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Technological advances in the fuel cell vehicle: Patent portfolio management

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ABSTRACT

With the shift from an industry-based society to a knowledge-based one, there has been a gradual increase in the importance of intangible assets such as technologies and information. Patents are a representative intellectual outcome of intangible assets and can be used as an objective measure of the level of technology or innovation of individuals, firms, and countries. In addition, patents can be regarded as a rich source of data for the provision of technological and commercial information. Patent data facilitate research on technological advances and innovation; hence, an analysis of this data can provide important insights into innovation activity and technology management strategies. This paper presents a method for extracting core technologies from core fuel cell vehicle (FCV) patents registered with the United States Patent and Trademark Office by using a data mining technique. Core patents are determined by analyzing patent citations, and the data mining technique identifies those firms with core FCV technologies and reveals the overall research focus of the firms by deriving patent portfolios and and technology recommendations considering the extracted core technologies.

1. Introduction

Recent years have revealed a growing global interest in conserving the environment and energy resources. The International Energy Agency points out that 17% of carbon dioxide (CO_2) emissions – the main cause of global warming – are attributable to transportation, including automobiles. Accordingly, an increasing number of studies have examined the effects of automobiles on climate change. In the last century, the use of fossil fuels to power automobiles was generally advantageous because of competitive prices and efficiency, but with the depletion of oil reserves and the strengthening of environmental regulations, there has been a gradual decline in their use.

As a result, the global automobile industry has been focusing on the development of fuel cell vehicles (FCVs) as a representative solution to transportation-induced environmental issues. To ensure a successful implementation, there has been a growing interest in the development of a wide range of high-quality parts. In particular, a fuel cell system as an alternative engine in an internal-combustion vehicle can reduce emissions by using air and hydrogen and, thus, is regarded as being more environment-friendly, which has motivated many studies on its global effects.

The purpose of this article is to provide FCV firms with supportive information for their decision making for differentiating between competitors in the FCV industry (who are the competitors?), analyzing technological competitiveness (how competitive is the market?), and developing portfolio strategies (what will be the firms' patent portfolio strategies?). In doing so, this study evaluates patent data as an important source of information and searches for hidden patterns from them. Although most studies so far have focused on quantitative characteristics of patent data, ignoring their various bias effects, this paper uses both quantitative and qualitative methods in an effort to gain important insights into their innovation activity.

This paper presents a citation analysis method for extracting core FCV technologies from core FCV patents registered at the United States Patent and Trademark Office (USPTO), and presents a data mining method for clustering core FCV technologies to derive portfolio strategies of distinguished FCV firms. After building the patent portfolios, technology recommendations are given to each firm by using social information filtering, which finds out other technologies that fit into the existing portfolio of a particular company by using the judgments of a peer group selected for similar technologies.

This paper is organized as follows: Section 2 provides the theoretical background and literature review on patent analysis methods using the patent citation analysis and data mining techniques. Section 3 describes the research model and methods. Section 4 analyzes the results of applying the model to FCV patent data, and Section 5 evaluates the appropriateness of core technologies derived and the relevance of technology recommendations. Section 6 concludes by summarizing the results and discussing interesting avenues for future research.

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2. Literature review

2.1. Patent data analysis

Schmookler (1966) was the first to employ statistical analysis to examine technological and economic issues surrounding patents; since then, his work has served as the core theoretical foundation for scholars interested in using patent data to analyze technological advances and related topics.

The analysis of patent data refers mainly to a method or approach for collecting, organizing, and processing the data. Various quantitative and qualitative methods and models can be employed to mine the economic and technological information contained in patent documents, which can guide managerial decision-making and innovation strategies (Chen and Xie, 2005).

The aim of patent data analysis is to study text contents, patent citations, and patent numbers in a directional selection and scientific abstracts in order to determine correlations and mine for tacit knowledge included in the patent data. According to a previous study (Huang et al., 2003a), firms examine patent information mainly to monitor patent activities, analyze technology fields, evaluate technology life cycles, and analyze competitive environments (refer to Table 1).

2.1.1. Monitor patent activities

Visualization methods are known as one of the best data mining strategies to understand patent activities because graphical display methods often offer superior results compared to conventional text-based or numeric techniques (Zhu and Yuan, 2004; Giudici and Figini, 2009; Han et al., 2012). Ganapathy et al. (2004) showed that visualization methods are especially effective in delivering quick and easy knowledge discovery to top managers who decide the directions of technology investments.

Black and Ciccolo (2005) applied a machine-learning technology to text classification of USPTO patent information to automatically differentiate between patents related to the biotech industry and those that were not. Fall et al. (2004) reported the results of applying a variety of machine learning algorithms for training expert systems in German language patent classification. Trappey et al. (2006) developed a platform for patent document classification and searching by using a back-propagation network, and Kim et al. (2008) proposed an alternative visualization method based on forming a semantic network of keywords from patent documents.

2.1.2. Analyze technology fields

Keyword-based patent analysis can be conducted through morphological analysis by extracting meaningful technical information from patent contents. This method has the advantage of retrieving detailed information regarding important technical factors mentioned in patents and can focus on the status of certain technology fields, such as identifying key technologies and monitoring technological advances (Shih et al., 2010).

Yoon and Park (2007) extracted keywords through text mining and analyzed the combination of keywords on major technology by constructing vectors from the extracted keywords and subsequently constructing a morphological matrix. The extracted keyword vectors specified the technology factors within a patent and technologies within a field. Lee et al. (2009) adopted text mining and correspondence analysis, where each patent document was transformed into keyword vectors. The keyword vectors were then used for charting two-dimensional patent maps through correspondence analysis, which is a sort of principal component analysis. The analysis results showed that technological vacancies represented opportunities for new technology creation.

Tseng et al. (2005) proved that most crucial category-specific terms of carbon nanotube patents occurred in the machine-derived extracts. The research computed the chi-square and correlation coefficients for detecting the best and worst terms, and the correlation coefficients exactly selected those words that were highly typical of membership. The results confirmed that important category features derived by machine could be comparable to those derived manually. Tseng et al. (2007) suggested a series of text mining techniques such as text segmentation, summary extraction, feature selection, term association, and topic mapping. They found that the topic mapping technique, which clusters topics based on the common co-occurring terms, was more effective than other classification methods.

2.1.3. Analyze technology life cycles

Every technology follows a typical development cycle, which can be visualized in an S-curve graph with four stages (Foster, 1986; Christensen, 1993; Ayres, 1994): innovation, growth, maturity, and decline. During the innovation stage, various innovative designs and systems emerge and compete with each other to be selected as the dominant design in the technology industry. The growth stage emphasizes such technologies to improve product performance and technological productivity. During the maturity stage, customers' product demands shift from high-performance to reliability, convenience, low price, and emotional aspects (Christensen, 2011). Technology life cycles are different from product life cycles which are widely used to comprehend various maturity stages of products in industry. That is, a product life cycle is the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products.

Chen (2006) analyzed the life cycle of each International Patent Classification technology and identified a set of trends as a result of using statistical methods. Kim et al. (2008) devised a method for visualizing patent maps that could overcome current limitations of the method and enable users to understand the life cycle of a given technology. Huang et al. (2010) devised a patent analysis model based on data mining to provide insights into firms' innovation activities. Park et al. (2013) proposed a new approach to identify promising patents for technology transfer. They adopted the theory of inventive problem solving (Teoriya Resheniya Izobretatelskikh Zadatch, TRIZ) using evolution trends as criteria to evaluate technologies in patents, and a subject–action–object-based text-mining technique to deal with and automatically analyze big patent data.

2.1.4. Analyze competitive environments

Network-based patent analysis can take a macroscopic look at the relevant technical fields of patent networks, since this method provides information about what patents are influential in a specific technical field. It is the basis of analysis for competitive environments including monitoring the competitiveness of technologies, evaluating technology evolutions by key competitors, identifying potential competitors and technologies, and developing competitive strategies (Yuan et al., 2006; Yang et al., 2008).

Table 1
Main objectives of firms analyzing patent data.

Objective	Action
Monitor patent activities	Monitor the number of patents and developmental environments of specific technology fields both domestically and internationally.
Analyze technology fields	Analyze the status of specific technology fields, identify key technologies, and monitor technological advances and international trends.
Analyze technology life cycles	Reflect changes in the technology life cycle, including the initial, growth, maturity, and decline phases.
Analyze competitive environments	Monitor the competitiveness of technologies and intellectual property rights, evaluate technology evolution and development trends of key competitors, identify potential competitors and technologies, and develop competitive strategies.