Technological Forecasting & Social Change 111 (2016) 164–175

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Towards robust technology roadmapping: How to diagnose the vulnerability of organisational plans

Changyong Lee [a], Juram Kim [a], Sungjoo Lee [b,*]

[a] School of Management Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Ulsan 44919, Republic of Korea
[b] Department of Industrial Engineering, Ajou University, 206 Worldcup-ro, Yeongtong-gu, Suwon 16499, Republic of Korea

ARTICLE INFO

Article history:
Received 15 October 2015
Received in revised form 19 June 2016
Accepted 20 June 2016
Available online 4 July 2016

Keywords:
Robust technology roadmapping
Vulnerability assessment of organisational plans
Field anomaly relaxation
Analytic network process

ABSTRACT

While technology roadmapping has been the subject of many previous studies, a general lack of attention to the issues of uncertainty exists, thus leading to difficulties in consensus-building in the follow-up activity phase of technology roadmapping. To counter this, we propose a systematic approach to diagnosing the vulnerability of organisational plans against complex future conditions. For this, first, field anomaly relaxation (FAR) is employed to generate and evaluate future scenarios in a structured manner. Second, analytic network process (ANP) is used to measure the ripple impacts of activities on organisational plans by considering the interaction between activities. Lastly, a vulnerability assessment map is developed to provide a comprehensive and balanced view of organisational plans. The systematic process and quantitative outcomes the proposed approach offers will assist robust technology roadmapping in the face of growing uncertainties associated with the future. A case study of the organisational plan for developing home security systems is presented.

1. Introduction

Technology roadmapping supports strategic and long-range planning by offering a structured means of exploring and communicating the dynamic relationships between markets, products, and technologies (Phaal et al., 2009). While this method has been the subject of many previous studies, there has been a general lack of attention on the issue of uncertainty (Ilevbare et al., 2014). This has led to difficulties in consensus-building in the follow-up activity phase where the technology roadmap is reviewed and validated and the implementation plan is developed. Specifically, although the desired shared understanding of the visions, objectives, and action plans of organisations may be achieved in the early phases of technology roadmapping, such understanding needs to be consistently reviewed and validated in the follow-up activity phase to cope with uncertain futures (Phaal et al., 2001; Strauss and Radnor, 2004). Moreover, this process should be executed periodically as uncertainty associated with the initial roadmap increases with the time frame. However, a major issue remains for decision makers to consider — how best to assess the vulnerability of organisational plans against complex future conditions.

One major attempt at dealing with this issue has been to integrate scenario analysis into technology roadmapping. A variety of issues and suggestions—such as the construction of scenarios (List, 2004; Graham-Saunders, 2009), integration of scenarios into roadmapping (Lizaso and Reger, 2004; Saritas and Aylen, 2010; Strauss and Radnor, 2004), and multiple path mapping (Robinson and Propp, 2008)—have been presented thus far. However, while all of these studies have proved quite useful for guiding organisations towards building scenarios and mapping multiple paths for the realisation of strategic goals, they have remained conceptual and focused predominantly on the preliminary and development phases of technology roadmapping. Thus, they cannot offer a concrete method to continually assess and adjust organisational plans according to variable future conditions (Lee et al., 2015). It is likely that the most scientific approaches are offered by repeated cross-impact analysis (Pagani, 2009) and system dynamics (Geum et al., 2014) to generate and evaluate future scenarios. However, these approaches are of little practical assistance in the follow-up activity phase, owing to the complexities involved and the limited scope of information provided by the methods. In particular, an established link between future scenarios and organisational plans is required, as future scenarios are not ends in themselves, but only a means of modelling uncertain futures and improving the quality of decision making (e.g., by asking if the organisational plan is robust against different future conditions; or what activities are critical to attaining organisational strategic goals) (Lee et al., 2015).

These drawbacks necessitate the development of new methods to assess the vulnerability of organisational plans against complex future conditions, so that such analyses more adequately inform decision making. In this study, a vulnerability assessment of organisational plans is

* Corresponding author.
E-mail addresses: changyong@unist.ac.kr (C. Lee), juram92@unist.ac.kr (J. Kim), sungjoo@ajou.ac.kr (S. Lee).

http://dx.doi.org/10.1016/j.techfore.2016.06.022
0040-1625/© 2016 Published by Elsevier Inc.

defined as the process of evaluating and prioritising activities according to their level of impact in attaining organisational strategic goals and probable change in the impacts of these activities under conceivable future conditions. Three main issues are central to this problem and need to be addressed. First, the assessment should be based on systems thinking in order to consider the interaction between activities and the organisational plan as a whole (Postma and Liebl, 2005; Saritas and Aylen, 2010; Lee et al., 2015). One activity has an impact, not only directly on the subsequent activities, but also indirectly on the interrelated activities, and eventually on the realisation of organisational strategic goals. Hence, such complex ripple impacts resulting from the interaction between activities should be considered at a system level to improve the quality of analysis. Second, the assessment should be flexible as differences exist in terms of organisation. The possible layers a technology roadmap can have are diverse, and the layer receiving the attention depends on the context of the organisation (Phaal et al., 2009). Note that some companies put a premium on markets and products, while other companies prioritise technologies and R&D. Therefore, any proposed approach needs to allow for the modelling of organisational strategic focuses, as well as the diverse possible layers of technology roadmaps. In addition, the adjustment of the approach should facilitate easy customisation to be deployed in practice. Last, but not least from a practical standpoint, the assessment should be in harmony with existing roadmapping processes. Given that technology roadmapping is mainly driven by experts in the relevant domains (Groenveld, 1997; Holmes and Ferrill, 2005; Lee et al., 2007; Phaal et al., 2004; Strauss and Radnor, 2004), the proposed approach should be able to aid experts with different backgrounds to reach agreements and reduce decision-making errors by minimising the complexities involved (Yoon et al., 2008).

Considering these issues, we propose a systematic approach to assessing the vulnerability of organisational plans against complex future conditions based on technology roadmaps. At the heart of the proposed approach are field anomaly relaxation (FAR), to explore different future scenarios in a structured manner; and the analytic network process (ANP), to measure the ripple impacts of activities on organisational plans by considering the interaction between activities. Specifically, we construct a sector-and-factor array to generate different future scenarios in a structured manner, and conduct pairwise comparisons to assess the probability of occurrence of each scenario in a quantitative manner. Here, the pairwise comparison can enhance the consistency, reduce the complexity of experts' judgments, and consider unexpected errors (Monti and Carenini, 2000). The ANP is then executed for the scenarios with a high probability of occurrence as derived via FAR. The integrated use of these methods can be assimilated effectively into existing roadmapping processes as they have definitive advantages for scientific communication and (notably) for group work, at acceptable levels of complexity and flexibility (Rhyne, 1981; Saaty, 1996). The approach we propose therefore incorporates the three issues stated above into the vulnerability assessment of organisational plans. Our method was applied to a roadmap for the development of home security systems. We found that the proposed approach provides a comprehensive and balanced view of organisational plans against different future conditions. Moreover, the results of our case study enabled us to identify a method to improve the proposed approach, which we expect to be useful as a complementary tool for technology roadmapping, in particular for organisations in dynamic industry environments. It is expected that our method will facilitate robust technology roadmapping by assessing the vulnerability of organisational plans in the face of future uncertainties.

The remainder of this paper is organised as follows. Section 2 presents the background to our research, and Section 3 explains our research framework, which is then illustrated with a case study of a roadmap for developing home security systems in Section 4. Finally, Section 5 offers our conclusions.

2. Background

2.1. Integration of scenario analysis into technology roadmapping

A technology roadmap has been described as "an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field" (Galvin, 1998). It is considered a dynamic framework that enables the evolution of a complex system to be mapped and shared, supporting the development and deployment of innovation and strategy (Phaal et al., 2009). Because of its benefits, this method has been widely accepted by corporations (Albright and Kappel, 2003; Groenveld, 1997), industrial associations, and governments (Kostoff and Schaller, 2001; Probert and Radnor, 2003). It has enabled technology and business planning at the firm level (Kappel, 2001; Saritas and Oner, 2004) and technology forecasting and policymaking at the industry level (Phaal et al., 2004).

However, technology roadmapping faces a serious challenge in terms of preparing for unpredictable and rapid changes, as only a straight-line projection has been considered thus far (Strauss and Radnor, 2004). Thus, the integration of scenario analysis into technology roadmapping has been attempted by many researchers. Early research focused on architectural formats and roadmapping processes to advance our understanding of scenario-based technology roadmapping. For instance, List (2004) proposed a network-based scenario analysis to consider multiple views of the present and the past occurring in multiple systems, Graham-Saunders (2009) suggested a visual technique to collect scenario planning information. With a greater focus on the integration of scenario analysis and technology roadmapping, Strauss and Radnor (2004) presented guidelines for developing multi-scenario roadmaps based on programme evaluation and review technique (PERT) charts. Lizaso and Reger (2004) developed a process of linking scenario analysis and technology roadmapping to plan the coordinated development and deployment of new and existing technologies and applications. Saritas and Aylen (2010) suggested three methods of combining scenarios and technology roadmapping (i.e., before, during, and after roadmapping) and demonstrated the approach using a clean production case. Robinson and Propp (2008) addressed multi-path mapping as a way to align emerging science and technology.

Recently, highlighting possible opportunities for methodological adaptation, the direction of research on scenario-based technology roadmapping has shifted from the construction of conceptual frameworks to the development of quantitative approaches, with the goal of improving the credibility of technology roadmapping. The results of the major studies can be summarised as follows: Gerdsri and Kocaoglu (2007) suggested the integrated use of the Delphi method and the analytical hierarchy process to build a technology development envelope that can be used as strategic inputs for multi-path mapping; Pagani (2009) proposed an approach to generating qualitative and quantitative scenarios using repeated cross-impact handling; Geum et al. (2014) combined system dynamics and technology roadmaps to support scenario planning; and Lee et al. (2015) developed a method of assessing the impacts of future changes on organisational plans using Bayesian network-based sensitivity analysis.

While these studies provide valuable information, as stated in the preceding section, they cannot support decision making in the follow-up activity phase where the technology roadmap created is reviewed and validated and the implementation plan is developed. These drawbacks motivate this research and they are fully addressed in this study. Table 1 summarises the differences between previous and the current studies.

2.2. Field anomaly relaxation (FAR)

FAR, which was proposed in the 1960s and is based on Lewin's social field theory, straddles the fence between hard and soft scientific