An Empirical Evaluation of the Technology Cycle Time Indicator as a Measure of the Pace of Technological Progress in Superconductor Technology

Aymen A. Kayal and Robert C. Waters

Abstract— **The Technology Cycle Time indicator (TCT) is a new measure of technological progress. The TCT is the median age of the patents cited on the front page of a patent document. The measure assumes that the more recent the age of the cited patents, the more quickly one generation of inventions is replacing another. The main purpose of the study was to evaluate the TCT in a dynamic context to determine how accurately it measures the pace of technological progress. This study found the trend in TCT changed abruptly from gradually increasing (slowing in cycle time) to steadily decreasing (speeding up in cycle time) following the discovery of high-temperature superconductors. The methodology prescribed in this study could potentially be used in assessing the pace of progress for different technologies or different nations in the same technology [9].**

Index Terms— **Management of technology and innovation, patents, superconductor technology, technological progress, Technology Cycle Time indicator (TCT), technology measures or indicators, validity study.**

I. Introduction

SENIOR managers usually examine diverse financial, marketing, and production information before developing strategic and subsequent plans. For technology-based organizations, technological change is a way of life and continuously creates disruptions in the industry structure. To make timely and valid decisions, managers frequently require early detection signs of technological change that is occurring in the relevant technologies shaping the industry.

Technology indicators such as patent count, R&D spending, and the number of scientists and engineers in R&D have been used to suggest answers regarding the rate of technical and scientific progress and how it has changed over time and across industries and national boundaries. Of all technology indicators, many researchers have considered patent data to be the most available and objective measure of innovative output [8].

Over the last decade, the use of patent data has been enhanced by the computerization of the patent system. A number of patent-based technology indicators have been developed for measuring the technological strengths of companies and countries. Unlike the previous aggregate uses of patents, these new technology indicators have been more advanced in terms of information obtained from the patent document. They have drawn from a widely used bibliometric technique called "science indicators" which used the cited references in scientific papers to indicate scientific activity [11]. The references cited in a patent, called "prior art" by the United States Patent and Trademark Office (USPTO), provide a unique feature which captures the linkage between an invention and the prior knowledge most closely related to it. Earlier studies point to the fact that "citations to a previous patent represent evidence that current state-of-the-art developments are related to or were derived from the earlier inventions" [3, p. 43].

CHI Research, Inc., a private consulting company, has created a series of technology indicators based on patent citations, with support from the U.S. National Science Foundation. These include the following.

- *Current Impact Index:* A normalized indicator of the importance of a company's patents, based on how often they have been cited in other patents, which shows how frequently they were used as the foundation for other inventions.
- *Technological Strength:* The number of patents a company has obtained multiplied by its Current Impact Index.
- *Science Linkage:* The number of references per patent to journal papers and other scientific publications. It is assumed that the higher the number, the more the company's patents are building on basic science and technology.
- *Technology Cycle Time:* The median age of U.S. patents cited in a specific patent. This indicator uses patent citations to indicate the age of the inventions on which a new invention is based. It is assumed that the more recent the age the more quickly one generation of inventions is being replaced with another.

The patent citation-based technology indicators have been accepted as being useful and important to the field of science and technology indicators [8], [10], [12], [13]. The Current Impact Index, Technological Strength, and Science Linkage have been empirically validated through previous studies [2],

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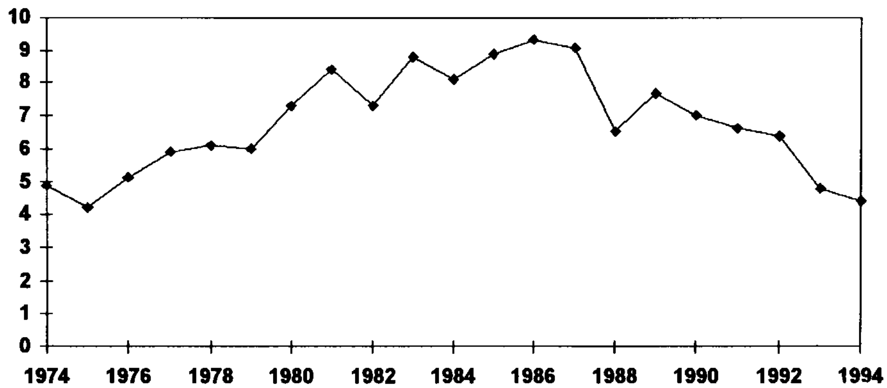

Fig. 1. Annual TCT values for superconductor technology, 1974–1994.

[6], [7], [12]. Thus far, no validation studies have been developed for the Technology Cycle Time (TCT) indicator.

Interest in the TCT has been prompted by its simplicity and potential usefulness as a tool to distinguish who is developing new technologies and who is improving old technologies. It is a pointer to those individuals and organizations who will be leaders in developing technology-driven products of the future.

II. Foundations of the Study

Ayres [5] suggested that the notion of the pace of technological progress might be considered as a sequence of substitutions of successively better combinations. Furthermore, he believed that the faster this sequence of substitutions occurs in a field, the faster the technology progresses. The objective of the TCT indicator is to measure this rate. Shorter cycle times reflect faster substitutions, indicating faster progress; longer cycle times reflect slower substitutions, indicating slower progress. Therefore, if TCT values indicate the pace of progress of a technology field, then patents relating to a rapidly progressing technology should have a smaller TCT value than patents relating to a slowly progressing technology. Narin [10, p. 22] wrote the following.

> TCT varies, of course, with each individual technology. In a fast-moving area such as electronics, the cycle time may be as fast as three to five years, whereas in some of the very old technologies, such as ship and boat building, the cycle time may be in the 15 to 20 years range.

This research has tested the proposition that the TCT indicator, when calculated as prescribed, may be used to measure the pace of technological progress. To verify this assumption, the authors calculated the technology cycle time for superconductor technology from 1974 to 1994 using the TCT indicator, then compared the TCT values with the actual pace of progress described by experts in superconductor technology.

A. Why Was Superconductor Technology Chosen to Evaluate the TCT Indicator?

Superconductor technology was selected for the study because it is a relatively well-defined field and appropriate historical information and patent data are available. Most importantly, the field provides a good example of a technology which has experienced a change in its pace of technological progress during the 1974–1994 period. According to the experts' perceptions of superconductor technology, the pace of progress decelerated from the discovery of the phenomena in 1911 to 1986; however, after the discovery of high-temperature superconductors in 1986, experts described the pace of its progress as suddenly accelerating [1], [4], [14], [15].

If a technological breakthrough in superconductor technology has significantly changed the pace of its progress from slow to fast, then any valid indicator of technological progress should identify this change. The thesis of this study is that the TCT indicator can measure the pace of technological progress and its cyclical variations for superconductor technology. This paper examines the assertion.

III. Data Collection

The superconductor technology field was operationally defined in terms of a set of U.S. patents. The set was determined by virtue of their placement in the U.S. Patent Classification System. The USPTO's Technology Assessment and Forecast Program has grouped the patents in a technology profile report. The report was generated by identifying appropriate patent classes and subclasses related to superconductor technology and then collecting all the patents filed under them. The report consisted of 3931 patents, dating from 1969 to 1994.

The second step in the data-collection procedure was to submit the patent numbers to CHI Research, Inc. From the patent numbers, CHI was then able to abstract patent citations for each patent number from its database which provided all the information needed to calculate the TCT. For consistency reasons, only the patents from 1974 to 1994 were used because some of the patents issued before 1974 did not have complete information in the database.

IV. Data Analysis and Results

After the TCT values were calculated for each year under consideration, these were plotted in a time series as shown in Fig. 1. The results of the calculations are also shown in Table I.

Next, the assumption that the TCT can actually indicate the pace of technological progress that occurred in superconductor technology from 1974 to 1994 was tested by use of a multiple regression model. Since the major breakthrough happened in

TABLE I

YEAR	TCT
1974	4.9
1975	4.2
1976	5.1
1977	5.9
1978	6.1
1979	6.0
1980	7.3
1981	8.4
1982	7.3
1983	8.8
1984	8.1
1985	8.9
1986	9.3
1987	9.1
1988	6.5
1989	7.7
1990	7.0
1991	6.6
1992	6.4
1993	4.8
1994	4.4

1986, and there is usually a time lag of one or two years between a patent application and a patent issue or grant,[1] the examined period was broken into two distinct periods: 1974–1987 and 1988–1994. The multiple regression model was formulated to reflect a major change in the slope of the line representing technological progress after 1987. The TCT values were fitted to the model in order to examine four questions.

- Are the errors normally distributed?
- Is the correlation coefficient large and significant?
- Is the change in the slope after year 1987 significant?
- Is the direction of the slope significantly positive in the first period and significantly negative in the second?

The analysis was concerned essentially with a test of the proposed assumptions, not a search for the best overall model or for predictive validity. The variables considered were the years and the corresponding TCT values. The multiple regression model developed was

$$\mathrm{TCT} = B0 + B1 * \mathrm{YEAR} + B2 * K + B3 * \mathrm{YEAR} * K + \mathrm{Error} \qquad (1)$$

where

$$K = 1, \quad \text{if YEAR} \leq 1987$$
$$K = 0, \quad \text{if YEAR} > 1987.$$

For years 1974–1987, the model becomes

$$\mathrm{TCT} = ((B0 + B2) + (B1 + B3)) * \mathrm{YEAR} + \mathrm{Error}. \qquad (2)$$

For years 1988–1994, the model then becomes

$$\mathrm{TCT} = B0 + B1 * \mathrm{YEAR} + \mathrm{Error} \qquad (3)$$

[1] A patent application is when the inventors actually submit an application, to the patent office, to patent their invention. A patent grant is when the patent office finally accepts and issues a patent number to the invention. The time lag between the two events was observed to be on average from one to two years. The data set in this study is based on patent grant dates.

where $B0$ is the intercept and $B1$, $B2$, and $B3$ are the slopes of the line in (1), (2), and (3).

Table II lists the output from the Statistical Analysis System software package. The model had an adjusted R-square of 0.8581. The normality assumption was checked, and it was concluded that the residuals were normally distributed. The most significant test was to evaluate the assumption that the slope of the model from year 1974 to 1987 was significantly different from the slope of 1988 to 1994; this would be captured if the parameter $B3$ was not zero. This assumption was also supported ($H0$: $B3 = 0$ was rejected with $P = 0.0001$).

An extension of the earlier analyses was to show that the direction of the slope changed from positive to negative. This was accomplished by conducting two separate regression analyses, one for the 1974 to 1987 period, the other for the 1988 to 1994 period. The results revealed that the slope of the line for the first period was significantly positive [slope $= 0.393, (P = 1.32E\text{-}07)$] and for the second period was significantly negative [slope $= -0.453, (P = 0.02)$], supporting a conclusion of decreasing pace of technology to 1987 and increasing pace in the superconductor industry thereafter.

A. Is There a Relationship Between TCT and the Number of Patents?

The aggregate number of patents per year and its growth or decline over time has been widely used as a technology indicator [8]. The increase in the amount of patenting in a certain industry, science, or technology field is considered to be a reflection of increasing technological activity. The authors expected to find a correlation between the TCT and the number of patents per year because, logically, one would expect to find no increase in the number of patents associated with a technology experiencing a slowing pace of technological progress. However, it is believed that the TCT is a more sensitive indicator of technological progress because it is a reflection of the time lag between a current patent and its prior art. Fig. 2 compares the time series for the number of patents granted per year with the TCT in order to show a possible relationship between the two indicators.

Although a statistical test of the linear correlation between TCT and number of patents was not significant, the data shown in Fig. 2 indicate a possible nonlinear relationship. When the number of patents remained constant from year 1974 to 1988, the TCT indicated a slowing pace of progress. When the number of patents increased dramatically after 1988, the TCT indicated a rapid pace of progress. Furthermore, the TCT indicated the change in progress one year ahead of the other indicator.

V. CONCLUSION AND RECOMMENDATIONS

The main conclusion drawn from this study is that the TCT is a valid measure of the pace of technological progress in superconductor technology. However, the findings cannot be generalized until the indicator is tested in many different technology fields.

TABLE II
RESULTS OF THE MULTIPLE REGRESSION MODEL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F- VALUE	PROB > F
MODEL	3	44.6716	14.890	41.306	0.0001
ERROR	17	6.1284	0.3605		
C TOTAL	20	50.8000			

PARAMETER ESTIMATES	T FOR H0: PARAMETER = 0	PROB > | T |
B0 = 14.3643	6.990	0.0001
B1 = -0.4537	-3.997	0.0009
B2 = -10.2115	-4.903	0.0001
B3 = 0.8465	7.040	0.0001

RESIDUALS W: NORMAL = (0.977936) PROB < W (0.859)

Adjusted R-square (0.8581)

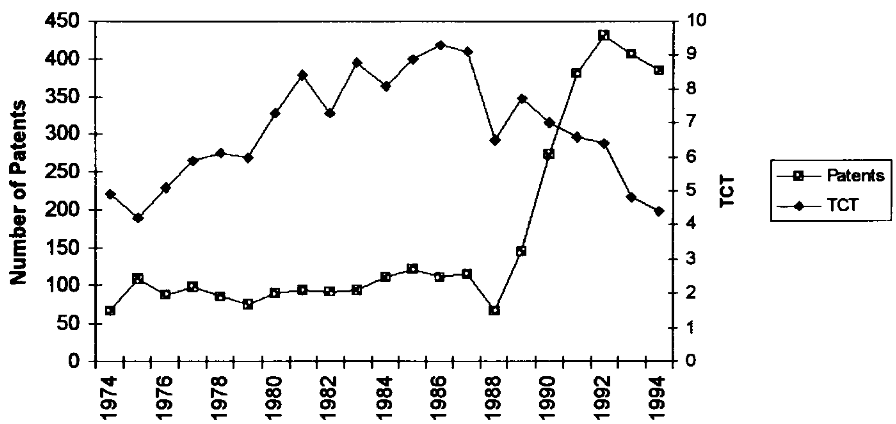

Fig. 2. Annual TCT values and the number of patents for superconductor technology, 1974–1994.

The TCT is believed to be a better indicator of the construct, "pace of technological progress," than the simple patents count because:

- the TCT may indicate a slowdown, or an increase, in the pace of progress more precisely and earlier than a patent count;
- in general, the rate of patenting has been increasing for most technology fields, which might be a result of many unrelated factors such as changes in the patent laws or Patent Office procedures; this effect might make patent counting an unreliable indicator for the pace of technological progress construct.

Potentially, the method could be repeated to describe the pace of progress of many other identifiable technologies. This indicator is of probable use to both academic theorists and industry analysts. In academia, it could be used to test theories of technological change and progress; while in industry, it could be used to indicate how rapid the overall progress in a technology is and how a company, or country, is progressing in comparison to its competitors. This measure, combined with other science and technology indicators, could be used in studies concerned with the technological advantage of firms or nations in critical technologies, and how this advantage changes over time.

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