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Technology Forecasting: A Tool for Prioritizing R&D

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Abstract – **This paper presents a novel framework for supporting the development of well-informed research and development policies and plans. The proposed methodology is based on Technology forecasting i.e. the description or prediction using a logic that yields relatively consistent result, of a foreseeable technological innovation, specific scientific refinement, or likely scientific discovery, that promises to serve some useful function, with some indication of the most probable time of occurrence. This paper evaluates technology forecasting and foresight methods in relation to a firm's R&D activities. The focus is on extrapolation and Delphi methods because they are so widely used in technology forecasting (TF). The paper concludes with prescience on how to choose a TF method for a particular scenario.**

Keywords: Forecasting, Operational Research, Industrial Engineering, Operations management, Technology forecast, Organization research, TF.

I. INTRODUCTION

As expressed by Ralph Lenz; "Technology forecasting may be defined as the prediction of the invention, characteristics, dimensions, or performance of a machine serving some useful purpose. The qualities sought for the methods of prediction are explicitness, quantitative expression, reproducibility of results, and derivation on a logical basis."[1] To address this very fundamental challenge, it is obvious that executives must be able to project, with reasonable accuracy, the nature, rate, magnitude, and implications of future advances in technology. Fortunately, a number of practical, proven techniques, commonly grouped under the designation technology forecasting, are available for making projections of this type.

In this paper, three topics will be addressed:

- The need of making valid projections of Technical advances in developing effective business plans and strategies.
- How technology forecasting approaches can assist in making credible, timely projections.
- How technology forecasting can be used to better evaluate longer-range R&D activities.

Need for valid forecasting:

In an interview in Business Week, Mr. Louis Gerstner, Chairman of IBM, noted that the most troubling challenge facing business executives today is that they must make plans for a decade into the future based on technologies that are changing dramatically every year [2]. Analysis of emerging technologies and their implications inform critical choices ranging from the Multinational level (e.g. the European Union) to the individual organization (e.g. a company). Small companies also depend on technological innovation for their existence. In these companies, TF methods are used to forecast adoption or diffusion of innovations, where parameters such as rate of imitation by other adopters or rate of response to advertising can be measured. TF studies in companies are often called "Competitive Technological Intelligence (CTI or TI)" [12]. In addition to the effort by businesses to map out commercially viable roadmaps for technological development, the TF field includes more social foresight and diffuse measurements as well. For example, Governments use national foresight studies to assess the course and impact of technological Change for the purposes of effecting public policy. This includes what is known as technology assessment (TA) or social impact analysis, which examines the likely long-term effects of technological development as its impact spreads throughout society. [3]

A technological forecast can help to:

1 Determine whether your current technical approach is reaching some fundamental barrier to progress, requiring the use of a success or approach
2 Estimate the likely performance of your competitors' designs at the time you plan to introduce a new design
3 Time scale estimation
4 Policy reorientation
5 Operational decision making

Part of Technology forecasting in R&D trend analysis:

There is enormous increase in the cost of conducting research and development. Under pressure to contain these costs, it has become increasingly important for R&D programs to focus on projects that will result in enhanced profits.

Historically, technological forecasting was based on the guesses of the most recognized and prestigious expert in the area. This is no longer appropriate because technological progress has become dependent on the interaction of several, often diverse, technologies. A single individual rarely has the requisite level of expertise in all relevant areas. Also, the management and funding of the several technologies have a significant impact on the degree and speed of technological change. The recent development is the integration of market considerations into technology forecasting processes. In simple terms, "If nobody buys it, it doesn't

matter." Technology forecasts take this reality into consideration, and a major goal is to determine what advances in technology will result in increased sales, enhanced profits, and delighted customers. The fact that a new capability is developed does not automatically mean that it will be put to use. The lack of application potential does not, of course, mean that the capability or scientific finding is worthless. When done properly, technology forecasting can assist in rationalizing the R&D process by better targeting R&D activities and by tying together technical advance and market opportunity. Governmental decisions to support some technologies and not others have a significant impact on technological innovation. For instance, the decision to support the space program had major impacts on miniaturization in the electronics industry, on the use of new materials and styles in the garment industry, and even on the look of television commercials. If technological forecasting predicts that a certain capability is technologically within our reach in the near future, and if the government chooses to support research in this area, it is much more likely that the technology will be developed-for example, new approaches to the generation of electric power. If the government decides to finance implementation of the desired innovation, there will probably be a near-term impact on profits and the speed of diffusion of the new technology.

Another characteristic of technological forecasting is uncertainty about the rate of change of technological capabilities. Many capabilities tend to grow exponentially until they reach some natural limit: for example, aircraft speed, computer memory size and memory access speed, horsepower per liter of internal combustion engines, among many others. When one technology impinges on another, the synergy often results in an unexpected and sudden increase in capability.

II. LITERATURE REVIEW

Dr. Eric Jantz, one of the pioneers in the practice of technology forecasting, once identified over 150 different TF techniques. However, at present, there are some 18 to 20 techniques being used by various business and government organizations for practical forecasting purposes. Since these techniques are widely discussed in the literature [5] [6] no attempt will be made to examine them in detail in this article. However, a few comments about the nature of forecasting techniques might be in order.

Delphi Method:

States Delphi method perhaps is the best known of the various judgmental approaches to technological forecasting [7]; the Delphi method uses a panel of individuals who make anonymous, subjective (biased) judgments about the probable time when a specific technological capability will be available. The results of these estimates are aggregated by a process administrator and fed back to the group, which then uses the feedback to generate another round of judgments. After several iterations, the process is stopped and areas of agreement or disagreement are noted and documented. The Delphi method has application beyond its use in

technological forecasting. It has been widely used as an aid in policy decision making. Its three main characteristics: anonymity, statistical formatting of results, and controlled feedback-make it an acceptable and reliable process for extracting numeric data from subjective opinion. Fig.1 shows the process graphically.

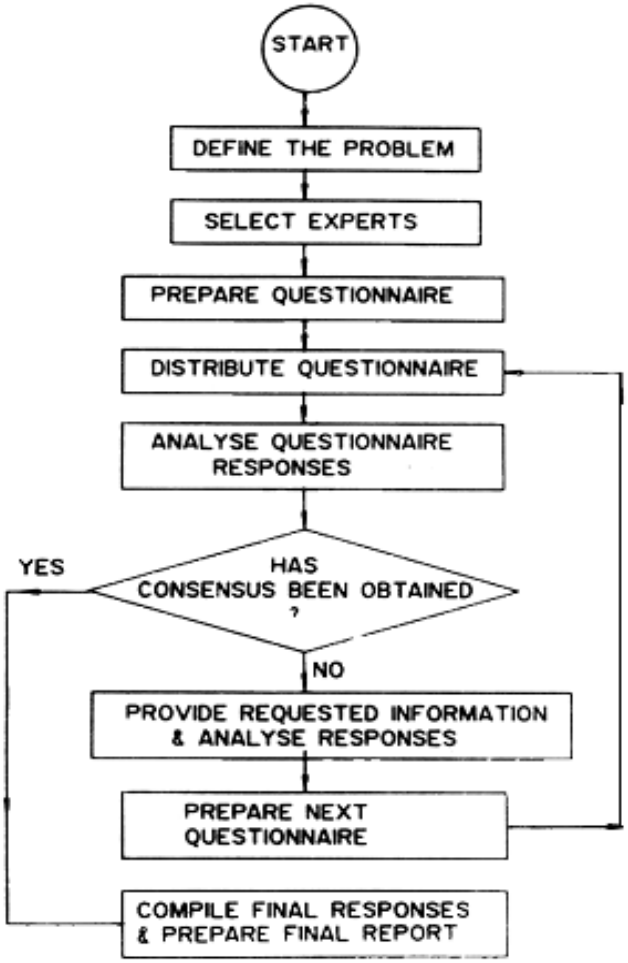

Fig. 1: Flow diagram for Delphi method

Trend Extrapolation:

To extrapolate is to infer the future from the past. If there has been a steady stream of technological change and improvement, it is reasonable to assume that the stream will continue to now. Powerful feedback mechanisms in our society cause trends and events to occur in identifiable cycles and predictable patterns, and one can best address the future by identifying and analyzing analogous situations from the past.Fig.2 shows the process graphically

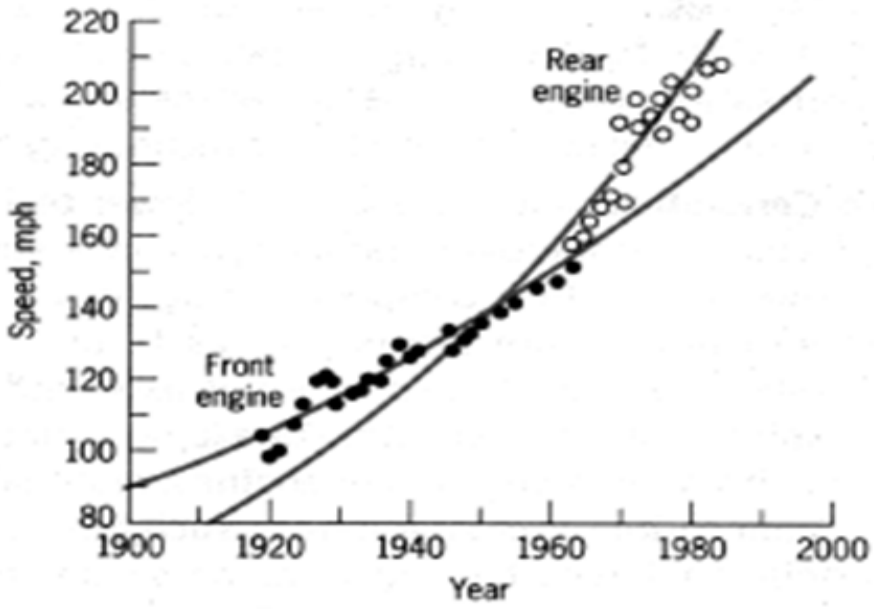

Fig. 2: Statistical curve fitting

Morphological Analysis:

It is a prescriptive technological forecasting technique because it makes assumptions about what people will want in the future and then investigates the possible ways those wants could be satisfied. Of all the techniques available for forecasting new products or processes, morphology is one of the most systematic. The technique relies on a matrix, usually called a morphological box, as shown in table 1 below,

TABLE I: MORPHOLOGICAL BOX

Key Parameters \ Alternates		1	2	3	4
Energy Source	A	Manual Winding	Vibration	Battery	Solar
Energy Store	B	Weight Store	Spring Store	Bimetallic Coil	No Store
Motor	C	Spring Motor	Electric Motor		
Regulator	D	Balance Wheel	Pendulum	Tuning Fork	Quartz
Gearing	E	Pinion Drive	Chain Drive	Worm Drive	
Indicator Device	F	Dial Hands	Slide Marks	Liquid Quartz	Light Indicators

Intuitors are convinced that the future will be shaped by a complex mixture of inexorable trends, random events, and the actions of key individuals and institutions. Because of this complexity, there is no rational technique that can be used to forecast the future. Thus, the best method for projecting future trends and events is to gather as much information as possible, and, then, to depend on subconscious information processing and personal intuition to provide useful insights.

Goal analysts believe that the future will be determined by the beliefs and actions of certain individuals and institutions. The future is susceptible to modification and change by such entities. Thus, the future can best be projected by examining the stated and implied goals of various decision makers and trendsetters, by evaluating the extent to which each can affect future trends and events, and by evaluating what the long-term results of their actions will be.

Trend correlation At times, one technology is a precursor to another. This is frequently the case when advances made in the precursor technology can be adopted by the follower technology. When such relationships exist, knowledge of changes in the precursor technology can be used to predict the course of the follower technology, as far in the future as the lag time between the two. Further, extrapolation of the precursor allows a forecast of the follower to be extended beyond the lag time. Figure 3 shows an example of a trend correlation, which compares the trends of combat and transport aircraft speeds. Another example of a trend correlation forecast is predicting the size and power of future computers, based on advances in microelectronic technology.

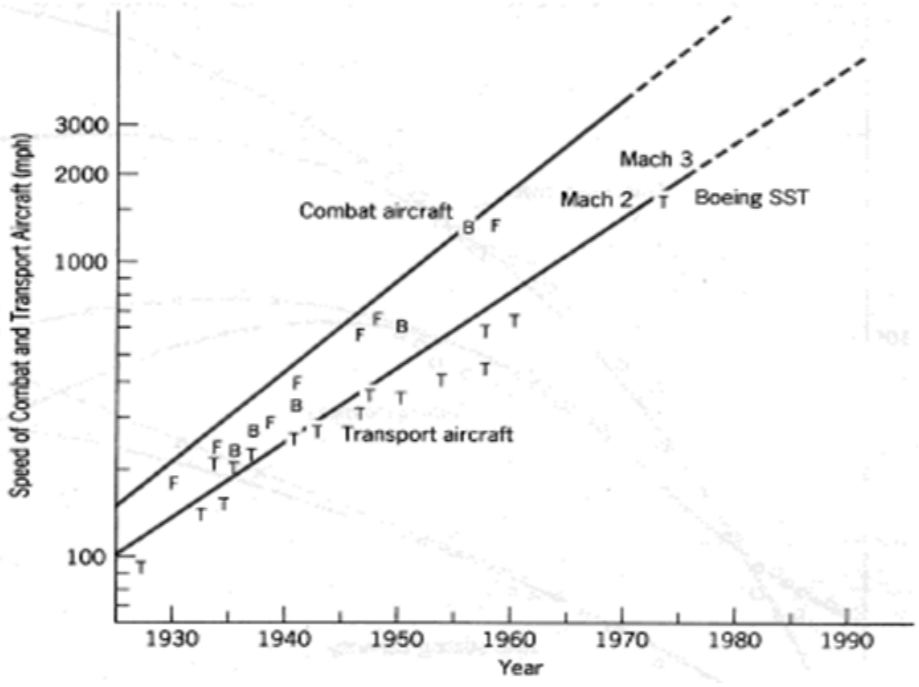

Fig. 3: Trend Correlation

Obviously, there are strengths and weaknesses to each of these approaches. In fact, almost everyone uses all of these approaches, to some extent, in his or her attempts to deal with the future. However, most people tend to give more credence to one or two of these approaches. Although there is not a one-to-one correspondence, we have found that, in general, most engineers tend to be extrapolators, pure scientists to be pattern analysts, marketing personnel and salespeople to be goal analysts, lower and middle managers to be counter- punchers, and high-level managers to be intuitors [4]

III. METHODOLOGY

In today's environment of restricted R&D budgets, there is increasing pressure to concentrate R&D efforts on projects and programs that can be directly related to the business activities of the organization. Countering the proposition that a rupee spent today is more valuable than a rupee earned tomorrow is the fact that, quite often, R&D efforts provide significant business opportunities that are not realized when the project is in its early stages. The transistor, for example, was originally viewed only as a replacement for the diode vacuum tube. The radio was primarily seen as a means for ship-to-shore communication. The personal computer was seen as a means of storing recipes and balancing home check books, while no practical use at all was seen for the laser [11]. Another factor, however, that mitigates against longer-term, more innovative R&D projects is the concept of the "time value of money." For example, if a company's required rate of return on investment is 20%, a rupee invested in R&D today must offer a guaranteed profit of Rs. 2.50 in five years to meet the required criteria. When the normal increased risk associated with longer-term projects is taken into consideration, it becomes very difficult to justify expenditures on such projects.

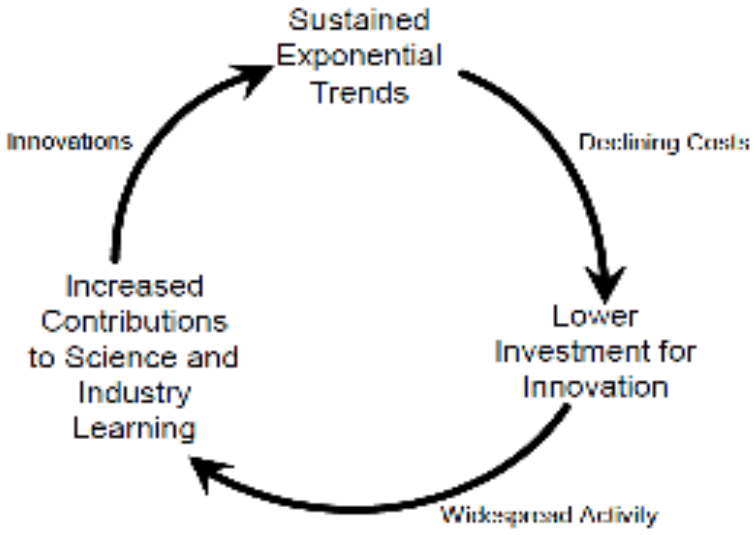

Fig. 4: Sustained technology trends lower investment, creating a positive innovation loop

Choosing a Forecasting method

A large number of methods have evolved for TF, but the quality of forecasts greatly depends on proper selection and application of appropriate methods. The application demands that the technique used need to be time-, space- and technology-specific. Yet, there is little research done on matching the TF methods techniques to a particular technology.

One such study comes from, Levary and Han [8], who have considered three basic factors, namely the extent of data availability, the degree of data validity and degree of similarity between proposed technology and existing technologies. Each factor has been categorized into cases as small/low, medium/moderate, large/high and their combinations. According to [8], given a small amount of low or medium validity data and no similarity between proposed technology and investment.

Since the early 1970s, various ministries and agencies in Japan have been conducting repeated technological foresight studies (among them the Ministry of Trade and Industry (MITI), Economic Planning Agency (EPA) and the Science and Technology Agency (STA))[10]. Western European countries followed with systematic technology foresight activities in the 1990s. 12 existing technologies, a reasonable choice is a method based on information obtained from a panel of experts (i.e., Delphi method or interviews). Given a moderate to large amount of medium to high validity data and a high degree of similarity between proposed technology and existing technologies, they propose using correlation analysis. When there is medium or large amount of high validity data, trend analysis is the most appropriate method. A more recent study [9] provides a comprehensive procedure to pick the right TF method: First they identify the characteristics of a technology that need to be considered (rate of change, ease of diffusion, number of alternatives available, etc). Next using a 10-point scale, experts of the selected technology rate each of the characteristics for the selected technology. Then, using the same characteristics, experts of TF methods rate every method in the same manner. Finally, the profiles for the TF methods and technology profiles are superimposed to ascertain the ‘‘best fit’’ i.e. the technique profile that closely matches the technology profile.

As we defined earlier, bibliometrics is the statistical analysis of text documents, typically publications and patents. Since publications in this case refer mainly to academic publications and patents, science and technology intensive industries would logically be a better fit for this type of analysis. As patents and publications often deal with ideas and techniques in the relatively early stages of development, this is the stage at which bibliometrics methods are most useful. Also, in the early stages of development, technical merit is probably the key determinant of success. Later on many other factors would influence the success of a technology or product, so there is a lot more complexity and noise. In such situations, "higher-level" features and pattern recognition techniques become more appropriate.

Many articles state that, because of the complexity of TF and because each forecasting method can deal with only limited aspects of a forecasting case, it is often advantageous to use several different forecasting methods simultaneously.

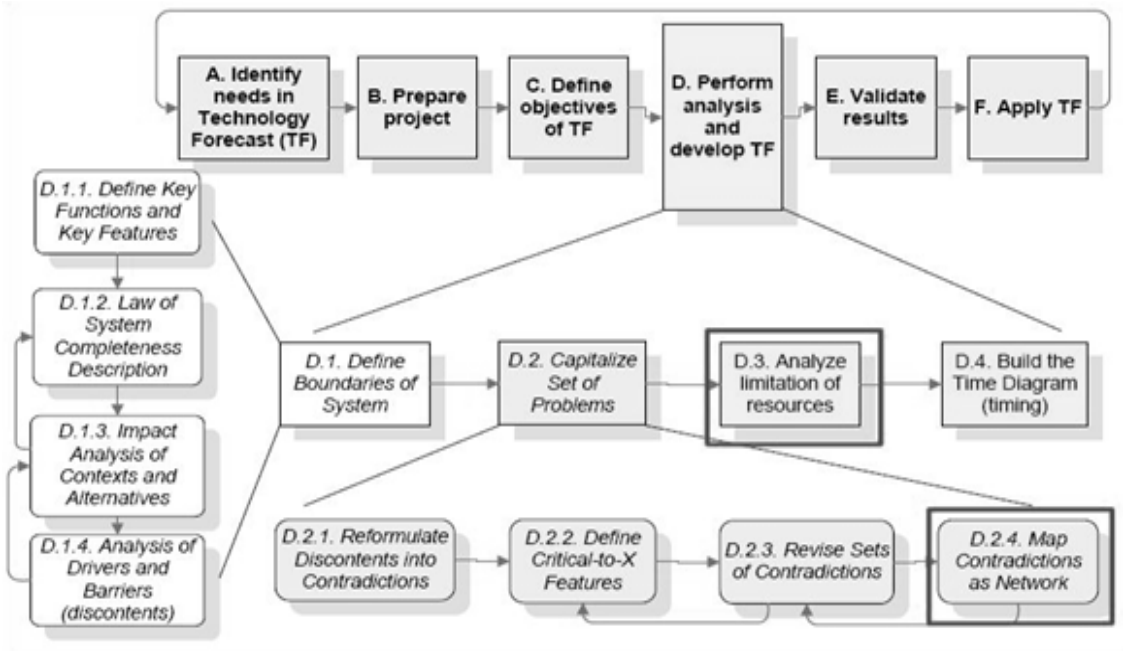

Fig.5: Choosing a TF Method

IV. CONCLUSION

In their seminal book, Reengineering the Corporation, [7] Hammer and Champy state three basic principles for continuing success in today's increasingly competitive environment:

- Companies must achieve quantum improvements in operations—improvements of 50%, 80%, or even higher.
- Improvements of this magnitude can only be achieved by more effective use of information technologies.
- Plans for improvement must be based on the use of information technologies that will be available in the future, not those that are available today.

In large measure, these three principles reflect the concepts of technology forecasting. Because of the requirement that companies be responsive to both present and future customer needs, management must often make decisions based on projected market opportunities, advances in technologies, and actions by competitors. Well conceived, organized, and executed technology forecasting activities can assist managers in making and evaluating such decisions.

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