Def Sci J, Vol 39, No. 3, July 1989, pp 277-285

Techniques of Technological Forecasting

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ABSTRACT

Technological forecasts can improve decisions through clearer delineation of future technological opportunities and threats. A review of the various methods applicable in the area of technology is presented. The limitations of a particular technique must be clearly understood before it is applied. Some defence applications have also been discussed.

1. INTRODUCTION

The aim of the technological forecasting is for planning the future research and development programmes through perceptive study and analysis of current and future conditions and environment. It is usually concerned with forecasting the occurrence and effect of events which imply fundamental change in technological and social environment. Corporate enterprises can no longer afford to engage in scientific research without some indications as to its outcome. Efforts have to be increasingly directed towards anticipating the possible and probable results of such research.

The rapid scientific progress has vastly increased the degree of complexity of the interrelated technologies. A systematic and comprehensive approach is required for forecasting such technological changes. We have to evolve tools which can cope with the complexity of interrelationship in technology, variability of events and lack of information about the future. Technological forecasting techniques provide some such tools.

It may also be mentioned that however trustworthy the techniques may be, it is not possible to guarantee the correctness of the forecast. Certain unforeseeable events like wars and economic crisis which result in the deflection of resources for scientific effort can upset even the most skilfully achieved forecast. Sometimes good forecasts are made just by intuition. Formalised forecasting techniques just augment the capability of the forecaster. Though the systematic forecasting of scientific

Received 27 August 1987

breakthrough and technological innovations was started in 1930s but during the last fifteen years there has been immense growth of interest in the subject.

Technological forecasting techniques are usually divided into two categories—exploratory and normative. Exploratory forecasting is based upon the past and the present knowledge and is oriented towards the future, while normative forecasting first sets up the future needs and objectives and then specifies the means to achieve them. Exploratory methods include intuitive methods, Delphi method, trend extrapolation, growth curves, analytical methods, etc., while normative methods include, relevance trees and scenario writing, etc.

2. EXPLORATORY METHODS

The easiest approach to obtain a forecast in a field is to get the opinion of an expert in that area. This can however be refined by introducing system and order to arrive at a rational analysis. Panel approach, brainstorming and Delphi are some of the systematised approaches.

2.1 Panel Approach

In order to eliminate the possibility of a heavy individual bias, a panel of experts achieve a consensus forecast by exchanging views. The US Navy and Air Force have used this method for defence forecasting. This method has the inherent weakness that the final result may be unduly influenced by the person with highest bureaucratic status.

2.2 Brainstorming

Brainstorming is used to explore what will happen when a particular foreseen event occurs. It involves the collection of a group of people under a leader. The leader encourages speculation from one basic event inorder to generate a large number of events which may possibly relate to it. Every idea however absurd it may look, is, given due consideration. Criticism of the feasibility of an idea is not encouraged during the brainstorming session. The result is a list of possible ideas of events which could happen. This could also serve as an input for other forecasting techniques.

2.3 Delphi Method

This technique was developed by the Rand Corporation in the 1940s. The aim of the Delphi approach is to obtain the consensus of opinion of a group of experts regarding a future event. This method eliminates the disadvantages of round-table discussions or direct confrontation of experts by maintaining anonymity. The diversity in the individual forecast is progressively narrowed down by successive rounds of interrogation and commentary. This method is applicable in cases where a policy or plan is required to be based on informed judgement.

A questionnaire is prepared and sent to a number of experts in the field. On receiving the responses, the interquartile range is determined. The first median response is sent to the participants who are asked to revise their previous answers if they so desired. Participants are also asked to elaborate reasons for disagreeing to the initial consensus. The results of the second round are again sent to the participants in terms of the average or median. Respondents are asked to revise their previous answers with reasons. In the fourth or usually the final round the participants again get a chance to revise their estimates. Thus the group consensus is obtained in the form of the median of the final responses.

This method can be expressed neatly in the form of a flow diagram as shown in Fig. 1.

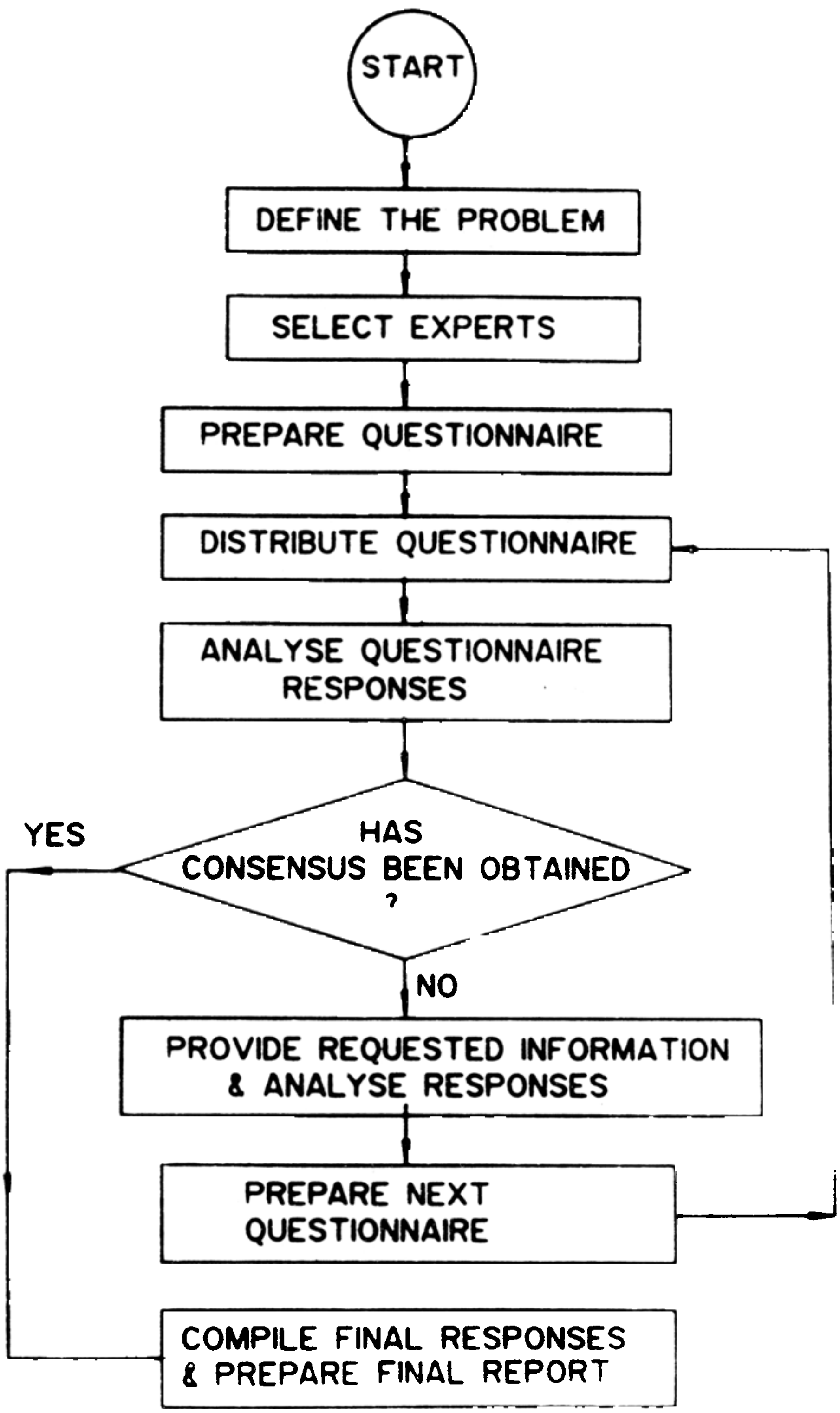

Figure Flow diagram of Delphi-method

It may also be mentioned that no basic data is provided to the participants and it is time consuming due to several rounds.

The modification of Delphi method is known as SEER (System for Event Evaluation and Review)[1]. In this process, instead of sending the questionnaire in the first round, an initial list of forecasts constructed through a series of interviews is sent to the participants. This method saves time as the number of questionnaire rounds is reduced. The participants are asked to answer questions in their respective areas of expertise. This reduces the possibility of distorted responses caused by lack of expertise in a particular area.

2.4 Trend Extrapolation

Trend extrapolation is a simple extrapolation of the present trend of a theoretical parameter. The basic assumption is that a large number of interacting forces which were influencing the past trend will generally continue to act in the same way. This assumption may seem valid in certain spheres like economics but in the field of science and technology certain revolutionary developments cannot be anticipated by simple extrapolation of the past. So in order to cover up the possibilities of certain jumps in a technology, trend extrapolation may be supplemented by brainstorming, scenarios and other similar devices. Indications of future needs, alongwith future economic and social constraints is also helpful for forecasting the tendency of a technology which may not agree with the mere projection of the current trend.

A particular technological capability can be extrapolated by using linear, exponential or double exponential extrapolations. Productions of commercial vehicles in India follows a linear trend with time[2]. Certain technological capabilities and technological parameters which have been growing exponentially with time can safely be subjected to exponential extrapolations. For instance logarithm of world's oil production has followed linear trend with time for a fairly long time.

In case of certain emerging technologies research and development (R&D) efforts are concentrated in the early stages of development. So, the inputs result in manifold development. In such cases double exponential method may be applied. In the field of laser technology, output energies from lasers follow this type of growth. When the collected time-series data for a selected parameter is plotted on a semilogarithmic graph, the straight line of the best fit is the trend line. In case of deviations from the straight line exponential trend, subsequent extrapolation does not remain valid unless fully explainable. For example, if rate of progress decreases in a regular fashion then the extrapolation will require a diminished incidence of increase. This diminished rate of increase may be as a result of maturity or some boundary conditions.

2.5 Regression and Curve Fitting

Statistical methods like regression and curve fitting can be made use of if large amount of past data is available. A straight line, an exponential or any real function of the form

$f(x) \propto x^p$ (where p is +ve or −ve) are the simple examples of continuous curves. A polynomial may be more suitable if a set of data points (i.e., a time-series) does not fit the above forms.

For N data points there exists at least one polynomial.

$a_0 + a_1x + a_2x^2 + \text{---------} + a_mx^m$ of degree $N - 1$

which exactly fit the data.

There can be higher degree polynomials which may also fit exactly. The precise problem is to find a function which fits reasonably well and realistic also. The choice of the form of the curve is not based on the mathematical considerations but the curve should be specified by morphological simplicity, smoothness, and symmetry. But it should necessarily fit in the past data with high correlation coefficient or low error so that it may be extrapolated into the future with confidence.

2.6 Substitution Technique

In certain cases a particular technology is under the natural process of substitution by some other technology like the substitution of natural fibres by synthetic fibres, soaps by detergents, etc. The parameters of a technology can be forecast by extrapolating the rate of substitution of that technology by some recent technology. This technique of forecasting using previous substitution rates has been developed by Fisher & Pry[3].

The fractional rate of substitution of a new technology for an old technology is proportional to the remaining amount of the old technology left to be substituted.

Mathematically it can be expressed as

$$\frac{1}{-}\left(\frac{df}{dt}\right) = 2a(1-f)$$

where f is the fraction of new technology or the extent of substitution and $2a$ is a constant.

2.7 Growth Curves

Certain technological parameters attain an ultimate saturation level i.e., the growth is restricted due to practical limitations. In such situations, logistic time growth S-curves can be used.

Pearls growth curve can easily be employed for the generation of information or performance of technology. The function can be expressed as

$y = L/(1 + ae^{-bt})'$

where y is the state of information or performance of technology or functional capability of technology at time t.

L = upper limit of growth and a & b are constants

when $t = -\propto, y = 0$

when $t = +\propto, y = L$

the values of a and b which give a good fit to the data are determined on the basis of some historical data. The equation can be rewritten as

$$L/y = \quad + ae^{-bt}$$

or

$$\log (L/y - 1) = \log a - bt$$

when log $(L/y-1)$ is plotted against time we get a straight line which can be extrapolated into the future. The curve is symmetrical about its point of inflexion $y = L/2$. Initially there is slow growth of technology and the upper flattening is due to the approaching of a limit.

In case of certain technologies where the growth in the initial stages is comparatively faster than shown by the Pearl curve, another curve known as Compertz *S*-curve can be used.

It can be expressed as

$$y = Le^{-b e^{-kt}}$$

or

$$\log [\log (L/y)] = \log b - kt$$

where y is the growth phenomena, t is the time, b and k are constants and L is the limit of growth at $t = \propto$.

2.8 Envelope Curves

Envelope curve is the extension of trend extrapolation technique. This technique can be applied where a technological parameter shows separate trends in different periods of time. The trend of that parameter in different time periods must be in the nature of *S*-curves. The envelope curve is usually in the shape of a big S embracing a series of small *S*-curves. That particular technological capability (whose trend is depicted by big *S*) is not restricted by the maturing of a specific technology but it is pushed further by a succession of different technologies. This method is applicable to those fields which have seen several technologies approach and pass maturity. For example, the speeds achieved by man through various means of transport at different stages of technological development are shown in Fig. 2. The estimations of the speed that may be achieved in the year 2000 AD and beyond can be made by a curve which envelopes the individual curves.

3. NORMATIVE TECHNIQUES

3.1 Relevance Tree Technique

Relevance trees are constructed to indicate in a systematized manner the sub-objectives and achievements which must be met for achieving the overall objective. We start with a main objective and then break it into various goals and sub-goals at lower levels. The shape of the tree is broadly pyramidal with the number of endpoint of branches increasing in number as one goes down the tree. Technological deficiencies for certain sub-objectives should also be identified.

Relevance trees can be used for R&D planning and decision making. Further the construction of the tree helps the specifications of alternative methods. By showing these, the estimation of the feasibility of achieving the particular objective is greatly improved. The relevance tree can be supplemented with probabilistic methods also.

An example of a relevance tree with relevance numbers is given in Fig. 3.

The tasks T_1, T_2 and T_3 are quantified using numbers which add up to one. The relative importance of each path is calculated by multiplying all the relevance numbers in a given path. Improvement of approach A_{11} is about twice as important as the improvement of approach A_{12}.

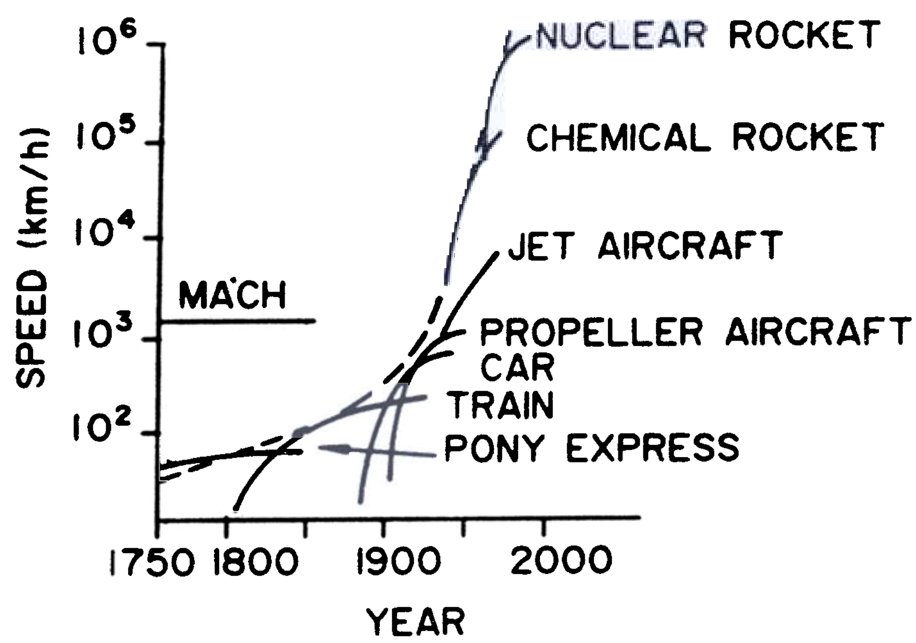

Figure 2. Envelope curve.

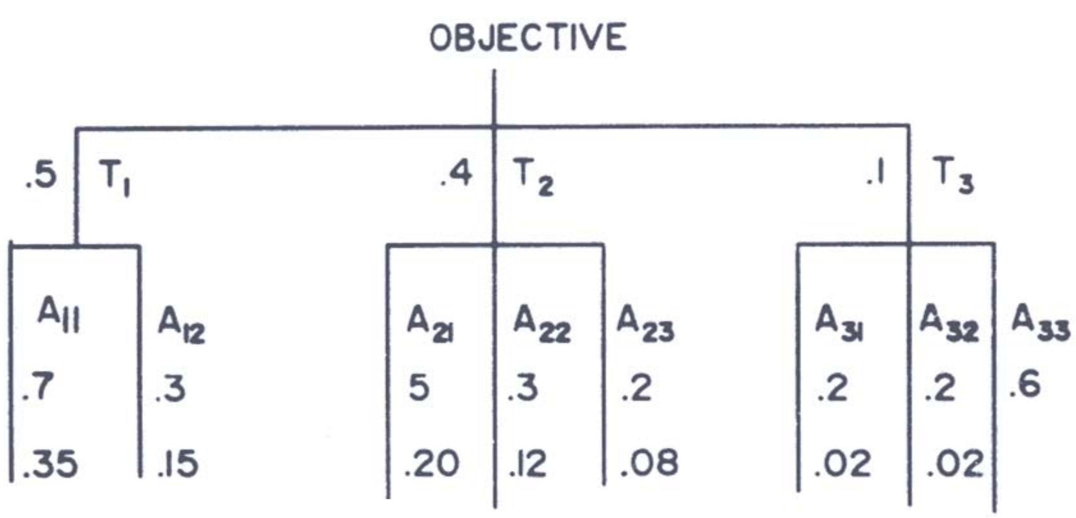

Figure 3. Relevance tree with relevance numbers.

3.2 Morphological Analysis

Morphological analysis involves the systematic investigation of all possible solutions to a given problem before the best solution is chosen. The problem is broken down into parts which are not interrelated. Overall solutions are obtained by taking one solution of each part. The total number of overall solutions is equal to the number of possible combinations, taking one solution of each part. However, only one of the solutions is actually feasible to meet the requirement of the objective. The feasible solution of each part is determined in order to evolve the best overall solution.

The method has the advantage that each alternative can be worked on individually, not requiring group interaction. The most essential element in the process is the clear definition of each part. This method has been successfully used for aerospace industry and defence planning.

3.3 Scenario Writing

This method was developed by Kahn & Wiener in 1965. It is suited to solutions where several aspects of a problem are to be dealt with simultaneously. The main purpose of scenario writing is to provide a composite picture of various relevant future events. It gives the collective impact of a group of interacting forecasts. It considers the interrelationship between the predicted events and develops a composite picture of the future. Scenario writing has been applied by several big oil companies which are deeply interested in future economic, political and social environment.

4. DEFENCE APPLICATIONS

The modern military technology depends on many fields of sub-technology and other non-technical influences like political and social. To attempt long term forecasts in this field is quite a complex procedure. In order to plan the development of defence and other support systems, it is vital to first conceive the potential and peripherial threat. It is also important that this is not left to adhoc activity. Technological forecasting techniques provide some tools for identifying attainable technological capabilities and system configurations to meet the projected enemy threat.

A formal forecast can provide inputs to feasibility studies at all levels of the operational and technical communities. The forecast can make available to laboratories and technical offices, projections of the state of art in supporting areas outside their immediate scientific or technical expertise. It can identify technological areas which have high potential for sensitive developments. For example, a moderate improvement in some technologies may have a high impact on operational effectiveness, while a large technical gain in other areas may not improve operational capability. The forecast can also identify the extent of inter-dependence of the various technical disciplines and areas in which component developments are compatible or augment on another. When more than one functional capability contributes to an end item development, a reasonable prognostication can determine the relative burden on the projected state of the art in each contributing area.

Before studying the technological developments in modern weaponary, one has to analyse some technology. Finally, we can study how these developments and applications may interact with international diplomacy. Some of the potential developments in basic technology are in the fields of materials, nuclear weapons electrical power sources, electronics, lasers and hypersonic aircraft etc. Some military applications of technology are in the fields of deep submergence, guidance, aerospace plane, space systems, communications and warfare by hardware proxy, etc. According to Brennan[4] 'The materials developments in the coming years will make possible submarines with a depth capacity of 20,000 feet or more. This would make most of the ocean floor accessible to submarines and submarine-supported technology. Many items of military interest are limited in their performance due to the non-availability of compact resources of electrical power. However, this problem has been satisfactorily solved for nuclear submarines which is not now limited by its power plant'.

ACKNOWLEDGEMENTS

The authors are grateful to Shri A.K. Chattopadhyay, Scientific Adviser to the Chief of the Army Staff for his guidance and useful suggestions during the preparation of this paper.

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