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Patent-based QFD framework development for identification of emerging technologies and related business models: A case of robot technology in Korea

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ABSTRACT

R&D planning for emerging technologies that reflect customers' future needs has a crucial role in national economies. In this paper, we propose a hierarchical quality function deployment (QFD) framework that enables one to set R&D priorities and then develop corresponding business models to meet future societal needs. The proposed QFD framework consists of a hierarchical structure with three house-of-quality (HOQ) stages, which are based on patent analysis and opinions of specialists and generalists. Based on the results of the HOQ and the convergence of iterated correlation analysis, prospective technology was identified. We applied the proposed framework to robotics technology in Korea and found that, for robotics R&D, position sensors are the most important emerging technologies, followed by distance sensors and motor-driven technologies. In addition, by utilizing reverse QFD, we suggest business models for cleaning, entertainment, and pet robots. We expect this research to open a new avenue in the R&D planning process.

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1. Introduction

Research and development (R&D) planning for emerging technologies that reflect customers' future needs has a crucial role in enhancing national competitiveness. For selecting prospective technologies, previous studies suggested various methodologies, such as Delphi surveys [10,12], bibliometrics [13], and patent analysis [1,25]. However, a systematic selection method must reflect customers' needs holistically, which those methodologies fail to do. In addition, selecting emerging technology is challenging because there are many candidate technologies which are not directly related to the final product and service [29]. To find emerging technology which satisfies with respondent's needs, we propose a quality function deployment (QFD) framework and set R&D planning priorities at the lowest level of technology classification. QFD has been

described as a "method to transform users' demands into design quality" and "to deploy the functions forming quality" [2]. According to Caetano and Amaral [8], it is used to identify gaps in the relationship between customers' needs and a given technology and to discover key elements contributing to new technologies' competitiveness. This concept is based on the theory of attractive quality, which was proposed by Kano et al. [21]. According to this theory, the fulfillment of attributes in two categories—one-dimensional quality and attractive quality—increases customer satisfaction. One-dimensional quality represents that attributes are linearly related to customer satisfaction. Attractive quality gives satisfaction to customer if present, but that produces no dissatisfaction if absent [37]. The proposed QFD framework consists of three house-of-quality (HOQ) stages.

The first HOQ stage relates megatrends of customers' needs to technological products. In this step, attributes of megatrends are developed by reflecting one-dimensional quality. In the second HOQ stage, using relevant patent information, an HOQ

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is developed to clarify the relationship between products/services and the primary level of technology classification, and the second HOQ stage reflects the prioritization of products in the first HOQ. In the third stage, an HOQ is constructed to present the relationship between the primary and secondary levels of technology classification based on patent information. The results of the second HOQ stage influence the third HOQ stage. Based on the third QFD, it ultimately becomes possible to evaluate the importance of prospective secondary-level technologies in reflecting future needs. As a result, importance of megatrends which are involved in one-dimensional quality is reflected in the second and third HOQ stages.

After identifying emerging technology in the third HOQ, we perform the HOQ process in reverse to construct a list of important megatrends only in relation to the technological services/products selected based on priority. Using this approach, one can suggest business models to reflect prospective technologies as well as customers' needs.

We apply the proposed QFD framework to robotics technology in Korea in an effort to identify related R&D priorities. According to Daim et al. [13], technology forecasting should reflect technical, personal, and organizational factors. To incorporate these three perspectives, we use patent information, survey analysis, and technology classification/technology development capacity, respectively.

This paper is organized as follows. Section 2 summarizes the relevant literature. Section 3 introduces the proposed three-stage QFD framework based on patents, while Section 4 applies the proposed framework to robotics technology. Lastly, Section 5 offers conclusions and suggests areas for future research.

2. Literature review

In this section, we review studies related to technology foresight, QFD, and patent network analysis.

2.1. Technology foresight

Formulating R&D strategies through technology foresight is a critical means of increasing national competitiveness and securing R&D funding. As methods of forecasting prospective technologies, some researchers have used qualitative approaches such as Delphi surveys, brainstorming, and technology roadmapping. The Delphi method involves the solicitation of expert views by means of successive iterations of a given questionnaire in order to identify opinion convergence as well as areas of dissent or non-convergence [16]. Brainstorming is a group technique for generating new, useful ideas and promoting creative thinking to solve a problem. It is an effective tool for predicting what is likely to happen in the future, as it benefits from a multitude of perspectives [18]. Technology roadmapping is a needs-driven technology planning process used to identify, select, and develop technological alternatives to satisfy a set of product needs [35]. While these qualitative approaches to technology foresight focus on expert opinions, the incorporation of quantitative data along with a qualitative approach will enable greater reliability and accuracy in the selection of prospective technologies.

Among various quantitative data resources that are available, scientific publications and patents are useful sources of

science and technology research for R&D planning [3]. As patents are major outputs of R&D activities and represent the characteristics of new technology [11], many researchers have approached technology foresight using patent information [15,27]. Trajtenberg [34] proposed that patents be weighted based on citations as an indicator of the value of innovations. More recently, Daim et al. [13] suggested three emerging technology areas by integrating the use of patent analysis and technology foresight tools such as scenario planning and growth curve analysis. In addition, Kim et al. [22] proposed a method of visualizing patent information based on keywords from patent documents in a target field. Shen et al. [29] suggested a hybrid selection model for prospective technology, with a selection framework based on the fuzzy Delphi method, the analytic hierarchical process, and principal component analysis. Using various forecasting analyses including Gompertz curve, Bengisu and Nekhili [3] found 20 emerging technologies under the machine and materials category for Turkey. Small et al. [31] suggested framework for identifying emerging topics in science and technology based on citation-based modeling. The authors develop citation network utilizing citation information from Scopus database. Yu and Lee [38] proposed a hybrid approach for selecting emerging technology based on two-level self-organizing map, analytic hierarchy process, and data envelopment analysis-assurance region. Lee and Song [24] found key research areas in nanotechnology area using technology cluster analysis.

Previous studies on technology foresight and customer preferences, however, have not considered the hierarchical interrelationships among customers' needs and the primary and secondary levels of technology classification. To overcome this limitation, we apply the QFD framework to technology foresight planning based on both customer's needs and patent information.

2.2. QFD and patent network analysis

The QFD framework is used to identify technical requirements in future markets [26]. It consists of an HOQ with a matrix-like structure to translate customer requirements into technology solutions [2,28]. QFD is useful not only in traditional product quality but also in technology foresight [20]. In particular, QFD has been applied to technology valuation [39], technology selection [40], and management strategies [17]. Groenvelde [41] and Phaal et al. [28] applied QFD to a technology roadmapping system, showing its potential as a technology foresight framework.

In this paper, we propose a technology foresight framework using a hierarchical HOQ based on patent information to select prospective technology for R&D planning. The hierarchical HOQ provides a detailed structure for guiding actions in different stages. In a general HOQ, WHAT and HOW represent quality and function requirements, respectively. Each WHAT and HOW can be subdivided from the HOQ to establish a new HOQ. Information can be communicated from one HOQ to another because they are linked [33]. This multi-stage approach has been adopted as a more realistic process [36].

An HOQ based on patent information requires a weighting scheme to determine the relative weight of a list of WHAT items. We considered four characteristics of a patent: importance based on citations, urgency based on trends, the ripple

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