Technological Forecasting: A Strategic Imperative

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INTRODUCTION

Assessing future opportunities and threats is a serious management concern. All we know about the future is that it will very likely pose new and different challenges. Hence, the basic resources which serve a business today may have little relevance under tomorrow's conditions. If a business is to survive, it must be prepared to adapt rapidly to the requirements of the future. Difficulty arises in forecasting these requirements. However imperfect forecasts may be, an attempt must be made to predict with some reasonable degree of certainty customer (product) needs and internal (process) company requirements.

As inputs to the process of strategy formulation and planning, forecasts have been used to gain a better understanding of the threats and opportunities to the business, and therefore the direction and magnitude of needed changes. Since technology has been responsible for many important changes in our society, forecasting future advances in technology may be as vital to executives in corporate level strategy formulation as it is for engineers and scientists reviewing an R&D program. During the last 30 years, numerous techniques for technological forecasting have been developed to enable a manager to obtain predictions which can be used with some certainty. These techniques will be addressed in this paper with emphasis on advantages and disadvantages from the manager's point of view.

Technology Forecasting Classification

Most technology forecasting is classified as exploratory or normative. Exploratory is based on predicting future events from what has happened in the past up to the present day. A normative approach starts in the future at some possible state of events and works backward to the present determining steps necessary to reach the end point and associated probability of success. Although the scenarios developed form normative forecasting are interesting, they are beyond the concern of the typical manager whose objectives are more specific and limited. In most practical forecasting problems, it is common to use a combination of techniques. Selection is sometimes as simple as the technique which seems to be giving the least amount of forecast error. From the manager's point of view it is important to examine data from as many different angles as possible before making decisions.

It is rare that one company or a series of decisions has a profound influence on the future of technology. If one company does not proceed with a potential innovation, it is highly probable that another will do so within a short space of time. The history of technology contains many examples where similar innovations occurred almost simultaneously in different locations. This is not chance, but the result of a combination of advances in several technologies necessary for the achievement of an innovation. Although the principle of the gas turbine had been known for many years prior to its development in the late 1930's, the development of high-temperature materials allowed the gas turbine technology to be practically produced. Another example of ancillary technologies being integrated with a primary technology is the use of transistors in electronic equipment. Although transistor technology is credited for size reduction in electronic equipment, without such technologies as tantalytic capacitors, transformers, printed circuits, dip soldering, nickel cadmium batteries, and silicon cell power supplies; the electronic equipment would only be about 10% smaller than a vacuum tube equivalent [3].Therefore, if forecasting is to provide useful information to managers regarding a specific innovation, it must take into account all technological advances in an area and their interactions.

Additionally, timing is extremely important. Before a certain date, it would be impossible to support the innovation because the technological capabilities would not exist. Once this stage has been reached, competitive forces are likely to ensure a limited time advantage to the company that seizes the initiative. Technology forecasting can assist in deciding when to start but will not guarantee success in the marketplace.

Development of the S-Curve

Fortunately for the manager, analysis of historical data from a number of phenomena shows that technological progress is not random or discontinuous but follows a regular pattern when a selected attribute is plotted against time. This pattern is referred to as an S-curve (See Figure 1). The curve is similar to a product life cycle which shows a slow initial growth, followed by a rapid rise of approximately exponential growth, which slows down as it approaches an upper limit set by some physical property. One can assume that there is a predetermined path that progress always follows. No progress occurs without management investment decisions. These decisions can significantly affect the slope of the S-curve and therefore the rate of growth of new technology [Twiss].

The manager must also remember that just because an S-curve is approaching a natural limit does not remove the need to continue forecasting. Generally, it is at this time that a new technology may emerge. This new technology will have a new natural limit and the potential for further progress in performance. This situation frequently creates a stair-step succession of S-curves (See Figure 2). Ayres has shown this application in two separate studies: (1) the first looking at efficiency of the external combustion engine over a 270 years period and (2) the second plotting computer performance over a 30 year period spanning four new technologies [1].

Obviously, the study of past technological progress confirms the existence of regular patterns and provides a framework within which forecasting can be undertaken. It also indicates the types of information that the manager would like to extract from forecasts. Armed with this information, the following section will describe six technology forecasting methods.

TECHNOLOGY FORECASTING TECHNIQUES

The following descriptions of a few of the most widely used techniques will not attempt to provide a working basis for their practical application; instead, they are intended to reinforce principles and show some of the potential problems likely to be encountered. Remember that the techniques are not an end in themselves, and their successful application must rest heavily upon the technological experience and insights of the managers using them.

Trend Extrapolation

The extrapolation of past trends into the future is a common technique used by economic forecasters for many years. This techniques seems to be an easy exercise of applying a mathematical curve-fitting technique to past data and extrapolating future requirements. However, the technological forecaster must be wary of potential difficulties and traps in this technique. Considerable judgment is required both in the choice and use of data.

Selection of the proper attributes to plot is very important. The wrong choice will certainly lead to the wrong conclusion. An example would be the late entry of the U.S. aircraft engine manufacturers into using gas turbines for civil air transport. One suggestion for this problem was the use of specific fuel consumption as the primary engine performance measure. Considering another parameter such as passenger miles per unit of cost would have shown the potential of the gas turbine power system in spite of high specific fuel consumption. Therefore, the traditional direction of technology established for over 30 years in the propeller-driven aircraft powered by piston engines caused engine manufacturers to lose sight of customer needs in a different market. This shows the danger of mechanically forecasting without a proper understanding of the technologies, their interactions, or the markets in which the technologies are to be used [8].

One of the most difficult problems in trend extrapolation occurs from the absence or inadequacy of data to use for forecasting. Whereas the economic forecaster has reliable statistics to use, this is rarely the case with historical technological data. Questions of where the data was obtained and how it was obtained (civilian aircraft versus military aircraft, actual test versus static testing, classified information, etc.) are relevant. Unless such questions are resolved, curve fitting can be difficult and plotted data will not be comparable. Therefore, most forecasters will make several projections using different curve-fitting techniques which may offer the manager little useful decision making guidance. As a manager faced with inadequate or little usable data, a system for collecting and recording data should be established so forecasting accuracy can be steadily improved.

In spite of difficulties of accurate trend extrapolation, it is one of the most widely used techniques used today. However, confidence will diminish over a long forecast time and this technique is consequently of greatest value in the short term.

Curve Matching Using Precursor Trends

Commercial application of a new technology is usually linked to a specific use where cost and reliability are very important. However, in pure scientific research or military applications, high cost or doubtful reliability may be less important than performance. Aerospace and electronics are two industries where this is particularly true.

The trends for both the initial technology application and the follow-on commercial adoption are likely to follow each other exactly but with a consistent lag. Lenz has shown that the speed of transport aircraft has lagged combat aircraft by about ten years over the period from 1930 to 1970. Therefore, if a forecaster can identify a precursor application which follows a regular trend behind his own application, then there is a good indication of the introduction of advanced technologies into commercial products [5].

The discovery of a precursor relationship gives the forecaster two data points for future use. One obtained from extrapolating the curve for his own application, and a cross-reference from the precursor. It may also provide the forecaster with useful data on the date when a new research laboratory technology is likely to achieve commercial introduction.

Delphi Technique

Expert opinion can give important insights into the future, particularly in the identification of potential innovations likely to disturb the path of progress away from the extrapolated trend. The Delphi technique was developed at Rand Corporation to overcome the weaknesses of the committee by using the individual judgments of a panel of experts working systematically and in combination, divorced from the distortions introduced by their personalities. Delphi attempts to eliminate these weaknesses by using a questionnaire techniques circulated to a panel of experts who are not award of the identity of their fellow members.

Selection of the panel members is an extremely important task. The value of the forecast is a function of the caliber and expertise of the individual contributors, as well as, the appropriateness and comprehensiveness of their areas of knowledge. Questionnaire formulation also requires considerable skill to ensure the right questions are asked and that they are framed in specific, quantifiable, and unambiguous terms. Delphi is widely used for longer range forecasts.

Evidence supports the contention that Delphi studies result in a gain of consensus; however, the question of forecast accuracy is still unanswered. There are some indications that there is a tendency to err in an optimistic direction in the short term due to an underestimation of development times. In contrast, long term forecasts may well be pessimistic due to the mind's inability to properly estimate the effects of exponential growth [6].

Scenarios

Scenarios describe a possible future situation based upon a wide range of environmental analysis. Several scenarios or alternate futures are frequently prepared supported by detailed research using a wide variety of technology forecasting techniques. Scenario writing is based on the idea that a choice between alternative set of assumptions is not always possible.

Energy forecasting is an area where scenarios have been use extensively . Several practical techniques for industrial scenario writing have been developed to enable the consideration of the interactions of a wide range of environmental factors both upon themselves and upon an organization's strategic objectives. Therefore, this is an approach which extends beyond top management to review their strategic assumptions and the consequences flowing from them [7].

Most authors stress the interaction between the decisions resulting from forecasts and the determination of the future. If a certain scenario is thought to be likely, then following a specific policy as a result of the forecast could make it a self-fulfilling prophecy. Few companies have the ability to shape the future; however, one can see how scenarios could be used to shape government policy. For example, if a specific scenario is highly undesirable for Americans in the future, then government policies could ensure that the path leading to it is sealed off [4].

Relevance Trees

A relevance tree is developed to determine and evaluate systematically the alternative paths by which a normative objective or mission could be achieved. Thus, starting from a desired objective, it is possible to examine exhaustively all possible alternative paths by which it can be reached, working backwards through a hierarchy ending with specific research projects. The next stage is to investigate each step in greater depth including feasibility, resources required, probability of success, and time scale. This involves the use of other technology forecasting methods such as Delphi and trend extrapolation.

This technique can lead to highly complex, sophisticated computer approaches which are very time consuming and expensive. Honeywell used a relevance tree to model all military and aerospace activities which the company was or could be involved. The cost of setup for this program was $250,000 with an annual run cost of $50,000. The scale of this effort should not deter the manager with limited resources. The basic relevance tree methodology can be a useful planning tool even in a simplified form [8].

Technology Monitoring

Although the simplest of the techniques that have been described, technology monitoring can be a very attractive technology forecasting method to the typical manager. Since the period between the emergence of a technological advance/new technology and its practical application may span many years, a well informed manager using judgment and insight may be able to accurately forecast application introduction.

Most managers receive their information randomly from reading, discussions, conferences, etc. If judgment is to be upon good and comprehensive information, the gathering of the information should be as organized as possible. Those of potential value should be stored with their significance noted.

Bright has proposed monitoring the environment on a systematic basis. The monitoring process is based upon journal entries of significant technological events with possible significance to your product or manufacturing process. These individual entries of information can be pieced together with managerial logic to form a picture of the future [2].

The attraction of monitoring is that it can be performed by any individual manager for his own information. It is surprising how much one person can glean from systematically processing information received daily. The richness of the information and the deductions are obviously enhanced if organized on a departmental or larger basis.

THE TECHNIQUES IN PERSPECTIVE

Vanston's 5 Categories

Putting these techniques into the context of the way forecasters view the future, Vanston (2003) classifies forecasting approaches based 5 classifications:

1. Extrapolators. Based on the assumption that the future will resent itself as an extension of the past, extrapolators believe that the future can best be forecast by extrapolating past trends in a logical manner. This approach may not take consider the possibility, sometimes likelihood, that some technologies can result in dramatic shifts.
2. Pattern analysts. Like extrapolators, pattern analysts follow the assumption that the future will replicate past events. Future events occur cycles and patterns that replicate the past. Identifying and analyzing similar conditions from the past and applying them to future circumstances then provides the best forecast.
3. Goal analysts. Goal analysts believe that by examining the stated and implied goals of various leading decision-makers and trendsetters the future can be projected by considering the impact each can have on future trends and events. The forecast, then, will represent the sum of the beliefs and actions of these people and institutions.
4. Counter-punchers. Counter-punchers approach the future as series of essentially random events that cannot be predicted. The best approach, then, is to consider a range of possible scenarios, and maintain a highly flexible system of planning. The complexity of society and technology often results in unexpected results.
5. Intuitors. Intuitors believe the future will be a result of complex forces, random outcomes and the actions. Because of

this complexity, there is no rational approach to forecast the future analytically. Forecasting, then, is approached through information, intuition, and insight [9].

Mehta's Future Signals

Mehta (2005) found in his research that executives at all of the "high-risk, high-growth" companies surveyed responded that considering future signals, rather than was largely responsible for successfully predicting outcomes, managing transitions, and adjusting their strategies for success. Carefully monitoring these signals allowed them to react quickly to environmental changes. Further, Mehta postulates that a strategy of simply attaining goals, without monitoring and considering these future signals may actually impede reaching those goals. In his study, Mehta identified roughly "90 unique future signals or leading indicators used by the 56 companies, with most companies tracking 10 or more regularly" [10].

CONCLUSION

Most of the initiatives in technology forecasting originated in the United States, where several major aerospace companies invested heavily in it. Some authors doubt whether the results justified the substantial investments. However, in recent years there has been a resurgence on two levels. The first is concerned with research and development planning decisions, while the second focuses on corporate strategic issues, sometimes referred to as "futures studies". It is also recognized that since technology now grows more rapidly than ever before, discontinuities may be experienced which may make extrapolation techniques of questionable use to managers. Therefore, a growth in the use of such techniques as scenarios and technology monitoring has been experienced.

A major cause for the low rate of acceptance in industries is likely to be reluctance to invest large resources in an untried technique. Nevertheless, as the pace of technological progress continues to increase, so will the need to accurately forecast the future. All R&D decision makers must take a conscious view of the future. Forecasts are needed which take full account of the information available and the techniques of technology forecasting. However, it should be noted that the effort devoted to technology forecasting should be related to the characteristics of the industry, the company, and the decisions to be made, rather than to the size of the company.

Technological forecasting cannot enable decision makers to predict the future with certainty, but it can assist them in refining their judgments. The value of the forecasts was seen to be highly dependent upon the quality of the inputted data to the forecasting process and the ability of the decision makers to use it properly. Sophisticated forecasting techniques can only be aids to this process, and care should be taken to guard against technology forecasting absorbing greater resources than can be justified by the introduction of the technology.

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