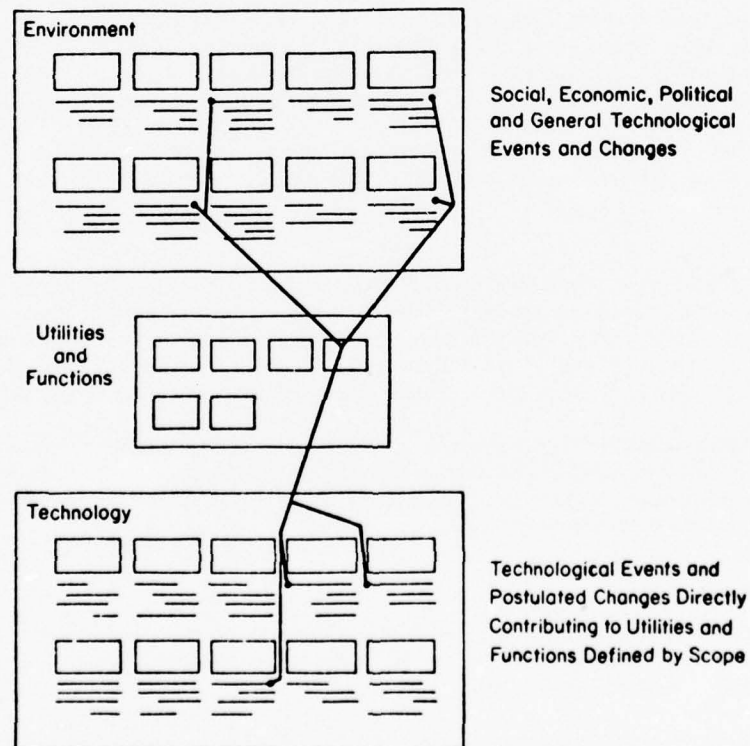


Figure 12

CHAPTER V

DECISIONAL RESEARCH

Decisional research can be defined as a search for the best of possible lines of action. In comparison with projective research and prospective research it is "teleological" in nature or goal-oriented, i.e., it is conducted with a view to analysing alternative paths which can lead to a given objective.

Most often decisional research is used as an evaluation tool. When applied to technological forecasting, it is expected to structure the events to be forecast within a decisional approach, so as to outline action options and facilitate choice of policies.

There exists a great variety of methods which vary widely, both in theoretical basis and applications. They range from project control devices to optimisation techniques and complex integrating models which attempt to take into account the whole concatenation of parameters, variables and their relationships.

The group of project control techniques includes mainly graph theory and network analysis. The group of optimisation techniques covers methods based on decision theory and derived from the experience of operations research and cost/benefit analysis. The techniques in the third group are characterised by a holistic or systems approach and include trees and system representations.

Graph Theory

Graph theory is designed to improve understanding of the structure and mechanisms of complex systems. It is primarily a structuring device. It consists of a diagram indicating interactions between parts of a system. The connecting lines may be arrowed to indicate the *direction of interaction (directed graphs)*. The graph may be represented by a matrix which can reveal certain features of the system, e.g., the number of linkages, nature of interrelationships, etc.

The claimed advantage of a graph is similar to that of a computer model, i.e., it enables us to illuminate a complex chain of interactions which cannot be grasped intuitively, if no detailed quantification is required.

Network Analysis

Graph theory has led to various network techniques which are used as management tools for the control of complex projects. For a given project, or research and development strategy, a network of possible stages and steps is mapped, to determine the optimal trajectory. This is the principle of *critical path evaluation* which involves the construction of "flow charts" indicating combinations of factors required for the realisation of a project and the necessary timing. In this way possible bottle-necks are pinpointed and factors are determined where major efforts will be needed.

A more sophisticated variant is *PERT* (Programme Evaluation and Review Technique) which allows for stochastic inputs and is used to compute probabilities for the time and cost involved in the realisation of a project. It was developed first for the Polaris missile system. Experience of U.S. agencies suggests that this method did not enhance technical performance but reduced the probability of a cost or time overrun.

Optimisation Techniques

These methods lean on some aspects of decision theory. They have mostly been developed for operations research and extended to wider uses in research management and industry. These methods are employed in an effort to determine the best way of reaching an explicitly defined goal.

Their common characteristics are as follows:

- (i) Formulation of an analytical framework or objective function, preferably in mathematical terms;
- (ii) outline of an array of alternatives containing the desired future orientations;
- (iii) determination of operational targets;
- (iv) selection of evaluation criteria and calculation of action options;
- (v) comparison of the merits of alternative projects.

These methods include linear programming, non-linear programming, quadratic programming, optimal control and many others.

In complex programmes, where criteria of cost and effectiveness are neither known nor obvious, the most often used methods are cost/effectiveness and cost/benefit analysis. To determine the desirability of a proposed project a time horizon is specified and all consequences that can be foreseen are listed. Costs and benefits are attached to each consequence, usually in monetary terms, discounting the present values, and total costs and benefits are compared to obtain a "net value" of the project.

Optimisation choice of decisions

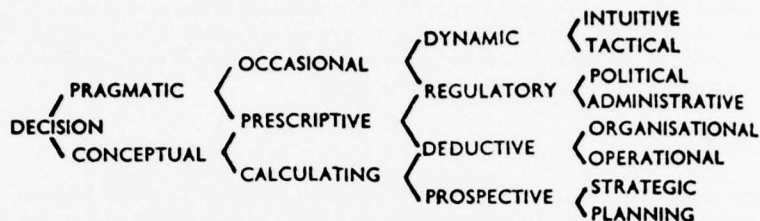


Diagram of the optimisation of decision-making as a function of the institutional and technical characteristics of each social-political system.

PERT (Progress Evaluation and Review Technique)

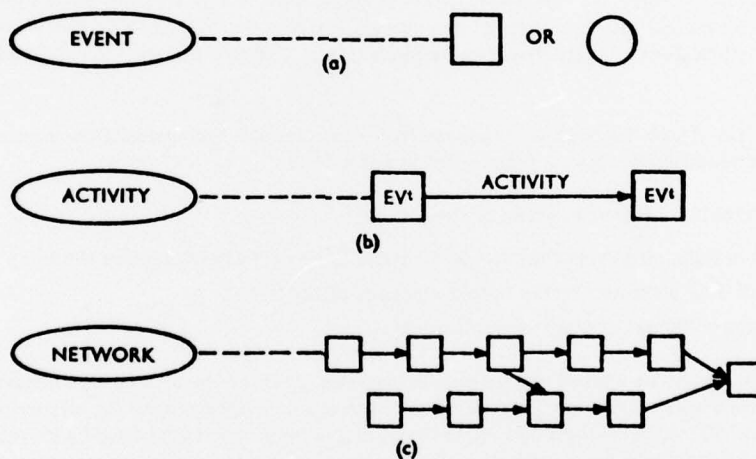


Figure 13

Gaming Models

Game theory is concerned with decision-making where alternatives are explicitly influenced by the actions of others. A set of possible strategies for the "players" is devised and under these conditions the optimum strategy for one player is calculated.

Gaming models are usually computer simulations based on some causal relationship. Factual information is separated from behavioural factors so that "policy decisions" by the players can be directly inserted to influence the observed evolution of the model. Gaming has been used mainly in situations where objective and subjective components of a system can be dissociated.

Systems Analysis Approach

Systems analysis implies a deliberate effort to conceptualise a given problem as a whole and to define the relationships between its components so as to permit a systematic exploration of its functioning. It aims at identifying

the best choice among possible alternatives, given the basic constraints of the system.

In technological forecasting the systems approach can take different forms, depending on the scope of the analysis.

A most straightforward method is to detect weaknesses and gaps in present operating systems and to define programmes for bridging them.

Another variant starts with hypotheses or expected future problems and attempts to define the characteristics of the technologies needed to solve them. Thus, for example, the various conceivable threats or attack patterns are identified and the analysts then try to define the performance characteristics needed to handle specific contingencies. On the basis of probability and cost calculations, necessary R & D programmes can be proposed.

Impacts study, which is still another variant of the systems approach, helps to determine the effects which new technological solutions would have on existing or anticipated operating systems. Cost and probability calculations at each performance level are made and are accompanied by parameter analyses, to serve as a basis for projecting the probable future state of the art and for determining the necessary support.

Decision and Relevance Trees

A tree is a structuring method in which several levels of objectives are linked within a hierarchical model so that sequential relationships can be explored. To apply a tree structuring method requires first a clear definition of the number of levels of the tree. This implies that a breakdown into linearly related levels should be feasible. The number of levels is not given *a priori* but reflects the decision-making structure of the organisation for which it is designed.

An *objectives tree* is thus essentially a hierarchy of objectives. In its basic conceptual form it consists of a diagram of dots or circles (vertices) joined by line segments. Each vertex is an objective or a sub-objective and each line segment represents the relationships between them. The only topological requirement is that there be only one path between each pair of vertices.

The same principle is applied in a *contingency tree*, in which the different levels or strata represent prerequisites and alternatives. The intent behind the structuring of a contingency tree is the same as that of an objectives tree, i.e., to stimulate creative identification of alternatives in a hierarchical way and to represent the relationships among alternatives at succeeding levels.

An extended form of tree structure is a *relevance tree*, which implies that quantitative measures or qualitative notes are attached to the evaluation of a system represented in a tree form.

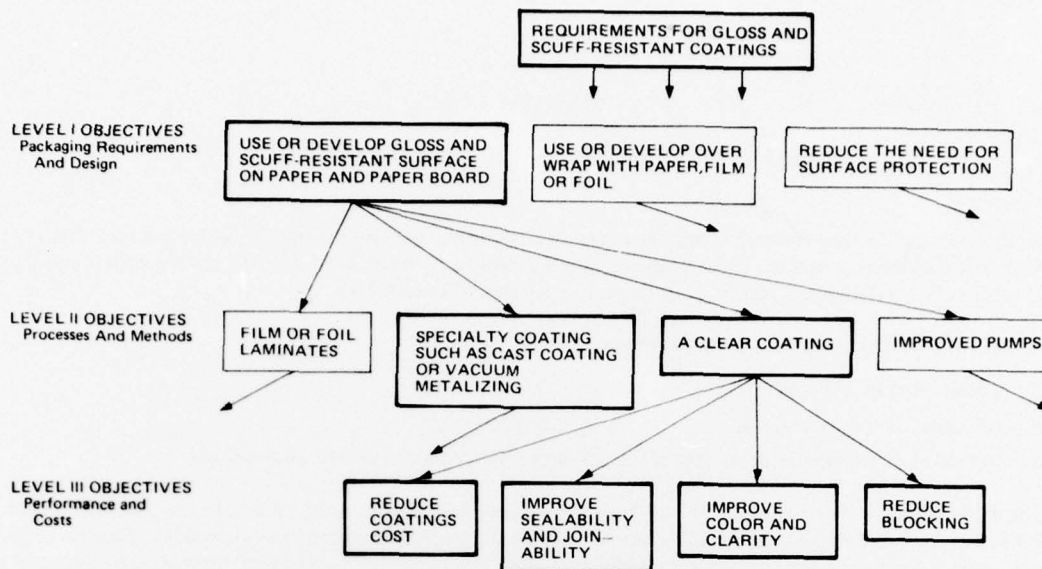
The working procedure consists basically of three steps:

- (i) definition of data, elements of the tree and criteria to be used at each level of the tree;
- (ii) forecasts of data pertaining to the various elements of the tree;
- (iii) computation of figures of merit or significance.

A quantitative value can be worked out for each alternative. This is done by means of a matrix in which the alternatives are matched against criteria. The criteria are given sets of weightings and the alternatives are given significance or relevance numbers. The criteria weightings relate to the long-term goal and are vertical with regard to the tree, whereas the significance numbers evaluate the contribution of the alternatives to each criterion and are horizontal to the tree since they refer only to one particular level.

If all the relevance numbers are multiplied and combined the result is an overall "relevance number". As such a unique value may be misleading, it may be left to the decision-maker to consider the proposed weighting figures at every important step on the way through the tree structure.

Objectives tree



An objectives tree related to gloss and scuff-resistant coatings on paper and paperboard (Thick-lined boxes indicate objectives directly related to the utilization of coatings).

Relevance tree

LEVELS

EXAMPLE OF A RELEVANCE TREE

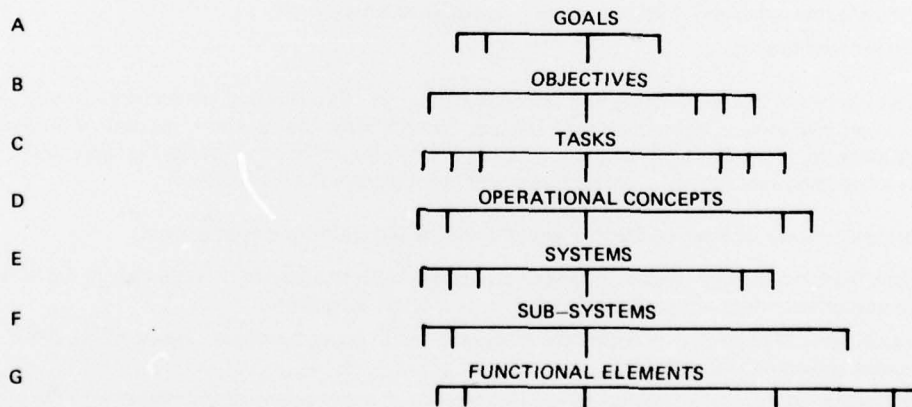


Figure 14

CHAPTER VI

SELECTION, PROCEDURE AND QUALITY CRITERIA

Strictly speaking, futures research is neither a scientific discipline *per se*, as viewed by some authors, nor a pre-scientific activity, as seen by others. It is a pluri-disciplinary approach which combines and applies with scientific rigour different pieces of knowledge and insight so as to explore an area of uncertainty.

The scientific method combines three elements:

- (i) construction of a theory;
- (ii) collection of empirical data;
- (iii) controlled experimentation to test coherence and validity of theoretical assumptions.

In futures research only *ad hoc* models can be built, because decisions must be taken. In the absence of hard data about the future, judgements and probabilistic analyses are used as substitutes for observation data. Finally, since experimentation is hardly feasible, analysts resort to simulation to test the implications of alternative decisions in the model. This model can be improved if more inputs are available and more experience is accumulated.

Many students of technological forecasting are of the opinion that the aim of technological forecasting is not to predict the precise form a technology will take in a given application at some future date but to evaluate the probability and significance of various possible future developments. The key word is *relevance*: analytical treatment of the forecasting model must be relevant to the policy issue and the results of the study must be relevant to the decision-maker.

Several factors make futures research in the area of technology difficult:

- (i) Inadequate data;
- (ii) discovery of totally new phenomena (scientific and technological breakthroughs);
- (iii) unpredictable interaction between technologies;
- (iv) unprecedented demands which are caused by positive feedback;
- (v) a distant time horizon.

There is an interactive linkage between and among these factors. By definition the future is an area of uncertainty, so that inadequacies will always exist in the data. The more remote is the time horizon, the more unforeseeable will be the demands. The more the technologies of the present will have interacted over future years, the more likely it is that completely new and important scientific and technological phenomena will be discovered.

From this brief outline of basic difficulties several procedural conditions can be derived:

- (i) Search for key variables: systematic examination and in-depth analysis of factors which are of fundamental importance and which are particularly sensitive and prone to change.
- (ii) Identification of inadequacies within the model so as to improve the understanding of the interrelationships between and among the variables.
- (iii) Verification that the technological forecasting remains at any moment close-coupled with the planning process, so that successive procedural steps and results can be confronted with the ongoing experience and vital objectives of the organisation.
- (iv) Continuous activity: ideally, futures research should be a continuous activity, allowing the revision and updating of forecasts as time brings technical, economic and social horizons closer and as more information is fed back and incorporated in the model.

The process of forecasting will be structured so as to keep close to the purpose for which it is undertaken. Its relevance and usefulness will be judged on its output, i.e., formulation of forecasts. To evaluate the quality of forecasts, a number of indicators are proposed which can help both analysts and users of forecasts to delineate general standards for common language and levels of confidence. These indicators are the following:

- (i) Specificity: A forecast should be stated in terms which are specific enough to permit unambiguous determination of fulfilment or non-fulfilment. These terms can be quantitative or not. As a rule, the forecast

should be as specific as the range of forecasted values which is expected or manageable from the decision-maker's point of view.

- (ii) **Uncertainty:** A forecast is only one of a number of possible futures. It should therefore be stated in terms of probability of occurrence or as a distribution of a value or a range of possible dates at which a probability of occurrence is expected to reach a given level.
- (iii) **Time relatedness:** A forecast expresses the future state of a given phenomenon which is determined by concurrent events that take place during a period of time. In the case of a technology it reflects different stages of growth, development and diffusion which it is important to delineate as closely as possible with regard to present conditions.
- (iv) **Intra-field relatedness:** A forecast of an event should reflect knowledge of competitive and complementary developments in the same field as the event. It is important to specify in the forecast the manner in which these developments will affect the forecasted event.
- (v) **Inter-field relatedness:** A forecast should reflect knowledge of developments in other fields that may influence the forecasted event.
- (vi) **Recognition of costs and benefits:** A forecast should incorporate knowledgeable judgements about economic and social costs and benefits, since any development is likely to include both potential benefits and disadvantages.

These indicators suggest not only the main categories of intrinsic conditions but also the extent of the informational framework and lead thus to general criteria by which a forecast can be evaluated as to its formal construction:

- reproducibility: a measure of the extent to which the same state of information or knowledge leads to the same forecast;
- validity: a measure of the extent to which a forecast utilises available information or knowledge effectively to reflect the real world and its perception of the future;
- value explicitness: a measure of the extent to which a forecast is dependent upon a forecaster's value system.

These criteria are familiar in scientific research. However, their use for evaluation of forecasting activities is made difficult by the fact that forecasting implies, by definition, hypothetical statements on the basis of heterogeneous pieces of information or simulated data. Nevertheless they have to be pursued as a continuous search for such proximate elements which make forecasting logically integrated and reconcilable with attainable scientific rigour.

Uncertainty in forecasting arises on the one hand from uncertainty in data and theory and on the other hand from the many difficulties of manipulating them. Where data are few and theory is weak, no amount of sophistication can compensate.

As can be expected, none of the various techniques reviewed here has proved completely satisfactory or generally applicable. It is often said that the best techniques to use in any circumstances will depend upon the purpose for which the forecast is made and the information available. However, this sounds a "hen-and-egg" argument, since the technique can help quite strongly to clarify the purpose, which is rarely clear-cut or perfectly explicit.

The forecasting team should develop ways of working together which made the best use of available talent and information to meet the needs of decision-makers. It seems advisable to use several methods in combination in order to stimulate imaginative analysis, to introduce added objectivity and to make sure that all relevant aspects of the problem are considered.

This may often be in contradiction with urgency. Many important problems require rapid decisions, which have to be taken without awaiting a comprehensive analysis. Even the most suitable combination of methods can prove useless if it takes too long to devise or to apply. This explains why the most straightforward methods continue to prevail, in spite of their acknowledged inadequacies.

In regard to the selection of a suitable technique, an example can be given of an attempt to characterise and to compare some of the main techniques in terms of time involved, data required, reproducibility, objectivity, confidence in accuracy, assumptions and general remarks. (Tables IV and V.)

This example suggests that for a quick, inexpensive, moderately reliable, short-term forecast it may be appropriate to get the opinion of an expert in the technological field. For better credibility and a longer time-span, a committee of experts or a Delphi survey may be employed. If resources are even more substantial and for a long-range time-span, a Delphi survey can be employed as a basis and lead to a consensus panel to provide additional insights. On the other hand, in cases where data is available easily in suitable form and the time horizon does not exceed 10 years, the use of trend analysis may be employed as providing greater objectivity, reproducibility and confidence.

Another example, based on experience in the management of research and development by leading manufacturing firms, has been given by EIRMA (European Industrial Research Management Association), which links forecasting techniques to the roles of technological forecasting in planning R & D activities. This cross-linking of roles and techniques

can be summed up as follows:

- (i) **Definition of the areas of interest to the organisation**
For fundamental and applied research projects one needs to identify the disciplines and technologies which are of interest to the organisation. This can be done in designing a product-technology-discipline matrix. For development projects the stress is on the product or operational system. The applicable method is a relevance tree, starting from the needs or functions which are satisfied by the present range of devices and exploring alternative technologies which can satisfy the same functions.
- (ii) **Generation of new R & D proposals**
The following techniques can be helpful. First is the monitoring of R & D by scientific communities and round-table interdisciplinary discussions on major trends and possible transfer of technologies between different fields.
Possible developments can be mapped out by Delphi analysis and probabilistic assessment of occurrence, significance and diffusion. Variants of flow charts or PERT networks, needed to link the present situation to the forecast event, may supply ideas on research to be started now.
A reversed approach consists of starting from the objectives or missions of the organisation and possible alternative ways of achieving them, which lead to identifying new research areas and to defining new research programmes. The suitable techniques are morphological analysis and relevance trees.
- (iii) **Evaluation and selection of R & D projects**
Here also the relevance tree correlating objectives-missions-systems-products-technologies appears as a suitable technique which helps to estimate the relative importance of the various levels of factors. Trend extrapolation can be a useful subsidiary to the relevance tree, giving an indication of the probability of reaching individual targets.
Cost/benefit analysis is an important tool for development projects related to new products.
- (iv) **Operational planning of selected R & D projects**
Trend extrapolation can be helpful for quantifying detailed targets of the project and so can the network techniques.

These examples may give useful hints, although it can be argued that each forecasting problem has some unique features and must therefore be handled with a specific set of tools.

The choice of an appropriate methodology will depend primarily on the purpose of the forecast, and on its use by the decision-makers in pursuit of their objectives. It will then depend on the ability of the forecasters, their complementary talents and the coordination of their efforts. Next in importance comes the data base, from the view point of reliability, completeness and quantitative precision. Another important factor is the time horizon of the forecast. Finally, the scope of the forecasting activity must be considered in an iterative way, in the light of available resources and time.

TABLE IV
Exploratory Techniques

| Technique (All Extrapolative) | Time Involved | Data Required | Reproducibility (years) | | | Objectivity | Confidence in Accuracy of the Method (0 when no data available) | | | Assumptions | Remarks |
|----------------------------------|------------------|----------------------|----------------------------|--------------|---------------|---------------------|---|--------------|-----------------|---|--|
| | | | 1-3 | 3-10 | 10 or More | | 1-3 | 3-10 | 10 or Higher | | |
| 1. Single trend extrapolation | Medium | High | Excel. | Excel. | Excel. | High | Very good | Good | Poor to mod. | Future - an extrapolation on past continuity | Work high if data obscure - low available. Confi- dence depends on ade- quate data over sufficient time. Only possible if data are available. |
| | | | 10 | 9 | 8 | | 7 | 6 | 0-4 | | |
| 2. Growth analogy | Medium | High | Excel. | Excel. | Excel. | High | Very good | Very good | Poor to mod. | Above and natural limits | Same as (1) above - treatment of natural limits is improvement. |
| | | | 10 | 9 | 8 | | 7 | 7 | 0-5 | | |
| 3. Correlation analysis | High | High to very high | Excel. | Very good | Mod. | High to moderate | Very good | Very good | Poor to mod. | Above plus tradeoffs | As in (1) and (2) above. Longrange forecast confi- dence depends on abun- dant and detailed data. |
| | | | 9 | 8 | 6 | | 7 | 8-9 | 1-6 | | |
| 4. Substitution | Medium | High | Very good | Very good | Very good | High | Very good | Very good | Poor to mod. | Once started, substitutions inevitable | Long-term analysis better for item substituted; valu- able for process trend analysis. (Fatalistic - not as useful to control the future.) |
| | | | 9 | 9 | 9 | | 7 | 7 | 0-5 | | |

TABLE V
Intuitive and Normative Techniques

| Technique (5-8 Intuitive; 9 Normative) | Time Involved | Data Required | Reproducibility (years) | | | Objectivity | Confidence in Accuracy of the Method (0 when no data available) | | | Assumptions | Remarks |
|--|------------------------|---------------------------|----------------------------|----------------------|---------------|-------------|---|-----------|------------------------|--|---|
| | | | 1-3 | 3-10 | 10 or More | | 1-3 | 3-10 | 10 or Higher | | |
| 5. Personal judgement | Very small 1 | No | Good | Mod. to poor 3 | Worthless | Low | Good | Poor | Poor | Hidden | Highly dependent on the individual. |
| 6. Genius (means knowledgeable person) | Very small | No | Good | Mod. | Poor | Low | 6 Very good | 1 Mod. | Poor | Hidden | Identification of indivi- dual difficult. Reputation protection leads to con- servatism. |
| 7. Consensus | 2 Small | 1 No | 6 Very good | 4 Mod. to good | 0 Poor + | Moderate | 7 Very good | Mod. | Poor to mod. | Partially visible | Initial choice and balance very important - social pressures to conform may be high. |
| 8. Delphi | 4 Small to large | 1 Some | 8 Very good | 5 Good | 2 Mod. | 4 High | 8 Very good | 4 Mod. | 2-4 Mod. | Partially visible | Comparatively good long- term where data base is poor or nonexistent. Depends heavily on ques- tion formulation and pro- gramming. (Trend analysis can be helpful.) |
| 9. Normative | 3-7 Large | 2 High to very high | 8 Very good | 6 Good | 4 Mod. | 5 High | 8 Very good | 5 Good | 2-4 Poor to Mod. | Specific desirable future exists | Total range of assumptions rarely specified (social, economic, and political). Tends to limit exploratory solutions. |
| | 8-10 | 8-10 | 8 | 6 | 4 | 6 | 7 | 6 | 2-4 | | |

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