A Review on Technology Forecasting Methods and Their Application Area

Daekook Kang, Wooseok Jang, Hyeonjeong Lee, and Hyun Joung No

Abstract—Technology changes have been acknowledged as a critical factor in determining competitiveness of organization. Under such environment, the right anticipation of technology change has been of huge importance in strategic planning. To monitor technology change, technology forecasting (TF) is frequently utilized. In academic perspective, TF has received great attention for a long time. However, few researches have been conducted to provide overview of the TF literature. Even though some studies deals with review of TF research, they generally focused on type and characteristics of various TF, so hardly provides information about patterns of TF research and which TF method is used in certain technology industry. Accordingly, this study profile developments in and patterns of scholarly research in TF over time. Also, this study investigates which technology industries have used certain TF method and identifies their relationships. This study will help in understanding TF research trend and their application area.

Keywords—Technology forecasting, technology industry, TF trend, technology trajectory.

I. INTRODUCTION

RECENTLY, the globalization and technology changes has been recognized as two mutually reinforcing factors that are playing the focal role for competitiveness of organization [1]. Under such turbulent environment, the timely anticipation and forecast of these challenges have been of vital importance for incorporating technological changes into strategic planning process [2]. A good forecast of technology can help maximize gain and minimize loss for the organization from a long-term perspective.

Technology forecasting (TF) has been acknowledged as an effective tool in order to anticipate and understand the potential direction, rate, and effects of technological change [3-5]. Given the effectiveness of TF, this area has received considerable research attention during 40 years. For example, Delphi

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remains a popular technique for technology forecasting. More advanced Delphi method also has been developed combining Bayesian weighting and Delphi questionnaire [6]. Meanwhile, recently, patent analysis frequently has been used as an objective method to recognize the trends in technological development [7-9].

However, even though there are vast amounts of TF research, till now, few attempts have been made to provide overview of the TF literature as shown in Table I. Table I shows that four TF review articles [1, 3, 10, 11] have been published so far. These review articles have some limitations. First, three of them only focused on type and characteristics of various TF methods, while only one covered evolution and practical applications of TF. Even though practical applications of TF were studied, it hardly provided information about which TF method were used in certain technology industry. Second, these articles focused TF itself so didn't cover patterns of scholarly research in TF over time. Third, these review articles included some TF research dealing with the demand forecasting of technology such as diffusion model and simple time series analysis. However, this demand forecasting method for technology is not appropriate for exploring the trend of technological advancement and anticipating the potential direction of technology which are defined as the main purposes of TF in our study. Therefore, to provide accurate overview of the TF literature, TF research containing this kind of methods is excluded in this study.

Accordingly, the present study aims to contribute to the extant literature on TF in three ways:

TABLE I
EXITING TF REVIEW RELATED ARTICLES

Article	Main characteristic
Slocum and Lundberg (2001)	Emphasis on TF method
Mishra, Deshmukh, and Vrat (2002)	Development of methodology to select appropriate technique for TF
Martino (2003)	Emphasis on TF method
Firat, Madnick, and, Woon (2008)	Summarization of various field of TF, its purposes, evolution, applications

1. To profile developments in and patterns of scholarly research in TF over time
2. To investigate which technology industries have used certain TF method and identify their relationships
3. To provide suggestions for future research in TF

The remainder of this paper is organized as follows. Section II describes the methodology used for the study. Then, in

section III shows trends in TF research. Finally, Section IV concludes the paper with contributions and future research.

II. METHODOLOGY

As one of the main aims of the present study was to profile developments in and patterns of scholarly research in TF over time, international refereed journals were considered to be the most suitable publication for examination in this study. Thus, we chose to cover the whole period from the year when the first TF article appeared in an academic journal (1970) till the end of 2013.

This study used a two-phased research approach to provide meaningful implications. First, all publication articles on TF were collected. Second, based on these articles, patterns of scholarly research in TF and application areas of TF method were investigated.

Phase 1: Collecting the Articles

An extensive search of the extant literature related with TF was conducted to develop a database of TF articles. The articles were collected through following sources:

1. Google Scholar and Sciencedirect.
2. NDSL and RISS which are Korea websites providing international science information such as articles and patent.
3. Reference lists of TF related books, and TF review articles

Especially, as a first step, we searched articles using keywords such as *technology forecasting*, *technology trend*, and *technology trajectory*. Then, articles related with demand forecasting of technology were excluded. As a result, total 106 articles were collected that were published in a period of 44 years (1970-2013).

Phase 2: Investigating Trend in TF Research

In phase 2, trend in TF research was investigated. Concretely, following four issues were investigated based on collected articles.

1. Number of TF Articles and their distribution over time
2. Leading TF Journals
3. TF methods and their types
4. Application areas of TF

To investigate these four trends in TF research, we used spotfire which was a programs providing data visualization, analytic dashboards and applications, and forward-looking predictive analysis with intelligence. In this study, bar chart, treemap, and pie chart were used to derive meaningful information about trend in TF research.

Especially, treemap is information visualization method for displaying hierarchical (tree-structured) data as a set of nested rectangles. Each branch of the tree is given a rectangle, which is then tiled with smaller rectangles representing sub-branches. Treemap has two advantages for the data visualization. First, one can often easily see patterns that would be difficult to spot in other ways, such as if a certain color is particularly relevant. Second, treemap visualization make efficient use of the available display space, mapping hierarchies onto a rectangular

region [12]. For these reasons, this study utilized treemap visualization.

III. TREND IN TF RESEARCH

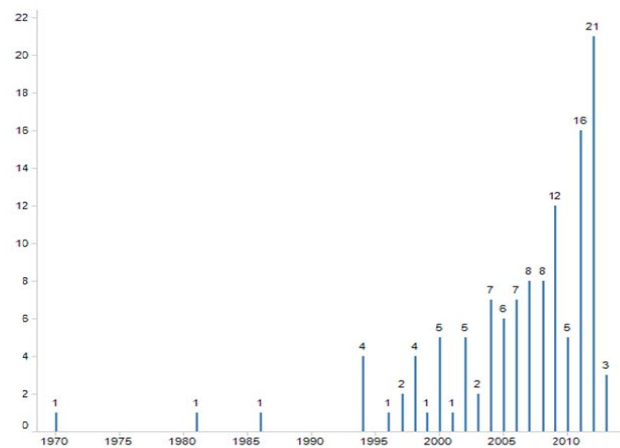### A. Number of TF Articles and their Distribution over Time

Fig. 1 Number of TF related articles published between 1970 and 2013

Though TF research dates back 44 years, most of the articles in journal have been published in the last 10 years. Especially, in the last 5 years, half of the articles have been published. Also, interesting finding is that the most recent years follow a clear upward direction as shown in Fig. 1.
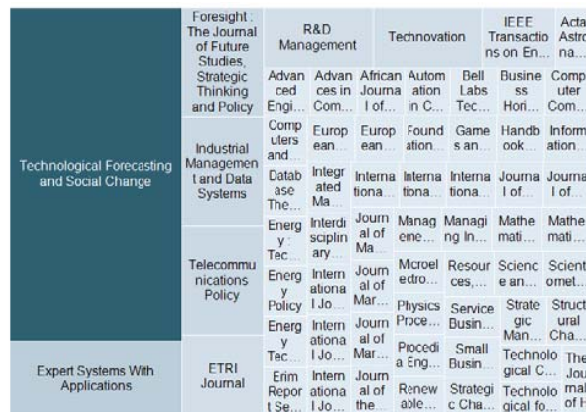
B. Leading TF Journals

Fig. 2 Treemap for journal of TF articles

Fig. 2 shows treemap for journal of TF articles. Articles related with TF research have been published in 63 different journals. Only 8 journals published almost 50 % of the all TF articles, namely *Technological Forecasting and Social Change* (26 articles), *Expert Systems With Application*s (6 articles), *Foresight - The journal of Future Studies, Strategic Thinking and Policy* (4 articles), *Industrial Management and Data Systems* (4 articles), *Telecommunications Policy* (4 articles), *ETRI Journal* (3 articles), *R&D Management* (3 articles), and

Technovation (3 articles). The other journal published less than 3 articles.

C. TF Methods and Their Types

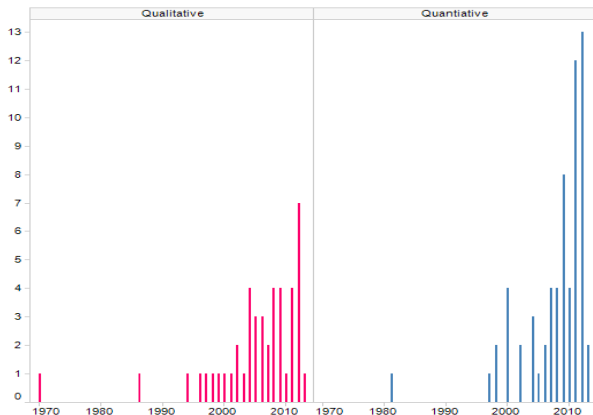1. Qualitative and Quantitative Approaches over Time

Fig. 3 Number of *qualitative* and *quantitative approaches* between 1970 and 2013

Fig. 3 depicts the number of qualitative and quantitative approaches between 1970 and 2013. When the first TF article appeared in an academic journal with *qualitative approach* in 1970, many articles containing *qualitative* and *quantitative approaches* have been published. First TF research with *quantitative* approach was published in 1980. This research proposed TF with logistic envelope approximation method [13]. After this research was published, many *quantitative studies* have been published compared with *qualitative studies*. Especially, in last 5 years, *quantitative studies* have been published almost twice as much as *qualitative studies*.
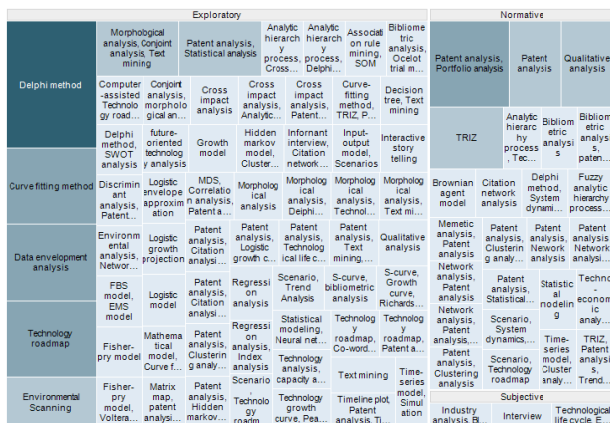
2. Leading TF Methods

Fig. 4 Treemap for TF methods

By referring previous research suggesting classification scheme of TF methods as *exploratory, normative,* and *subjective approaches* [1], we drew treemap for TF methods and their type. In here, e*xploratory approaches* are outward bound methods for seeing where events and trends might take us from the present to the future such as Delphi methods and technology roadmap. In contrast, *normative approaches* are inward bound methods. Thus, they begin with a preliminary view of a possible (often a desirable) future. Then, they work backwards to see if and how these might futures might or might not grow out of the present such as simulations and network techniques. Meanwhile, *subjective approaches* are assessment methods based on the individual subjective opinion such as survey and interview.

In Fig. 4, most frequently used method in TF research was *exploratory approaches* such as Delphi, curve fitting, data envelopment analysis, and technology roadmap. Meanwhile normative approaches such as patent analysis and TRIZ were used in some degree. However, *subjective approaches* such as industry analysis and interview were not used very much.

D. Application Areas of TF

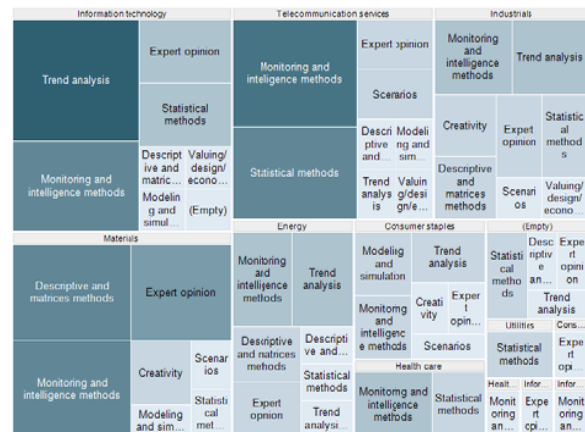1. Application Areas (10 industries) and TF Method (9 categories)

Fig. 5 Treemap for application areas and TF method

We classified application area of TF research into 10 sectors based on Global Industry Classification Standard (GICS) which is an industry taxonomy developed by MSCI and Standard & Poor's (S&P). The GICS structure consists of 10 sectors, 24 industry groups. In this study, we adopted sector classification scheme due to the ease of analysis. Also, to provide a clear visualization and ease of interpretation, types of TF methods were classified based on the classification scheme of previous research suggesting 9 categories of TF methods as e*xpert opinion, trend analysis, monitoring and intelligence methods, statistical methods, modeling and simulation, scenarios, valuing/decision/economics methods, descriptive and matrices methods,* and *creativity* [3].

From Fig. 5, we can know that information technology, materials, and telecommunication services have received most research attentions as application areas of TF methods. Among these three industries, *trend analysis* was frequently used in information technology industry, whereas *descriptive and matrices methods* were applied to material industry and

monitoring and intelligence methods were utilized in telecommunication services. Meanwhile, in the other industries, most frequently used methods were *monitoring and intelligence methods*, *trend analysis*, and *descriptive and matrices methods* in principle. Also, *statistical methods* and *expert opinion* methods were applied to almost every industry partly. However, there is no TF method applied in financials industry.

2. Ratio of Quantitative and Qualitative Approaches in each Industry
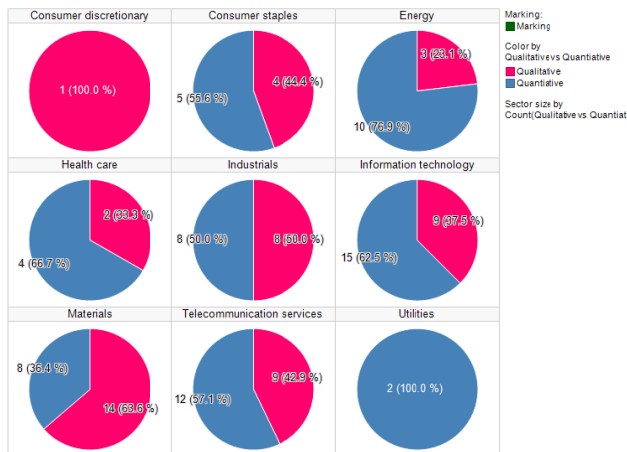

Fig. 6 Pie chart for the ratio of *quantitative* and *qualitative approaches* in each industry

In this part, ratio of *quantitative* and *qualitative approaches* in each technology industry was investigated. Except financials industry, 9 industries were investigated. Overall, *quantitative approaches* were well used across many technology industries.

Typical industries applied *quantitative approaches* were information technology, energy, telecommunication service, and health care. These industries are relatively high-tech industries, so advances in these industries have been made in recent years. In addition, because of technology-intensive characteristics of high-tech service industries, *qualitative approaches* depending on subjective opinions were somewhat hard to be applied. Instead, *quantitative approaches* based on the analytic result of data about detail characteristics of technologies were preferred to forecast trend of complicated high-tech service industries.

Meanwhile, *qualitative approaches* were used in several industries such as material, industrials, and consumer discretionary. These industries have some common characteristics. First, these industries are related with manufacturing, not service. Second, large-scale capital goods are mainly produced in these industries and, so, boom and recession of these industries are greatly affected by global economic climate. Because of this, expert opinions are more needed to forecast technology trend by reflecting situation of the world economy. For these reason, *qualitative approaches* were well used in these industries.

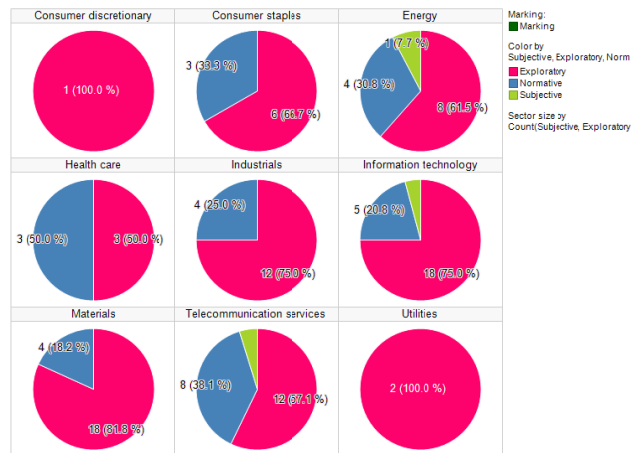3. Ratio of Subjective, Exploratory, and Normative Approaches in each Industry

Fig. 7 Pie chart for ratio of *exploratory*, *normative*, and *subjective approaches* in each industry

In terms of classification scheme of TF methods as *exploratory, normative*, and *subjective approaches*, the most applied approaches across almost every industry were *exploratory approaches*. This is because the purpose of TF is mainly on the detection of past, present, and future trends of technology, not on the consideration of the normative value for future direction of technology.

However, in some industries such as healthcare industry and telecommunication services, the normative value for future direction of technology should be considered for the well-being of human society. For this reason, *normative approaches* were used in some degree for these industries compared with other industries.

IV. CONCLUSIONS AND FUTURE RESEARCH

Main contribution of this study is to profile developments in and patterns of scholarly research in TF over time and investigate which technology industries have used certain TF method. The major findings can be summarized as follows:

1. There has been a steady growth in the number of TF articles published in journal, especially during the last 10 years (2004-2013).
2. TF Research has mainly used *quantitative approaches* compared with *qualitative approaches.*
3. *Exploratory approaches* such as Delphi, curve fitting, DEA, technology roadmap were frequently used and also *normative approaches* such as patent analysis and TRIZ were somewhat used.
4. Information technology, materials, and telecommunication services have received most research attention as an application area of TF.
5. *Monitoring and intelligence methods*, *trend analysis*, and *descriptive and matrices methods* were most frequently used methods across almost industries.

6. *Quantitative approaches* tended to be applied in high-tech service industries, whereas *qualitative approaches* tended to be applied in industries related with large-scale capital goods.

7. *Exploratory approaches* are the most frequently used approaches across almost every industry. Meanwhile, *normative approaches* were mostly applied in healthcare industry and telecommunication services.

Despite all major findings and contributions of this study, it has several limitations that suggest paths for our future research. First, this study investigated TF related articles mainly focusing on journal papers. Therefore, other sources containing TF topic such as magazine, proceedings of conferences, and various books can be investigated to provide more fruitful information. Second, this study only covered application area of TF methods. Strength and weakness of TF methods for selecting complementary and appropriate TF for a certain technology industry can be provided in future research.

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