



Study of Technology Forecasting Methods

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Abstract:

The primary function of forecasting is to predict the future using data we have in hand. Technological forecasting is the process of predicting the future characteristics and timing of technology. The technology forecasting methods can be classified as exploratory and normative forecasting methods. There are many changes being performed in different technologies such as software technologies, computing technologies, hardware technologies, etc. There is a need to find the trends and predict the future of these technologies. The technology forecasting methods are useful to find the trends and predict the future. In this paper, we focused on various technology forecasting methods which can be used to track the trends of different technologies.

Keywords: Technology forecasting, Exploratory, Normative.

1. Introduction

All that we know about the future is that it will be different from the present. Forecasting is nothing but predicting what the future is going to be using some historical data. The primary function of forecasting is to predict the future using data we have in hand. It is important to both planning and decision making. Technological forecasting is the process of predicting the future characteristics and timing of technology [1]. Technological forecasting is aimed at predicting future technological capabilities, attributes, and parameters. Forecasting a technology includes not only specifically “mechanical/physical hardware”, but also encircles associated “software” such as procedures and methods for organizing human activity, and means for manipulating or engineering human behavior.

In this paper, section II describes the classification of technology forecasting methods with their advantages, disadvantages and applications. Section III gives literature review of technology forecasting methods. Section IV concludes the paper.

2. Classification of Technology forecasting methods

The technology forecasting methods can be classified as exploratory and normative forecasting methods. Exploratory technological forecasting starts from today’s assured basis of knowledge and is oriented towards the future, while normative technological forecasting first assesses future goals, needs, desires, mission, etc., and works backwards to the present.

Table 1: Technology forecasting methods

Technological Forecasting Methods						
Exploratory				Normative		
Delphi	Trend Extrapolation	Growth Curves	Technology Monitoring	Relevance Trees	Morphological Analysis	Mission Flow Diagrams

Delphi Method

Delphi method is one of the most popular methods for knowledge extraction from experts and other important stakeholders. This method involves questioning a panel of experts and drawing out forecasts on specific technology with minimum face to face interactions. A moderator collects the data and conducts multiple rounds of interviews where the panelists are allowed to withdraw, change or justify their predictions. At the end of the rounds a report is generated with all the predictions, objections and changes noted.

The Delphi method has three characteristics.

Anonymity: During the Delphi process, no any member knows the specific contributions of the other members. In most cases a person would not even know who the members of his/her group are. This methodology has its unique benefits. It avoids any influence of opinion owing to the reputation of other members. The anonymity also provides the experts an opportunity to come back to their expressed opinions, without the fear of embarrassment, when they encounter any proof converse to their expectations.

Iteration with controlled feedback: The survey coordinator extracts responses which are assumed relevant to the topic and these are sent back to the group. This sort of mediation throughout the process ensures that biased opinions are not pushed by merely repeating or restating them over and over again.

Statistical group response: In the Delphi method, for every item the responses are drawn with statistics that describe both the important view as well as the degree of spread.

The Delphi process involves the following steps:

- Identify the subject in which the Delphi survey is to be conducted.
- Recruit a group of experienced people who can prepare the questionnaire for forecasting the technological developments.
- During the first round the questionnaire is then distributed among experts to address all possible aspects of the issues. These participants are asked to forecast events or predict trends regarding the issue. The responses are collected and all opinions including the extreme ones are taken into consideration.
- In the second round, results of the first round are sent back to the participants and it contains a merged list of all the responses. The participants are then asked to forecast the possible occurrences enlisted in each of the responses.
- In the third round, all the responses are sent back to the participants. This time, along with the inclusion of statistical details, they are also asked to re-evaluate their responses. After the end of the third round, the moderator processes the response by combining it with similar responses, summarizing lengthy ones, etc.
- The questionnaire for the fourth round contains the responses, the statistical information and the summary of points for modifying the forecasts, if any. Here the participants are required to provide reasons for any change in a given forecast value.
- At the end of the fourth round, the moderator collects and summarizes the results and comes out with forecasts, the degree of disagreement and a summary of critical issues for each forecast.

Advantages: Delphi method is useful for (a) Obtaining forecasts when there is a limited amount of historical data. (b) The sum total of the information available to a group is at least as great as that available to any one individual. (c) Committee can bring in interactive aspects which a single member cannot contribute. [4]

Disadvantages: Delphi method has some drawbacks. (a) If all the experts involved are misinformed, then the forecasts also tend to be erroneous and correction is difficult. (b) Collecting data from experts and preparing for the different rounds of Delphi is time consuming and expensive. (c) Getting the experts' time can be expensive as well. (d) Can take a relatively long time. [4]

Applications:

The Delphi method is used to:

- identify new factors likely to affect the future state of technological development,
- obtain forecasts of a time scale for an event where other methods cannot be used,

- obtain subjective quantitative measures of technological performance in the absence of objective data.

Trend Extrapolation

In this method, the rate of progress of technology in the past is determined and extended into the future by using historical data rate. This type of forecasting implies that the factors which affected the past trends would continue to impact in the same known manner. But this methodology cannot be applied in every technology context. There are instances where natural limits exist for the governing factors and hence, extrapolation will give skewed results. There are two types of extrapolation based on the rate of progress of past behavior – linear and exponential methods. [2][3]

Linear Extrapolation is used where a linear growth function is predicted. The trend is explained using the linear equation:

$$y_i = Ax_i + B$$

y_i is the value of the dependant variable in the i^{th} time period

x_i is the value of the independent variable in the i^{th} time period

A and B are estimated by the method of sum of squares and minimizing them from the projected extrapolation.

The second method of trend extrapolation is the **Exponential Extrapolation** method. An exponential growth curve could be assumed to be as follows:

$$y_i = AB^{xi}$$

y_i is the value of the variable to be estimated

x_i is the impact variable

A, B are constants to be estimated. [2][3]

In general trend extrapolation method consists of following steps:

- Selecting an appropriate parameter to describe the attribute of interest to the forecaster.
- Collecting past data of this parameter for a reasonable period.
- Plotting the data graphically to determine if straight line/exponential can best describe the trend.
- Fitting an appropriate curve as described earlier & using the mathematical equation to project events in the near future.

Advantages and Disadvantages:

Trend Extrapolation is an objective technique and does not use any intuition for its application. The method is teachable/learnable, reviewable and reproducible by others. It is simple to use and quick to interpret, but extrapolation cannot be used unless there is sufficient past data.

Applications:

Extrapolation of past data can be used for predicting future trends and thus finds application in predicting future performance characteristics of a technology, production level of a product.

Growth Curves

The growth pattern of a technological capability is similar to the growth of biological life. Technologies go through an invention phase, an introduction and innovation phase, diffusion and growth phase, and a maturity phase. In doing so, their growth is similar to the S-shaped growth of biological life. Technological forecasting helps to estimate the timing of these phases. This growth curve forecasting method is particularly useful in determining the upper limit of performance for a specific technology. Forecasting by growth curves involves fitting a growth curve to a set of data on technological performance, then extrapolating the growth curve beyond the range of the data to obtain an estimate of future performance. This activity involves three assumptions:

- The upper limit to the growth curve is known.
- The chosen growth curve to be fitted to the historical data is the correct one.
- The historical data gives the coefficients of the chosen growth curve formula correctly.[17]

There are basically two types of s-curve formulations, which can be adopted based on the requirements of the forecasting.

a. Pearl-Reed Curve

The Pearl-Reed curve is symmetric about the inflection point and plots a straight line on a semi log graph. The pearl curve is used to track individual technologies. But the overall growth of technologies is tracked by integrating the s-curves of all the individual curves.

Pearl-Reed Curve Formula

$$y_t = \frac{L}{1 + ae^{-bt}}$$

where y_t is the value of interest, L is the maximum value of y_t , a describes the location of the curve, and b controls the shape of the curve, t is time.

b. Gompertz curve

The Gompertz curve is not symmetric about the inflection point and does not plot a straight line on a semi log graph. These curves are used to represent technologies where the growth in the initial stage is faster than in the Pearl curve.

Gompertz Curve Formula

$$y_t = Le^{-ae^{-bt}}$$

where y_t is the value of interest, L is the maximum value of y_t , e the base of the natural logarithms, a describes the location of the curve, and b controls the shape of the curve, t is time.

Advantages and Disadvantages:

This is the only approach which can be used when the system is bound by a limit. When one has a set of historical data, it has to be decided which of the growth curves will be appropriate to use. Pearl and Gompertz have different applications. In case of broadcasting of new technology, initially there are only few suppliers, few after sales facilities, few users etc. As broadcasting progresses further substitution is easier, but easiest applications are normally completed first and the tougher ones later. Under this

situation, Pearl curve is more appropriate. But, where success of broadcasting does not make further substitution easier, Gompertz curve is more appropriate.

Applications:

Growth curves could be used for forecasting how and when a given technical approach will reach its upper limit. Analysis of most of the technologies shows that when a technical approach is new, growth is slow because of initial problems. Once these are overcome, growth in performance is rapid. As the limit is approached, additional increments in performance are difficult. Growth curves can be used for forecasting parameters having a limit and they are useful for estimating demand for new technologies, performance characteristics of newer technological approaches etc.

Technology Monitoring

Technology is changing rapidly. If one has to reduce uncertainty, there has to be a system for monitoring the signals of technological change, followed by analysis of the meaning of signals of change. Technology monitoring is one of the techniques, which can be used for monitoring breakthroughs through forerunner events. Most large manufacturing organizations have formed systems for continuously scanning the technological environment, known as technology scanning/monitoring/intelligence, etc.

Monitoring process has following steps:

1. Information Scanning.
2. Screening the scanned information.
3. Evaluation of the screened information & development of ideas.
4. Utilization of the evaluated ideas for R&D planning, project formulations, etc.

Major steps involved in technology monitoring are:

- Scanning
- Filtering
- Analysis and Development of forecast

a. Scanning

The idea behind scanning is to collect as much information that is available on the particular field of technology. The information could cover the following aspects:

- Research plans and developments
- Environment of the technology
- Support of various governments for the technology
- Human skills and capabilities
- Social and ethical issues
- Benefits of the technology

b. Filtering

In most cases, not all the information captured on the technology would be relevant for a particular forecast. Hence, based on the forecast required, the necessary information is identified through filtering of relevant data.

c. Analysis and Development

This methodology is appropriate in situations such as developing Research and Development plan; and identifying new sources of technology or emerging technologies. [2][3]

Advantages and Disadvantages:

The advantage of this method is that it can be an efficient early warning device on threats to existing products/services; or may provide signals on opportunities for new products or services. It is a useful method for decision makers. The disadvantage of this method is that it is very difficult to use. To enable it to be useful a team is needed for carrying out the monitoring work and at least two years of basic data collection as well as storage is necessary. All these may be possible only in the case of comparatively large corporations or industry associations or government.

Applications:

Technology monitoring is a useful tool for anticipating changes through continuously monitoring the signals of change, especially the following:

- a) to plan R&D,
- b) to obtain new ideas on product/process/technology,
- c) to identify possible sources for technology procurement/licensing etc.

Normative methods

Normative methods are also called as goal-setting methods. Normative technological forecasting first estimates future goals, needs, and desires, etc., and work backwards to the present. They are used to determine the level of functional capability that must be achieved to solve a problem or overcome a difficulty. There are basically three types of Normative Technological Forecasting methods.

a. Relevance Trees

The concept of relevance tree was first described by C. W. Churchman in 1957. It is an organized 'normative' approach starting with a particular objective and used for forecasting as well as planning. The basic structure looks like an organizational chart and presents information in a hierarchical structure. The hierarchy begins with the objectives which are further broken down into activities and further into tasks. As one descends down, the details increase at every level. The entries when taken together at each level describe the preceding level completely. Also, all activities and tasks represented should be mutually exclusive. The principle behind using the relevance tree is to evaluate systematically all the related technologies that would lead to the success of the intended objective. [3]

Advantages: The advantages of Relevance Trees are (a) It provides a systematic method for estimating the route to be used for achieving a defined future objective or solving a given problem. (b) Helps in deciding whether an objective is likely to be achieved or not. (c) Helps in determining alternative ways by which a given objective might be achieved.

Disadvantage:

The relevance tree for a large complex technology could become too complicated to be handled.

Applications:

Relevance tree is a powerful and general-technique with wide range of applicability. It can be used for identifying new system alternatives and this can be a technique for obtaining different solutions to a given problem.

b. Morphological Analysis

It is a normative technique developed by Fritz Zwicky which provides a framework for exploring all possible solutions to a particular problem. The morphological analysis involves the systematic study of the current and future scenarios of a particular problem. Based on this study, possible gaps are identified and the morphological analysis further provides a framework to explore other alternatives to fill these gaps. From the forecasting perspective, the method enables creation of a list of all the possible outcomes of a technology in order to determine different categories of its applications. [2][3]

Advantages and Disadvantages:

Morphological models can be used to identify requirements for individual technologies of a specific system, but cannot be used to obtain quantitative estimates of relative importance of various technological goals. This is a static model and is not suited to take care of systems that change with time or describe the logical sequence of events.

Application:

Morphological analysis is a useful technique for encouraging the thinking process and allows examination of all combinations of alternatives to achieve the objective.

a. Mission Flow Diagrams

Mission Flow Diagrams have been originally conceived by Harold Linstone as a means of analyzing military missions. This involves mapping all the alternative routes or sequences by which a given task can be completed. The analyst needs to identify significant steps on each route and also determine the challenges/costs associated with each route. The performance requirements can then be derived for each associated technology and the same can be used as normative forecasts. [2][3]

Advantages of Normative methods: The advantages are (a) It is more dynamic. (b) It can generate range of alternatives. (c) It is cost effective and simple in application.

Disadvantages of Normative methods: The disadvantages are, (a) the decision variables and hierarchical structure of technology must be known and weightages are to be objective in nature. (b) Time period is usually not clearly forecasted. (c) Accuracy cannot be clearly defined.

3. Literature Review of Technology Forecasting methods

Method	Problem	Author	Publication Year
S Curves	Technology Forecasting and its Application On 3D TV Technology [5]	Gizem Intepe, and Tufan Koc	2012
Gompertz Growth Curve	Forecasting the U.S. Population [6]	Peter Pflaumer	

Growth Curve	Technology level evaluation methodology [7]	Jiyeon Ryu, Soon Cheon Byeon	Elsevier Inc., 2011
Gompertz Growth Curve	Mobile Broadband Traffic Forecast Modeling for Network Evolution Studies [8]	István Z. Kovács, Preben Mogensen, Birger Christensen, Rauli Jarvela	IEEE 2011
Growth Curve	Evaluation of product Quality Growth [9]	Pei-Hsi Lee, Chih-Ping Chiang	IEEE 2010
Growth Curve	Logistic growth of the global economy & competitiveness of nations [10]	Witold Kwasnicki	Elsevier Inc., 2012
Delphi	Choosing a data center location for enterprise [11]	Fei Yang, Li Xuan Ye	IEEE 2011
Delphi	Analyzing Technology Evolution and Open Source Thin Computing [12]	V. J. Ryyänen, M. Karvonen, T.Kässi	IEEE 2008
Delphi	Understanding the most critical skills for managing IT projects [13]	Mark Keil, Hyung Koo Lee, Tianjie Deng	Elsevier 2013
Delphi	Categorization of fire safety management [14]	Jim Baker, Dino Bouchlaghem, Stephen Emmitt	Elsevier Ltd., 2013
Relevance Tree	Assessment and Forecasting for Electrical Engineering Education [15]	Dale C. Ray	IEEE 1974
Morphological Analysis	Enhancing performance of MA by employing conjoint analysis (CA) and citation analysis on Patent information. [16]	B.G. Yoon, Y.T Park	IEEE 2004

4. Conclusion

Forecasting is nothing but predicting what the future is going to be. Technological forecasting is the process of predicting the future characteristics and timing of technology. We have discussed the technology forecasting methods. The technology forecasting methods can be classified as exploratory and normative forecasting methods. Exploratory technological forecasting starts from today's assured basis of knowledge and is oriented towards the future, while normative technological forecasting first assesses future goals, needs, desires, etc., and works backwards to the present.

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