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Technology opportunity discovery to R&D planning: Key technological performance analysis☆

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There is a gap between technological opportunities and R&D planning because opportunity information is too broadly defined. Thus, we suggest a method of transforming such technological opportunities into a customized and detailed R&D plan. We identify key information for R&D planning, extract such information from bibliometric data by chunk-based mining, and convert it to a usable form for R&D planning. A systematic analysis of normalized performance gaps, performance structure, R&D feasibility and technological alternatives identified important and feasible target technological performance metrics as well as R&D solutions. Our method can increase the practical value of technological opportunities while reducing the efforts required of experts.

1. Introduction

Over the last few decades, some innovative companies and entrepreneurs have explored and exploited technological opportunities better than others, thereby gaining competitive advantages (Day et al., 2004; Newbert et al., 2006). At a national level, the causal link from technological opportunities to economic growth has also been observed in many countries (Audretsch, 1995; Hung and Chu, 2006; Olsson, 2005). Consequently, there have been many efforts to better identify technological opportunities in both private and public spheres.

Technological opportunity is defined as a set of possibilities for technological advances to improve either production or functional attributes of a product (Klevorick et al., 1995; Olsson, 2005). According to the current literature, technological opportunities can be divided into two types: 1) innovative opportunities, and 2) arbitrage opportunities (Eckhardt and Shane, 2003; Kirzner, 1997). Researchers have made efforts to identify innovative opportunities to anticipate the future of emerging technologies (Savioz and Blum, 2002). Some researchers focused on the latter, and have tried to identify application opportunities for existing technologies (Shin and Lee, 2013; Yoon et al., 2014). Overall, innovative opportunities have been of interest both in academia and in practice.

Several methods have been suggested to better identify innovative technological opportunities. Early studies depended on expert judgment and entrepreneurial recognition (Baron and Ensley, 2006; Salo and Cuhls, 2003). The increasing complexity of technology, the environment and mutual interactions have reduced the reliability of this method. Researchers have focused on utilizing electronic science and technology data, including patents and journals, as substitutes or complements to recognition. Conceptual frameworks, models and systems have been generated, including Technology Opportunities Analysis (TOA) and technology intelligence (Brenner, 1996; Kerr et al., 2006; Porter and Detampel, 1995). Despite some differences, they all have common characteristics of monitoring and bibliometric analysis.

Focusing on the potential value of bibliometric analysis, some researchers have developed advanced techniques by using social network analysis (Shibata et al., 2011; Von Wartburg et al., 2005), morphology (Xin et al., 2010; Yoon et al., 2014), topology (Shibata et al., 2008), text mining (Kostoff, 2001; Lee et al., 2014), novelty detection (Lee et al., 2015), patent maps (Lee et al., 2009b) and others. These studies are a response to the need for more accurate and comprehensive opportunity identification in the earlier stages of an emerging technology, and they also reduce the weaknesses of bibliometric data such as truncation bias and unequal patent value.

Another important issue is practical operationalization for corporate functions including strategy, planning, research and development (R&D) and product development. Recently, some researchers have linked technological opportunity identification to business planning (Lee et al., 2009a), technology planning (Huang et al., 2014) and product development (Lee et al., 2008; OuYang and Weng, 2011; Yoon et al., 2014). They narrowed searches down to key patents or keywords, identified technological opportunities, extracted information (including business items, technological performance metrics and product

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attributes), linked each opportunity to relevant information and evaluated its strategic priority.

Though these approaches are valuable, some problems remain unsolved. Above all, the key target of technological performance identification depends upon expert judgment, and thus is subject to its typical drawbacks including subjective bias and bounded knowledge. Overall technology/product performance is not easy to optimize because the causal relationships among performance metrics are not sufficiently considered. Trade-offs and synergies between different technological performance metrics must be identified, but this is rarely done. Also, there is little consideration for customization, which reduces planning efficiency because experts have to spend time reviewing and filtering out information, including irrelevant opportunities, unimportant technological performance metrics, and infeasible R&D methods.

To address these issues, we suggest a way of linking technological opportunities to practical R&D planning customized to a company. Customized technological opportunities are identified based on Lee et al. (2008, 2014), which provide a starting point for R&D planning. Sequential iterations of chunk-based text mining and expert judgment enable us to comprehensively identify key technological performance metrics as well as competitors in the target market segment while minimizing several biases due to either text mining or expert judgment.

Combining the normalized performance gap analysis with the decision making trial and evaluation laboratory (DEMATEL), we can narrow potential items down to important target technological performance metrics for a specific company, identify the performance structure of their synergies and trade-offs, and select target performance metrics to maximize R&D effectiveness. Further, we can evaluate the R&D feasibility of target performance metrics, which enables R&D experts to select more feasible target performance metrics by utilizing their existing technological capability. R&D efficiency can be increased by focusing on more feasible performance metrics. Finally, the patent-based technological trajectory is of great help to identify candidates of R&D solutions to achieve targets. A systematic use of these tools can transform a broadly defined technological opportunity to a specific R&D plan with clear target technological performance metrics, solution candidates and competitors.

The remainder of this article is organized as follows. In Section 2, we review existing TOA research. The research framework and our methodology are explained in Section 3. Subsequently, an empirical analysis about battery separator opportunities using membrane technology is provided. Finally, conclusions are drawn after relevant discussions.

2. Technology opportunity analysis

In the 1990s, it became important to identify early signals of technological changes to optimize organizational response options (Brenner, 1996). The first technology signals emerge in scientific and technological discussions or gray literature (Johnson, 2000). Later signals include scientific papers, patents and R&D collaborations. Porter and Detampel (1995) suggested using TOA to recognize the explosion of later signals in electronic technology databases. This method combines monitoring with bibliometrics, which are used to analyze information gleaned from such databases to identify emerging technologies.

Researchers have worked to improve TOA and were driven by the increasing volume of data as well as the need for new opportunities. Key TOA processes consist of monitoring, bibliometric analysis, augmented analysis and visualization (Porter and Detampel, 1995; Zhu and Porter, 2002). There has been some research about the modification and extension of TOA frameworks and systems (Cozzens et al., 2010; Kerr et al., 2006; Porter and Newman, 2011). However, most researchers focused on improving the effectiveness of a particular process.

Bibliometric analysis is an important area of research. Many believe that advanced bibliometric analysis can be used to identify emerging and unexplored technological opportunities more comprehensively and accurately. Simple bibliometric indicators including counts of publications and citations (Albert et al., 1991) have been replaced by advanced indicators (van Raan, 1996). Some researchers appreciate the potential of the bibliometric indicator network such as the citation network, and improve its analytics by using topology (Shibata et al., 2008), clustering (Shibata et al., 2011), citation vectors (Érdi et al., 2013), weighted citation networks (Fujita et al., 2014) and other approaches.

Advances in natural language processing have encouraged researchers to use various mining techniques including text mining (Kostoff, 2001; Porter and Cunningham, 2005), semantic analysis (Gerken and Moehrle, 2012), term clumping (Zhang et al., 2014), Action-Object (AO) analysis (Lee et al., 2014) and others. Some studies integrate two research streams into new methods using a text-mining network (Yoon and Park, 2004) and a Subject-Action-Object (SAO) network (Choi et al., 2011).

However, the most advanced bibliometric approaches depend heavily on expert judgment for evaluation and selection of opportunities. Thus, there have been attempts to improve expert judgments. Qualitative techniques from other disciplines have been introduced to make expert judgment more systematic and comprehensive, and these have been coupled with bibliometric tools, including morphology (Yoon et al., 2014), TRIZ (OuYang and Weng, 2011), and conjoint analysis (Xin et al., 2010). These methods can be used to narrow our focus to valuable and feasible opportunities, but require intensive training and involvement of experts.

Less attention has been paid to other processes. Some researchers have recognized the importance of opportunity information visualization, but they cannot go beyond simple clusters, maps and networks (Shibata et al., 2008; Zhang et al., 2014; Zhu and Porter, 2002). Advanced monitoring methods including real-time Delphi (Gordon and Pease, 2006) and scouting networks (Rohrbeck, 2010) have been suggested, but they are not tightly integrated with TOA in academic disciplines.

Opportunity identification itself has been a primary focus of TOA. However, the issue of practical operationalization forces researchers to broaden the scope of TOA. In response to this trend, some researchers have suggested ways of linking technological opportunities to strategy and planning. Pioneering research in the field of TOA has focused on facilitating expert-based strategic planning methods including TRIZ and brainstorming by providing core keywords and patents related to opportunities (Lee et al., 2008; OuYang and Weng, 2011). Going a step further, recent research has created keyword links between technologies and products, thereby making the link more specific (Yoon et al., 2014).

An important issue related to the appropriateness and usefulness of opportunity information used by strategic planning experts remains unsolved. Many opportunities described by keywords and patents are too ambiguous to be easily used for planning. Thus, in practical strategic planning, several experts must spend a lot of time to understand, evaluate and specify opportunities. They identify key technological performance metrics, select target performance metrics, and create specific plans for R&D and new product development. This time-consuming process decreases R&D planning efficiency while reducing the application value of TOA information. Thus, to boost the practical value of TOA, opportunity information that strategist/planners need should be identified, extracted and provided to them in a suitable form along with the appropriate tools and processes.

3. Methodology

3.1. Research framework

Our method consists of seven phases, as shown in Fig. 1. Once a company is selected, we identify its customized technological opportunities based on Lee et al. (2008, 2014). An expert-based technological attribute-application table is created and used to identify technological opportunities and its technological capability. Using multiple keyword matching, we select relevant and feasible opportunities customized to