Technological Forecasting & Social Change xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage:

An instrument for scenario-based technology roadmapping: How to assess the impacts of future changes on organisational plans☆

Changyong Lee [a,1], Bomi Song [b,2], Yongtae Park [b,*]

[a] School of Technology Management, Ulsan National Institute of Science and Technology, UNIST-gil 50, Ulsan 689-798, Republic of Korea
[b] Department of Industrial Engineering, School of Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 14 January 2013
Received in revised form 15 August 2013
Accepted 29 December 2013
Available online xxxx

Keywords:
Scenario-based technology roadmapping
Future changes
Uncertainty
Ripple impacts
Sensitivity analysis
Bayesian network

ABSTRACT

Scenario-based technology roadmapping offers a strong capability for strategic planning to respond to increasingly volatile environments. However, previous studies cannot guide organisations towards making robust decisions against complex future conditions since they remain conceptual and rely solely on graphical mapping tools. To counter this, we propose a systematic approach to making scenario-based technology roadmapping more robust by adding the ability to assess the impacts of future changes on organisational plans. At the heart of the suggested approach is a Bayesian network that can examine uncertainty inherent in future changes and ripple impacts resulting from interdependence among activities. The proposed approach is designed to be executed in three discrete steps: defining a roadmap topology and causal relationships via qualitative and quantitative modelling; assessing the impacts of future changes on organisational plans via current state analysis and sensitivity analysis; and finally managing plans and activities via development of *plan assessment map* and *activity assessment map*. A case study of photovoltaic cell technology is presented to show the feasibility of our method. We believe the systematic process and quantitative outcomes the suggested approach offers can facilitate responsive technology planning in the face of future uncertainties.

1. Introduction

The general need for scenario planning is not controversial in theory and practice as markets shift rapidly, technologies proliferate unceasingly, and thus innovation cycles become ever shorter [1]. It has been widely recognised that success depends on the ability to create and apply knowledge in ways that fit increasingly dynamic and volatile environments [2]. Even though the impacts of future changes vary considerably, organisations can have the opportunity to gain or maintain a competitive edge by managing crucial uncertainty inherent in strategic decision making [3]. In addition, many of these studies have shown that an inadequate response to future changes may lead to the decline of long-established organisations [4]. Consequently, recent years have witnessed a significant increase in attempts to devise models, methods, and tools to facilitate scenario planning.

One such attempt is to integrate scenarios into technology roadmapping so as to improve preparedness in the event of a range of futures [5]. At its most basic, multiple paths are mapped for different future conditions by extending a straight-line projection approach [6]. A wide variety of suggestions and issues have been presented so far to deepen understanding of scenario-based technology roadmapping—architectural formats and roadmapping process [6,7], interaction between scenarios and roadmapping [8], multiple path mapping [9], and scenario construction [10,11]. However, while these have proved useful for mapping multiple paths towards realisation of strategic goals or guiding organisations towards building scenarios, these

☆ It is confirmed that this item has not been published nor is currently being submitted elsewhere.

* Corresponding author. Tel.: +82 2 878 8358; fax: +82 2 878 8560.
E-mail addresses: changyong@unist.ac.kr (C. Lee), blue1821@snu.ac.kr (B. Song), parkyt1@snu.ac.kr (Y. Park).
[1] Tel.: +82 52 217 3125; fax: +82 52 217 3101.
[2] Tel./fax: +82 2 878 3511.

0040-1625/$ – see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.techfore.2013.12.020

still remain conceptual, and cannot provide a concrete way to facilitate decision making against different future conditions [12]; therefore, this method has not become fully inculcated into on-going management and faced credibility issues in practice. This is mainly due to the innate weakness of scenario-based technology roadmapping in analytical power that stems from its sole reliance on graphical mapping tools [13]. In this respect, highlighting possible avenues for methodological adaptation, some recent research has focused on combining quantitative methods and scenario-based technology roadmapping. Probably the most scientific approaches are offered by cross-impact analysis for examining probabilities of scenarios [14] and the analytical hierarchy process for investigating changes of technological value over time [15]. While these are both clear and useful, previous studies have focused only on future changes which are not ends in themselves but only a means for addressing uncertainty in the environment and improving the quality of technology roadmapping. A link is still missing in the literature as to how to translate future changes into organisational decisions and actions, thus leading to difficulties in consensus-building in planning and operational stages. Specifically, when organisations develop and adjust scenario-based technology roadmaps, or when organisations are confronted with uncertain futures, the methods cannot guide organisations towards making robust decisions.

These drawbacks necessitate the development of a systematic approach to assessing the impacts of future changes on organisational plans, so that such analyses adequately inform decision making. Key to this problem is three crucial issues that need to be addressed. First of all, high uncertainty inherent in the future means that future conditions cannot be described in single deterministic values. It has been found that deterministic methods should be limited, while probabilistic forecasts should be more widely used [16]. To this purpose, future conditions need to be modelled as random variables so as to provide a fair reflection of future changes, in line with the increasing demand for probabilistic forecasting [17]. Second, future changes have an impact not only directly on the compensable activities, but also indirectly on the interrelated activities, and consequently the strategic goals [3,8]. The complexity of the relationships is highlighted by the fact that one future change may also trigger the others. Such complex ripple impacts should be considered at the system level to improve robustness of analysis [18,19]. Finally, throughout scenario-based technology roadmapping, companies frequently ask “what-if” scenarios about future changes and their impacts on organisations [6], often constructing and managing a portfolio of strategic options. In this regard, the methods should be flexible and efficient in order to examine different potential future conditions easily and to aid a speedy investigation.

Taking these considerations into account, we propose a systematic approach to assessing the impacts of future changes on organisational plans by integrating the strengths of sensitivity analysis, for coping with the intrinsic variability of systems, into scenario-based technology roadmapping. At the heart of the proposed approach is a Bayesian network that can examine the uncertainty and dependence relationships associated with a complex process using a set of random variables [20]. The suggested approach, therefore, incorporates the issues of uncertainty and ripple impacts mentioned above. The flexibility and simplicity of Bayesian networks to conduct a sensitivity analysis also enable analysts to incorporate various scenarios regarding futures. Note that scenarios are used to consider some future states or conditions in which the institution is embedded, and used to stimulate analysts to develop and clarify practical choices, policies, and alternative actions that may be taken to deal with the consequences of the scenarios [2]. Moreover, we develop a software system to implement our method in a simpler way, thus allowing various “what-if” scenarios to be easily examined by modifying the probabilities of future conditions and their causal relationships. Given the complexities involved, the proposed approach is designed to be executed in three discrete steps: designing a roadmap topology and causal relationships via qualitative and quantitative modelling; assessing the impacts of future changes on organisational plans via current state analysis and sensitivity analysis; and finally managing plans and activities via development of *plan assessment map* and *activity assessment map*. It is expected that the systematic process and quantitative outcomes the suggested approach offers can facilitate more responsive technology planning in the face of future uncertainties.

The remainder of this paper is organised as follows. A general background of scenario-based technology roadmapping and Bayesian networks is presented in Section 2. The proposed approach is explained in Section 3, and illustrated with a case example of photovoltaic cell technology in Section 4. Finally, Section 5 offers our conclusions.

2. Background

2.1. Scenario-based technology roadmapping

A technology roadmap is defined 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 [21]. It has been considered as a dynamic framework that enables the evolution of a complex system to be explored and mapped, supporting the innovation and strategy development and deployment [22]. Technology roadmapping, since its first development by the Motorola and Corning in the late 1970s, has gained acceptance by not only corporations such as Philips [23] and Lucent [24], but also industrial consortia and governments [25–27]. Specifically, this method facilitates technology forecasting and policy making at an industry level [28,29] while technology and business planning at a firm level [30,31].

However, technology roadmapping is forced to face serious challenges in terms of preparing for changes that are volatile and rapid since only a straight-line projection or single scenario has been taken into account [6]. The basic concept of scenario-based technology roadmapping was initiated in this context, integrating the flexibility of scenario planning together with the clarity of technology roadmapping. Specifically, scenario planning can capture the full context of decisions and enable the anticipation of a broad range of possible changes [32], while technology roadmapping can address the strategies, directions, and detailed tasks explicitly [22]. In light of these, researchers and industrial practitioners are now increasingly focusing attention on scenario-based technology roadmapping.

A wide variety of suggestions and issues have been presented so far to deepen understanding of scenario-based technology