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Development of the scenario-based technology roadmap considering layer heterogeneity: An approach using CIA and AHP☆

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ABSTRACT

Scenario-based roadmapping has been considered as an effective means to deal with the dynamics of business environments. However, previous research on the scenario-based roadmap has commonly employed a single methodology to develop technology roadmaps, even if the characteristics of layers in technology roadmaps are different. The market planning deals with 'external scenarios' which are uncontrollable, whereas the product and technology planning is associated with 'internal scenarios' which are controllable. The former is related to the analysis and evaluation, whereas the latter is associated with strategic decision-making. This leads to the important implication that we have to consider two different perspectives of planning and have to utilize two different methodologies. In response, this paper employs an approach using cross impact analysis (CIA) and the analytical hierarchy process (AHP) as a tool for scenario-based roadmapping. CIA is employed for roadmapping the market layer due to its ability to measure the impact of the external environment, whereas AHP is employed to roadmap the technology and product layers, due to its characteristics of decision-making process. To illustrate the working of proposed approach, a case study was conducted for the u-healthcare services.

1. Introduction

Today, the business environment has become fierce, volatile, and dynamic due to rapid technological innovation and the increasing bargaining power of customers. For this reason, uncertainty and flexibility are two important issues: the former as a motivation, and the latter as a solution. This is especially important in long-term planning, typically with a ten-year timeframe (Phaal and Muller, 2009).

To deal with uncertainty, what has been vigorously discussed is the use of 'scenarios.' Scenarios are defined as hypothetical sequences of events, through which possible future developments are made visible (Gausemeier et al., 1998). Therefore, scenario planning has been utilized as an effective means to deal with the dynamics of business environments (Chermack, 2005; Godet, 1987; Postma and Liebl, 2005). Quite naturally, scenarios have also taken a front seat in the development of the technology roadmap (TRM) which has been discussed as a prominent strategic planning tool.

There exists a broad spectrum of literature to study the integration of scenarios and technology roadmapping, which can be summarized from two different perspectives. The first category deals with multi-path roadmapping, representing various scenarios in a single roadmap (Postma and Liebl, 2005; Strauss and Radnor, 2004; Gerdsri and Kocaoglu, 2003; Gerdsri and Kocaoglu, 2007a; Robinson and Propp, 2008). The second category is related to the methodological approach to reflecting on the impact of scenarios on the technology planning (Chermack, 2004; He et al., 2005; Lee et al., 2010). This research employs a probabilistic approach, such as the Bayesian network (Lee et al., 2010), a simulation approach such as system dynamics (He et al., 2005), and a decision making approach (Chermack, 2004) such as the analytic hierarchy process (AHP) (Martin and Daim, 2012).

However, previous studies on TRMs have employed a single methodology to develop the TRMs. However, layers of the TRM, known as the market, product, and technology layers, clearly have different characteristics. First, the market layer, the top layer, is related to the changes in market trends, customer needs, and innovation drivers (Phaal and Muller, 2009). This means that scenarios in the market layer are a given problem, which is an uncontrollable factor. However, the characteristics of the other layers are quite different. The middle and bottom layers, the product layer and the technology layer (sometimes including a service layer), represent the product functions, product features and product performance that firms want to develop (Phaal and Muller, 2009). Therefore, these layers are related to the internal decision-making,

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i.e. what kinds of products we have to consider, and what kinds of technology we have to develop. Therefore, a scenario in the product layer and the technology layer is a decisive problem, which is controllable factor in the firm.

This is also found in the previous literatures. Phaal et al. (2005) mentioned that the top layer of the roadmap is concerned with know-why, together with factors influencing the purpose of firms, which are trends and drivers. They also mentioned that the market layer includes both external and internal perspectives, which are market and business. Yoon et al. (2008) mentioned that roadmapping processes identify product or technology functions that can satisfy market needs, which means that product or technology layers are decisive but the market layer is predictive factor. In many studies, the development of market layer has been discussed with the market identification, i.e. market evaluation (Ibarra et al., 2008; Ibarra et al., 2014; Jin et al., 2015).

However, despite the fact, many studies on technology roadmapping have employed a single methodology. Methodological approach to the technology roadmapping can be summarized from two different perspectives: decision making approach such as linking grid (Geum et al., 2011), QFD (An et al., 2008; Geum et al., 2011; Jin et al., 2015), and AHP (Gerdsri and Kocaoglu, 2007b; Martin and Daim, 2012), and prediction approach such as system dynamics (Geum et al., 2011), cross-impact analysis (Pagani, 2009), and Bayesian network approach (Suharto, 2013). However, what is required in the market layer is the evaluation of the external environment, whereas what is needed in the product/technology layer is the selection of internal strategy. Therefore, different methodologies are required to develop scenario-based TRMs.

In response, this paper focused on the needs for the differentiated methodologies to develop scenario-based TRMs. Therefore, this paper applies different methodology for each layer of the TRM: the cross-impact analysis (CIA) for the market layer and the analytical hierarchy process (AHP) for the remaining layers. CIA and AHP fit the purpose of scenario-based planning for the following reasons.

First, CIA is a practical method for scenario planning (Weimer-Jehle, 2006), specifically for forecasting the emergence of new events and identifying the interrelations between events (Sarin, 1978; Weimer-Jehle, 2006). The essence of CIA lies in the determination of the likelihood of future events and the forecasting of future events based on probabilistic calculation (Sarin, 1978). For this reason, CIA is appropriate for the measurement of the market layer of a scenario-based roadmap. Market changes, with their unpredictable characteristics, are not to be decided, but to be predicted and evaluated. In particular, under the complex circumstances of multiple scenarios, CIA plays a key role in measuring the impact of several scenarios, assessing the occurrence probability of each event. Therefore, the use of CIA can contribute to the planning of the market layer of the TRM.

Second, the use of AHP fits the purpose of planning the technology and product layers. Following on market (or environmental) planning, firms now decide what products to develop and how to develop them (Phaal et al., 2004b). Therefore, this is a matter of multi-criteria decision making, in which AHP plays a key role. AHP has been actively employed for product selection or technology selection, considering firms' internal and external circumstances (Chen et al., 2006; Banuls and Salmeron, 2008). Considering many relevant decision criteria, AHP works as a prominent decision-making tool for developing product/technology layers of the TRM.

The remainder of this paper is organized as follows. Literature review deals with both the theoretical and methodological background of this paper. Proposed approach describes the concept of our approach. The structure and procedures are provided in detail. Illustrative examples are provided to illustrate the working of the proposed approach. A summary and the limitations of this study are given in the Conclusion.

2. Literature review

2.1. Scenario planning

The term 'scenario' originates from Kahn and Wiener (1967) introduction of 'future-now' thinking. Since then, scenario planning has been defined in several ways and many different definitions are suggested regarding scenario planning. Schwartz (1991) defined scenarios as "a tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out." Schoemaker (1995) offered the following definition of scenario planning: "A disciplined methodology for imagining possible futures in which organizational decisions may be played out." In general, scenarios are defined as hypothetical sequences of events, through which possible future developments are made visible (Gausemeier et al., 1998). Scenarios were used primarily by enterprises operating in unstable political and social environments and that took 'long-term views' as a basis for their planning (Gausemeier et al., 1998).

To conduct scenario planning, an important question arises: how we can develop a good scenario? Many studies have attempted to answer this question. Van der Heijden (1997) developed the six features of well-written scenarios. In terms of the comprehensive and fundamental view, Chermack (2005) provided a scenario-planning approach based on Dubin (1978)'s eight-step theory building. As quantitative approaches to the scenario planning, structural algorithms and mathematical modeling of operational research/management science (OR/MS) were applied to scenario planning by Amara and Lipinski (1983). The integrative approach of intuitive and quantitative techniques was also proposed by Millett and Randles (1986), creating procedural scenarios.

2.2. The use of the TRM for scenario planning

Among the many techniques for scenario-planning, the TRM has occupied the front seat. TRMs are prominent tools for the strategic planning of R&D activities (Kostoff and Schaller, 2001; Lee and Park, 2005; Lee et al., 2007; Phaal et al., 2004b; Phaal et al., 2006; Rinne, 2004). The use of a TRM was first introduced in Motorola in the 1980s and has since been extended to many industries. The main purpose of TRMs lies in the strategic planning for products or technologies, as well as in forecasting technological or market trends. TRMs helps organizations plan their technologies by describing a path to integrate a given technology into products and services (Caetano and Amaral, 2011). The TRM is composed of two-dimensional structures, making the horizontal axis the timeline and the vertical axis the layered structure of the market, product, technologies, and R&D, as shown in Fig. 1. It provides a graphical means for exploring and communicating relationships between markets, products, and technologies over time (McCarthy et al., 2001; Phaal et al., 2003; Lee and Park, 2005; Geum et al., 2011).

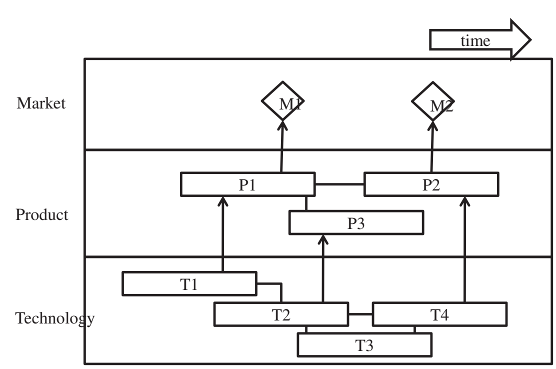

Fig. 1. Technology roadmap.

According to Phaal et al. (2004a), the top layer (usually the market layer) relates to the trends and drivers that govern the overall goals for the roadmapping, including external market and industry trends/drivers and internal business trends/drivers (Phaal et al., 2004a). Based on this external/internal trends and needs, the market layer is developed. The external trends in the market layer include social, technological, environmental, economic, political, and infrastructural issues which is closely associated with the forecasting issues. For this reason, the market layer is related to the question of "know-why." However, the middle and the bottom layer is related to the "know-what" and "know-how," which are the resources needed to respond to the trends and drivers, and the tangible systems that are developed to respond the trends and drivers, respectively (Phaal et al., 2004a).

The technology and product selection, which is conducted in the middle and bottom layer, is related to the multilevel decision-making, including the tactical level decision making and the strategic level decision making, considering the enterprise's long term goal and current location of market, product, and technology (Lee and Park, 2005; Shengbin et al., 2008). In terms of mapping objective, the product layer and technology layer are related to the strategic decision-making of products and technology (Lee and Park, 2005).

TRMs have been employed as a prominent tool for scenario-based planning. Strauss and Radnor (2004) introduced a scenario-based TRM that integrates the TRM and scenario planning, illustrating encompasses key tasks, their interdependency, and key decision points to the original TRM. Lizaso and Reger (2004) tried to link the TRM with scenario planning for strategic technology planning, including the identification, analysis, assessment and projection of technologies under different future circumstances.

Some researchers suggested an integrative way to the development of scenario-based roadmaps. In Gerdsri and Kocaoglu's (2003) work, a Delphi method and hierarchical decision model were employed to build a technology development envelope (TDE): a curve representing a series of technologies with maximum impact on a company's competitiveness over time (Gerdsri and Kocaoglu, 2003). The resulting TDE then works as a strategic input for the technology roadmapping process by enabling a multi-path roadmapping. Recently, some authors suggested a concept of 'risk-aware' roadmapping embedded with risk management procedures (Ilevbare et al., 2014). This risk-aware roadmapping highlights how to deal with uncertainty and risk, which are two important aspects of recent strategic planning.

Despite much literature, previous research commonly fails to differentiate the internal scenario and the external scenario, and reflect different types of scenario into the TRM. The TRM contains both the market layer which is a non-controllable external scenario and the product and technology layers which are controllable and decisive internal scenarios. Therefore, development of roadmaps should be differentiated according to the different characteristics in the TRM layers.

2.3. Cross-impact analysis

To evaluate market uncertainty of TRMs, CIA can play a key role, with its ability to measure interdependence of external events. CIA has been used as a practical methodology to forecast the emergence of new technologies and to identify the interrelations between technologies by defining the emergence of new technologies as event occurrences (Choi et al., 2007). The first approach to cross-impact analysis was conducted in the 1960s in response to a shortcoming in Delphi surveys (Weimer-Jehle, 2006). In the early stages of cross-impact analysis, the mutual influence existing between the technologies was not taken into account (Weimer-Jehle, 2006). This was extended by Gordon and Hayward, who introduced the idea that the occurrence of an event modifies the occurrence probability of other events, and that the impact of event x on the occurrence probability of event y was called 'cross-impact' (Gordon and Hayward, 1968). The first operational analyses using the cross-impact method were made in studies designed to forecast issues and opportunities for the State of Connecticut and to identify developments of importance to the future of education (Enzer, 1972). The five major steps employed to perform a general cross-impact analysis are as follows (Choi et al., 2007):

1. Define the events to be included in the analysis.
2. Estimate the initial probability of each event.
3. Estimate the conditional (or impacted) probabilities for each event pair.
4. Perform a calibration run of the cross-impact matrix.
5. Evaluate results.

The most important steps are the second and third: estimate initial and conditional probabilities, which are generally conducted by the subjective estimation by experts (Choi et al., 2007). It should be noted that the range of conditional probability should keep the following consistency (Gordon, 1994):

$$\frac{P(B)-1+P(A)}{P(A)} \le P(B|A) \le \frac{P(B)}{P(A)}.$$

2.4. Analytic hierarchy process

To guide the decision-making process of product/technology layers in TRMs, AHP fits the purpose. Since its invention by Saaty, AHP has been discussed as an important multi-criteria decision-making (MCDM) tool in almost all the applications related to decision making (Vaidya and Kumar, 2006). It has been employed in many different areas, such as selection, evaluation, benefit-cost analysis, allocation, planning and development, priority and ranking (Vaidya and Kumar, 2006).

Analytic hierarchy process decomposes a problem into several levels that make up a hierarchy in which each decision element is supposed to be independent (Lee et al., 2009a). The AHP differs from conventional decision analysis techniques by requiring that its numerical approach to priorities conform with scientific measurement (Saaty, 1990). A basic premise of the AHP is that much of what we consider to be 'knowledge' actually pertains to our instinctive sense of the way things really are. Therefore, Saaty suggested a three-part process that includes objectives, criteria, and alternatives within a hierarchy. The evaluation is conducted based on pairwise comparisons at each level of the hierarchy.

The AHP has gradually evolved through a number of applications as diverse as energy allocation, marketing decisions, project selection, technology selection, new product screening, and conflict resolution (Chen et al., 2006; Gerdsri and Kocaoglu, 2007b; Fenwick et al., 2009; Kim et al., 2009; Lee et al., 2011). In terms of strategic planning, AHP has been vigorously discussed with the combination of TRM (Gerdsri and Kocaoglu, 2007b). Gerdsri and Kocaoglu (2007a) proposed the concept of TDE which transformed technology roadmapping into a dynamic, flexible, and operationalizable approach, using AHP as a part of the TDE. Fenwick et al. (2009) suggested a value-driven technology roadmapping (VTRM) process which integrates decision making and marketing tools into the TRM. In particular, they integrated AHP into the roadmapping process, especially for impact ranking and gap analysis of products.

The AHP has been actively employed in many decision-making process in a firm. Chen et al. (2006) employed three criteria – organization & market, manufacturing capability, technology & engineering – and corresponding 10 sub-criteria for product-mix selection. Lee et al. (2011) employed a fuzzy AHP to prioritize the relative weights of hydrogen energy technologies to develop the energy technology roadmap (ETRM) under a finite R&D budget. Similarly, Kim et al. (2009) used AHP for prioritizing the technology fusion-based research programs to develop a TRM. The evaluation criteria are as follows: 1) possibility of creating a new market; 2) market needs; 3) policy fitness; 4) degree of goal achievement; and 5) size of future market (Kim et al., 2009). The analytic network process (ANP), a generalization of AHP, has also been discussed in much of the literature, especially for strategic decision-making problems (Lee et al., 2008; Lee et al., 2009b).

3. Proposed approach

3.1. Overall process

The tenet of this paper lies in employing CIA and AHP to support scenario-based roadmaps. When considering scenarios, two types of scenario might take place: an external scenario that deals with changes in external markets, and an internal scenario that is related to the firm's decision making (Gausemeier et al., 1998). According to the scenarios, the characteristics and usage of each layer in the TRM should be differentiated, as shown in Table 1, and Fig. 2. What CIA contributes to the scenario-based planning is the evaluation of external scenarios, i.e. the development of the market layer, whereas AHP contributes to the selection of internal scenarios, in which the decision-making process of a firm is covered, i.e. the development of technology and the product layers.

The proposed approach is mainly composed of three modules: scenario-level planning, external-level planning, and internal-level planning, as shown in Fig. 3. First, scenario-level planning looks at what scenarios we have to consider and how we build the scenarios. The second and third modules deal with actual planning processes. The external-level planning deals with market analysis, using cross-impact analysis as a supporting methodology. The third module is related to the internal-level planning, which considers the decision-making process of a firm under the market changes, using AHP. As a result, the TRM was developed, considering two types of scenarios and two corresponding methodologies.

3.2. Detailed procedures

3.2.1. Building scenarios

Scenario building is the first and foremost issue in the success of scenario planning. To gain acceptance for scenarios in a certain firm, managers should participate in the scenario-construction process and translate them to their own decision situations (Postma and Liebl, 2005).

Alcamo et al. (2008) suggested that the following four characteristics are required to improve the quality of a scenario: relevance, credibility, legitimacy, and creativity. Firstly, the scenario should be relevant to the particular needs of its audience and those of the potential user. The second criterion is credibility, which is connected to the 'valid and true' scenario. This is related to the consistency of the causal relationship with existing information, sound models, and acceptable scientific methods. Third is legitimacy, which is related to the scenario users' perceived fairness. The final factor to be considered for scenario quality is creativity, which is related to provoking new and creative thinking in the scenario (Alcamo et al., 2008).

Generally, in most business cases, the basic approach for considering various types of impact is the three-scenario approach: using a baseline scenario and two plausible extremes (Klein and Linneman, 1981; Schnaars, 1987). In many cases, these 'two plausible extremes' were optimistic scenarios and pessimistic scenarios, or three (neutral, optimistic, and pessimistic) scenarios were employed (Tenaglia and Noonan, 1992; Steenhof and Fulton, 2007).

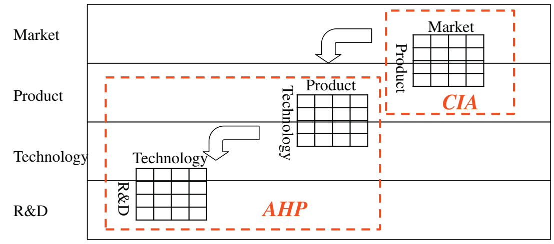

Fig. 2. Technology roadmapping using CIA and AHP.

3.2.2. Identifying possible events and possible development plans

The second step is to include the possible events which may happen in future scenarios. Key factors for scenario planning have been discussed such as social, economic, political, technological, and environmental. These factors may include demographic patterns, social and lifestyle factors, economic conditions, natural resources, ecosystems, political and regulatory forces, technological forces and international conditions (Huss and Honton, 1987).

3.2.3. Measuring the impact of external environment: CIA

The third step is to measure the impact of the external environment, in other words, the impact of the key factors identified in the previous step. To measure this impact, CIA, whose essence lies in the determination of the likelihood of events based on probabilistic calculation (Sarin, 1978; Weimer-Jehle, 2006), is employed to analyze the interrelations between events.

In CIA, five major steps exist to evaluate future situations (Choi et al., 2007). The first step is to define the events to be included in CIA, which has already been mentioned in the previous step, looking at social, economic, political, technological, and environmental factors. The second step is the estimation of the initial probability of each event, which is estimated based on expert judgment. The cross impact among different factors is then estimated. Based on this information, a calibration run of the cross-impact matrix is performed. Lastly, the final probability of each event and possible consistent scenarios are identified based on the Monte Carlo simulation, considering all permutations and combinations of occurrences and non-occurrences of events.

3.2.4. Developing a market layer for the technology roadmap

In this step, the market layer was developed, based on the result of CIA. Basically, the event with the highest impact should be included in the market layer of TRM. This means that this future event with a high impact and probability should be considered in the technology planning. In addition, related events should also be mapped in the TRM.

It should be noted that the market layer can be developed twofold. First, the market layer can be considered to be an object of planning. This means firms can select what market segment they should focus on. In this case, the market layer of the TRM should consist of the relevant market segment, and related business events should be included in the intermediate layers. Some research has noted that layers in TRMs can include other intermediate layers to focus on key enablers and barriers which are required for bridging the relevant layers (Phaal and Muller, 2009). Second, if one wants to consider a market layer as the changes of external markets, business events derived from the CIA are directly mapped in the TRM.

Table 1
Complementary roles of CIA and AHP in scenario planning.

Types of scenarios	Explanation	Characteristics	Related layer in TRM	Approach
External scenario	Changes in external (market) environment	A given problem (uncontrollable)	Market	CIA
Internal scenario	Strategic decisions of a firm	A decisive problem (controllable)	Technology, product, (service)	AHP

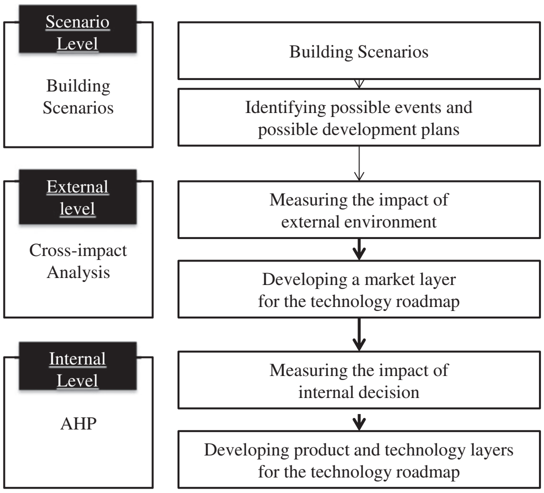

Fig. 3. Overall process of this paper.

3.2.5. Measuring the impact of internal decision: AHP

Following on the identification of market changes, internal decision making regarding product development and technology development should be conducted. For this purpose, AHP plays a key role in deciding what to develop. Another issue, when to develop, is also important, but this is generally decided based on experts' knowledge after the TRM workshops. To make internal decisions, four steps are needed, as listed below.

The first step is to create alternatives for the product, technology, and R&D, which is the most critical part of technology roadmapping. Making practical, realizable, but challenging alternatives determines the success and failure of technology planning. In this step, analysis grid is applied to identify relevant products or services for the target market. The analysis grid provides a means for relating the technology, product features and market/business drivers, connecting the various layers of the roadmap (Phaal et al., 2003). Product/technology alternatives derived from the analysis grid are then used for AHP evaluation.

The second step is to identify evaluation criteria for selecting the technology, product, and R&D. In order to conduct AHP, the most important factor is the identification of relevant decision criteria. For this purpose, we conducted a literature review on technology planning, strategic planning, and technology acquisitions. Taking into account Lee et al.'s (2008) work, frequently used criteria for internal decision making was summarized in Table 2. The main criteria, attractiveness and feasibility, have been considered being critical decision criteria (Lee et al., 2008; SQW/PREST, 1994; Tegart, 1997). For both of the two criteria, technological and market issues need to be considered as the sub-criteria. This is consistent with two important drivers of innovation, namely technology-push and market-pull in technology management, as noted in Lee et al. (2008). The decision criteria in Table 2 consider both the market-based view and resource-based view. The market-based view is reflected in the market attractiveness and market feasibility, whereas the resource-based view is reflected in the technological attractiveness and technological feasibility. In the technology attractiveness and feasibility criteria, several resource-based factors such as technological strength, difficulty of imitation, R&D capability, and R&D infrastructure are considered.

Some organizational factors are also considered. In previous research, a main difficulty in exploiting new technology is related to the lack of organizational capacity (Rosenbloom and Christensen, 1994), which means consideration of organizational factor is needed to the firms' decision making processes. Considering that AHP is conducted in the situation that a firm selects its product alternatives or technology alternatives, some organizational factors such as firm size, institutional leadership are not included as the decision criteria in AHP. However, important organizational factors related to the product or technology selection such as firms' financial condition, firms' physical resources are partially reflected in the current criteria, such as development cost, development time, commercialization capability, and commercialization cost.

Based on the decision criteria, the AHP model should be built. The AHP model is composed of a hierarchical structure, as shown in Fig. 4. Based on the pairwise comparison, product and technology alternatives should be selected.

3.2.6. Developing product and technology layers for the technology roadmap

After selecting the target products and technologies, these are transferred to the TRM development. The result of internal decision making should be reflected in the internal layers of the TRM, i.e. the product, technology, and R&D layers.

Table 2
Decision criteria for technology and product selection.

Criteria	Sub criteria	Factors	References
Attractiveness	Technological	Potentiality	Martin, 1993; Durand, 2003; Lee et al., 2008
		Technological strength	Lee et al., 2008; Shen et al., 2010
		Difficulty of imitation	Steensma and Corley, 2000; Lee et al., 2008
	Market	Market profitability	Tegart, 1997; Durand, 2003; Lee et al., 2008; Shen et al., 2010
		Market size	Cho and Yu, 2000; Lee et al., 2008; Shen et al., 2010
		Potential market growth	Lee et al., 2008
Feasibility	Technological	R&D capability	Martin, 1993; SQW/PREST, 1994; Tegart, 1997; Cho and Yu, 2000, Moenaert et al., 1990; Nelson, 1982; Pisano, 1990; Lee et al., 2008
		R&D infrastructure	Ford, 1988; Cho and Yu, 2000; Lee et al., 2008
		Development time	Lee et al., 2008
		Development cost	Martin, 1993; Chiesa, 2001; Cho and Yu, 2000; Tyler and Kevin Steensma, 1995; Croisier, 1998; Hamel et al., 1989; Dodgson, 1992; SQW/PREST, 1994
	Market	Commercialization capability	Cho and Yu, 2000; Hamel et al., 1989, Dodgson, 1992; Walker and Weber, 1987; Baughn and Osborn, 1990; Mahoney, 1992; Llerena and Wolff, 1994; Veugelers, 1997; Lee et al., 2008
		Time to market success	Lee et al., 2008
		Commercialization cost	Lee et al., 2008

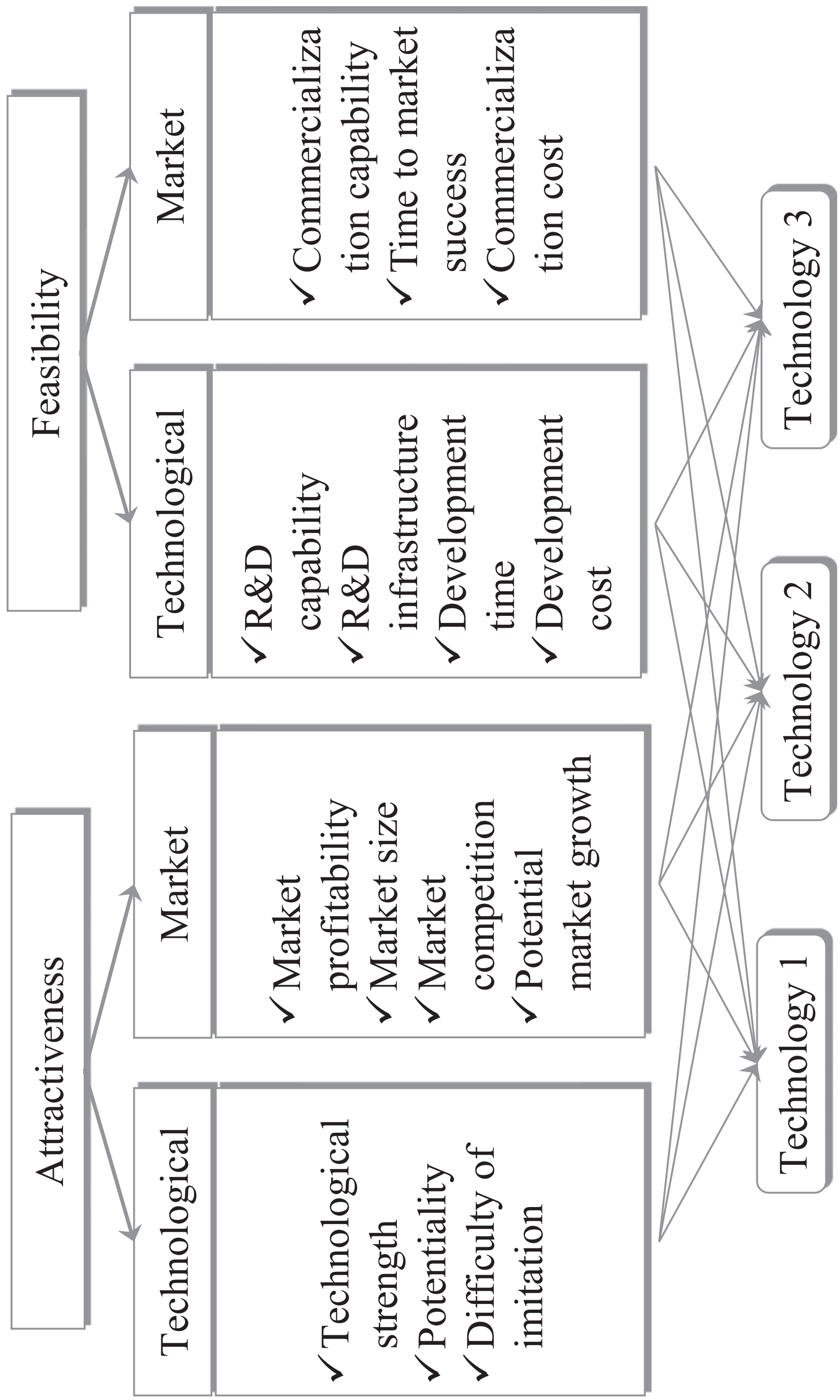

Fig. 4. AHP model for selecting products or technologies.

Table 3
Possible future events for external scenarios.

Event	Time	Name	Initial probability
A	+2 year	Policy for enhancing wearable computer	0.6
B	+1 year	Emergence of security issues	0.2
C	+3 year	Policy for supporting telemedicine	0.7
D	+5 year	Increase of a 'silver age' (10% baseline)	0.6
E	+3 year	Emergence of sustainability issue	0.4
F	+1 year	Increase of home-networking service	0.7
G	+3 year	Policy for enhancing context-aware services	0.7

4. Illustrative examples

4.1. Case overview

To illustrate the applicability of the proposed approach, illustrative examples are provided. We selected a u-healthcare service for mobile devices as a case study of scenario-based roadmapping. The u-healthcare service is a representative example of a business in which a lot of uncertainty exists. Despite the significant attention, practical utilization of u-healthcare has been limited, due to the lack of professional services and the resistance of medical personnel. As a result, u-healthcare services have been subjected to only peripheral services which are not significant. For this reason, both government and private firms have attempted to promote u-healthcare services using various scenarios. These scenarios include many different aspects, such as the emergence of a smart service system, behavioral changes of customers, and changes of policy. In this study, we assume that a firm wants to launch a new u-healthcare service based on mobile devices, creating a new development portfolio for u-healthcare services.

4.2. Case illustration

4.2.1. Identifying possible events: expert panel evaluation

First of all, what we have to do is to identify possible events for the future, together with drivers and barriers. For this purpose, events for external scenarios are identified based on both the literature review and practical interview. To identify the events and their possibility, we employed three experts with at least 5-years of experience in the healthcare services. These experts have a great insight for u-healthcare services, thus can provide a great help to identify possible events for the u-healthcare and their probabilities. Based on the expert judgment, possible scenarios and their probabilities are identified, as shown in Table 3.

4.2.2. Measuring the impact of external environment: CIA

For identified events, cross-impact analysis is conducted. First, the initial probability of each external event is identified based on expert judgment. Since this process is very qualitative and expert-based, in-depth investigation is required. Second, a cross-impact matrix is developed, considering the impact of each scenario element on the other scenario element. Experts are required to evaluate the cross-impact between two events. In this analysis, judgment is made in a qualitative scale as follows:

- -3: strongly restricting influence
- -2: moderately restricting influence
- -1: weakly restricting influence
- 0: no influence
- +1: weakly promoting influence
- +2: moderately promoting influence
- +3: strongly promoting influence.

Based on judgment of five experts, Table 4 shows the result of evaluated cross-impact matrix.

Once this cross-impact matrix has been estimated, the next step is to run the calibration run of this matrix, calculating the impacts on all other events due to occurrence and non-occurrence (Gordon, 1994). For this purpose, we used a freeware, ScenarioWizard, which is available as a free download at http://www.cross-impact.de/english/CIB_e_ScW.htm (Weimer-Jehle, 2006). In this analysis, impacts on other events are calculated, and scenarios with consistency are generated, using the cross-impact balance (CIB) analysis, proposed by Weimer-Jehle (2006).

How the scenarios are selected and evaluated is explained as follows. Summing up the highlighted rows summarizes the influences impacting the scenario descriptors. The scores of the impact balances which correspond to the given scenario are calculated as the final balance. The total impact score is calculated as the sum of the impact scores of all selected states of this scenario (Weimer-Jehle, 2006).

Suppose that we select scenario A1-B2-C1-D1-E1-F1-G1, we extract the rows explaining A1, B2, C1, D1, E1, F1, and G1 from Table 4. Table 5 shows the calculation process of cross impact of scenario A1-B2-C1-D1-E1-F1-G1. The balance of descriptor A is calculated as 6 for A1 and 0 for A2, thus, A1 is selected (the cross impact is 6). With the similar processes, the total impact balance for other descriptors are also calculated, as shown in table 5 (B2 = 0, C1 = 9, D1 = 2, E1 = 6, F1 = 13, and G1 = 17) and the sum of the impact scores for the selected states

Table 4
Cross-impact matrix.

Event		Cross-impact													
		A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
A	A1. Happen	–		0	0	3	0	0	0	1	0	5	−1	5	−3
	A2. Not happen			0	0	−1	0	0	0	0	0	−1	0	−3	0
B	B1. Happen	0	0	–		−1	0	0	0	−1	0	−1	0	−1	0
	B2. Not happen	0	0			0	0	0	0	0	0	0	0	0	0
C	C1. Happen	1	0	0	0	–		2	−1	1	0	3	−1	3	−1
	C2. Not happen	0	0	0	0			0	0	0	0	−1	0	0	0
D	D1. Happen	0	0	0	0	1	0	–		3	0	1	0	1	0
	D2. Not happen	0	0	0	0	−1	0			−1	0	0	0	0	0
E	E1. Happen	0	0	0	0	0	0	0	0	–		1	0	3	−1
	E2. Not happen	0	0	0	0	0	0	0	0			0	0	0	0
F	F1. Happen	2	0	0	0	2	−1	0	0	1	0	–		5	3
	F2. Not happen	−1	0	0	0	0	0	0	0	0	0			0	0
G	G1. Happen	3	0	0	0	3	0	0	0	0	0	3	−1	–	
	G2. Not happen	−3	0	0	0	−1	0	0	0	0	0	0	0		

Table 5
Example of the cross balance scores for the selected scenario A1-B2-C1-D1-E1-F1-G1.

Event		Cross-impact													
		A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
A	A1. Happen	–		0	0	3	0	0	0	1	0	5	−1	5	−3
B	B2. Not happen	0	0			0	0	0	0	0	0	0	0	0	0
C	C1. Happen	1	0	0	0	–		2	−1	1	0	3	−1	3	−1
D	D1. Happen	0	0	0	0	1	0	–		3	0	1	0	1	0
E	E1. Happen	0	0	0	0	0	0	0	0	–		1	0	3	−1
F	F1. Happen	2	0	0	0	2	−1	0	0	1	0	–		5	3
G	G1. Happen	3	0	0	0	3	0	0	0	0	0	3	−1	–	
	Sum	6	0	0	0	9	−1	2	−1	6	0	13	−3	17	−2
	Select	V			V	V		V		V		V		V	

(A1, B2, C1, D1, E1, F1, G1) is calculated as 53, which is $6 + 0 + 9 + 2 + 6 + 13 + 17$).

As a result, 14 scenarios are generated using the weak consistency option, whereas four scenarios are generated using the strong consistency option. The final results, four strong consistent scenarios, are summarized in Table 6.

4.2.3. Developing a market layer for the technology roadmap

Considering the consistency value and impact score in Table 6, we choose the second scenario. Therefore, we choose the scenario element as A (policy for enhancing wearable computer), C (policy for supporting telemedicine), D (increase of a 'silver age'), E (emergence of sustainability issue), F (increase of home-networking service), and G (policy for enhancing context-aware services). Based on this scenario, the market layer of the TRM is developed, as shown in Fig. 5.

4.2.4. Measuring the impact of internal decision: AHP

Following on the development of a market layer, internal scenarios should be developed and selected under six external events: a policy for enhancing wearable computer; a policy for supporting telemedicine; an increase of a 'silver age' (10% baseline); an emergence of sustainability issue; an increase of home-networking service; and a policy for enhancing context-aware services. For this purpose, what first has to be done is to list the product alternatives, service alternatives, and technology alternatives. The term, 'internal scenario', refers to the decision making among various alternatives within a firm.

When the market factors are decided based on CIA simulation, product and service alternatives should be selected. The selection process is conducted via a two-step process. The first step is to apply linking grid to identify relevant products or services for the target market. After the screening process, AHP evaluation is conducted to identify the most relevant products or services considering the firms' condition.

Firstly, we suggested possible product and service elements. For the service elements, several alternatives are suggested, such as pulse information monitoring, disease prediction, data processing, TV doctoring service, exercise management, sleeping management, personal identification, location-based health-care service, and a home monitoring system, and so on. For example, a home monitoring system extends the application areas of u-healthcare into the home environment, integrating monitoring devices and sensors, as well as integrating home automation devices in the system (Caytiles and Park, 2012). Location-based health-care services offer a delivery of timely information according to the users' location, finding the most accessible hospitals or clinics based on their location or individual health conditions (Caytiles and Park, 2012). Product alternatives includes various product elements such as vital sign sensors to check heart rate, blood pressure, the heart's rhythmic regularity, respiratory rate, oxygen saturation and body temperature (Park and Lee, 2009). Also, sensor mobility, web service, network optimization, biometrics, error perception are also considered as product alternatives. Since the purpose of roadmapping is to develop a mobile-based u-healthcare, smartphone is also included as a product alternative.

Secondly, in order to identify possible alternatives which are related to the market scenario factors, this study employs the linking grid (analysis grid) to identify and assess relationships between various layers of technology roadmaps, as shown in Fig. 6. Twelve alternatives for product elements and service elements are evaluated for the relationships with market scenario factors, as shown in Fig. 6.

Table 6
Four possible consistent scenarios.

Type	Scenario factors	Results
Scenario 1 (consistency value: 3 total impact score: 49)	A. Policy for enhancing wearable computer	Happen
	B. Emergence of security issues	Happen
	C. Policy for supporting telemedicine	Happen
	D. Increase of a 'silver age' (10% baseline)	Happen
	E. Emergence of sustainability issue	Happen
	F. Increase of home-networking service	Happen
	G. Policy for enhancing context-aware services	Happen
Scenario 2 (consistency value: 3 total impact score: 53)	A. Policy for enhancing wearable computer	Happen
	B. Emergence of security issues	Not happen
	C. Policy for supporting telemedicine	Happen
	D. Increase of a 'silver age' (10% baseline)	Happen
	E. Emergence of sustainability issue	Happen
	F. Increase of home-networking service	Happen
	G. Policy for enhancing context-aware services	Happen
Scenario 3 (consistency value: 0 total impact score: 0)	A. Policy for enhancing wearable computer	Not happen
	B. Emergence of security issues	Happen
	C. Policy for supporting telemedicine	Not happen
	D. Increase of a 'silver age' (10% baseline)	Not happen
	E. Emergence of sustainability issue	Not happen
	F. Increase of home-networking service	Not happen
	G. Policy for enhancing context-aware services	Not happen
Scenario 4 (consistency value: 0 total impact score: 0)	A. Policy for enhancing wearable computer	Not happen
	B. Emergence of security issues	Not happen
	C. Policy for supporting telemedicine	Not happen
	D. Increase of a 'silver age' (10% baseline)	Not happen
	E. Emergence of sustainability issue	Not happen
	F. Increase of home-networking service	Not happen
	G. Policy for enhancing context-aware services	Not happen

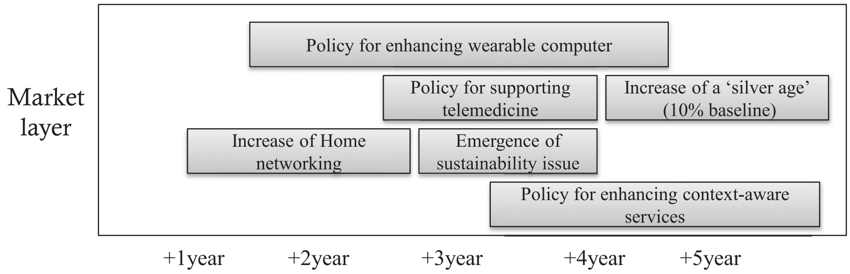

Fig. 5. Market layer of TRM.

Table 7 shows the service and product alternative which are derived from the analysis linking grid in Fig. 6.

Finally, AHP evaluation is conducted for the selected product/service alternatives in Table 7. To conduct AHP evaluation, we employed five experts with at least 5-years of experience in the new product development (NPD). Note that these experts are different from those employed for the scenario building process of healthcare services. Each expert is required to evaluate the relative importance of each decision criterion using pairwise comparisons. For the pairwise comparison, the relative importance values are determined with a scale of 1–9, where a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared to the other one (Lee et al., 2009b). The number in this matrix shows the intensity of dominance of the criterion in the column over the criterion in the row (Saaty, 1990). Final priorities are the components of the eigenvector of the matrix (Saaty, 1990). The evaluation criteria based on the literature review (as shown in Table 2) are employed as evaluation criteria in AHP. To avoid inconsistency in the evaluation process, AHP evaluation for each expert was repeated until a pairwise comparison matrix with CR ≤ 0.1 has been achieved.

In aggregating the group opinions, two methods can be employed in AHP. In the first method, the geometric means of individual evaluations are employed as elements in pairwise comparison matrices and then priorities are computed, whereas in the second methods, priorities are computed and then combined using a weighted arithmetic mean (Forman and Peniwati, 1998; Ramanathan and Ganesh, 1994). We used the first method – the use of geometric means of individual experts as the element of pairwise comparison matrices. Expert choice 11.5 was used in the pairwise process of AHP. Using pairwise comparison for decision criteria, the relative importance of each criterion is calculated, as shown in Table 8. Pairwise comparison is generally conducted for product/service alternatives which are required at the same time. However, firms sometimes have to select product or service alternatives due to the limited resources. Therefore, we conducted pairwise comparison for all product/service alternatives whose time to market is different. Table 9 shows a partial process of the AHP, comparing the relative importance of product elements with respect to R&D capability criteria. Based on these criteria, preference scores of service alternatives and product alternatives are calculated, as listed in Table 10 and Table 11, respectively.

Table 10 and Table 11 represent the relative importance and corresponding priority derived from the AHP evaluation. Among these alternative, several alternatives are selected to be developed, considering limited resources and corporate circumstances. This case study selected four elements among six. It should be noted that priority is not synchronized with timeline. The evaluation criteria in AHP consider both the

Product alternatives \ Market scenarios	Policy for enhancing wearable computer	Policy for supporting telemedicine	Increase of a ‘silver age’	Emergence of sustainability issue	Increase of home-networking service	Policy for enhancing context-aware services
Vital sign sensor	●					
Weight of wearing	○	○				
Sensor mobility	●				○	○
Barcode encoding						
Error perception						
Web server		○		△		
Network optimization					●	○
Sphygmomanometer	●					
Process optimization						
Biometrics/ Iris scan		△				
Smartphone	△	△				○
RFID/USN						

(a) Analysis grid for selecting product alternatives

Service alternatives \ Market scenarios	Policy for enhancing wearable computer	Policy for supporting telemedicine	Increase of a ‘silver age’	Emergence of sustainability issue	Increase of home-networking service	Policy for enhancing context-aware services
Pulse information monitoring	●				●	●
Disease prediction	○	○				
Data processing	△					
TV doctoring service		△				
Healthy food delivery						
Exercise management		○				○
Personal identification	○	○			○	○
Home Monitoring System	○				○	
Sleeping management						
Medical fitness service	△		△			
Emergency care	○		●			
Location based services					○	●

(b) Analysis grid for selecting service alternatives

Fig. 6. Analysis grid for selecting alternatives.

Table 7
Alternatives for internal scenarios.

Time	Service alternatives	Time	Product alternatives
+2 year	Pulse information monitoring (PM)	+2 year	Vital sign sensor (VS)
+4 year	Disease prediction (DP)	+3 year	Weight of wearing (WW)
+1 year	Emergency care (EC)	+4 year	Sensor mobility (SM)
+2 year	Sleeping management (SM)	+1 year	Web server (WS)
+2 year	Personal identification (PI)	+2 year	Network optimization
+4 year	Location based healthcare services (LH)	+4 year	smart phone (SP)
+3 year	Home monitoring system (HM)		

importance and urgency of alternatives, since the main criteria includes attractive and feasibility of each product and service element. This means the service alternative derived as the 1st priority alternative, disease prediction, does not mean that this is the urgent one (which should be developed in the next year), but is the most important alternative that should be developed. The service element 'disease prediction' will be developed after four years when related technologies and product elements are prepared. In summary, the priority in AHP evaluation is not synchronized with the timeline, but is a result of complex evaluation considering importance, urgency, capability, development time, development cost, infrastructure, and market profitability. The selected elements are then mapped in the TRM, considering its expected timeline.

4.3. Development of TRMs

According to the results of the CIA and AHP, we select relevant events for the external environment and the preferred product alternatives and service alternatives for technology roadmapping. First, six scenario elements are identified as being valid for the development of the market layer, considering the cross-impact of each event. Second, product and service alternatives should be selected based on the project budget and corporate strategy. In this case study, pulse information monitoring, disease prediction, personal identification, and location-based healthcare services are selected as service alternatives, whereas vital signs sensor, sensor mobility, network optimization, and smartphone are selected as product alternatives, assuming that there is only a limited budget enabling the selection of only four products and services. The selected elements can then be employed as inputs for technology roadmappingd, as shown in Fig. 7. The horizontal axis represents the timing of development, whereas the vertical axis represents each layer. Since different market scenarios exist, several products or services are required for the same period. In this case, these product/service alternatives are targeted at the same period. For example, The service 'personal identification' is required for the scenario element 'policy for enhancing wearable computer', whereas the service 'pulse information monitoring' is required for the scenario element 'increase of a silver age'.

Table 8
Relative importance of each decision criteria.

Criteria	Sub criteria	Factors
Attractiveness (0.5)	Technological (0.25)	Potentiality (0.457)
		Difficulty of imitation (0.543)
	Market (0.75)	Market profitability (0.637)
		Market size (0.105)
		Potential market growth (0.258)
Feasibility (0.5)	Technological (0.75)	R&D capability (0.578)
		R&D infrastructure (0.116)
		Development time (0.072)
		Development cost (0.234)
	Market (0.25)	Commercialization capability (0.701)
		Time to market success (0.097)
		Commercialization cost (0.202)

Table 9
Result of pairwise comparison with respect to R&D capability.

	VS	WW	SM	WS	RU	SP
VS	–	1/3	3	2	1/3	1/5
WW	3	–	3	3	1	1/3
SM	1/3	1/3	–	1	1/3	1/3
WS	1/2	1/3	1	–	1/3	1/5
RU	3	1	3	3	–	1/3
SP	5	3	3	5	3	–

5. Discussion

5.1. Results of case study

The selected market elements are policy for enhancing wearable computer, policy for supporting telemedicine, increase of a silver age, increase of home networking, emergence of sustainability issue, and policy for enhancing context-aware services. According to the market trends, we define what kinds of services we should develop. Relevant methodologies can vary such as linking grid, quality function deployment (QFD), and AHP, but what we employed is AHP to reflect various characteristics of decision making environment.

When policy for enhancing the wearable computer is established, prominent services to utilize the wearable computer such as pulse information monitoring services can be developed within next two years, with related services including personal identification. To enhance these services, product elements such as vital sign sensor and network optimization technologies should be equipped with. The market element – increase of silver age – also affects the development of disease prediction services as well as corresponding vital sign sensors and complex sensor-equipped smartphone.

Currently, as shown in Fig. 6, product planning and service planning currently ignores two market elements: increase of home networking trends and emergence of sustainability issue. Therefore, how to cope with these two market elements is another important decision making. It should be noted that this is not mandatory, since whether a firm prevent all kinds of unexpected things or not is simply a matter of decision, if a firm does not possess enough resources and capabilities.

5.2. Varying degrees in technology roadmapping

There is also varying degrees in the internal decision making process. From the macro perspective, the decision on products or services can be conducted. In this case, firms have to decide what kinds of products or services to develop. From the micro perspective, firms also have to decide the detailed specification of products, including quality specification, technology level, and size specification. In case of the service layer, what firms have to decide is the decisions such as operational-level service specification, organizational requirements to develop certain services, or prerequisites of services.

5.3. Combination with other methods

Even if CIA and AHP fit the purpose of layer heterogeneity in developing TRMs, other methods can be applied in combination with CIA and

Table 10
Preferences of service alternatives.

Service alternatives	Preference	Priority
Pulse information monitoring	0.206	2
Disease prediction	0.344	1
Data processing	0.063	7
Emergency care	0.049	6
Personal identification	0.123	3
Location based healthcare services	0.121	4
Home monitoring system	0.094	5

Table 11
Preferences of product alternatives.

Product alternatives	Preference	Priority
Vital sign sensor	0.256	2
Sensor mobility	0.372	1
Web server	0.047	5
Sphygmomanometer	0.045	6
Network optimization	0.168	3
Smart phone	0.111	4

AHP. First, for the external environment analysis, STEEPI (Social, Technological, Economic, Environmental, Political, Infrastructural Trends & Drivers) analysis, SWOT (Strengths, Weaknesses, Opportunities, Threats), and Michael Porter's five force analysis can be applied for planning the market layer (Phaal et al., 2005) The results of both STEEPI and five force analysis can provide the input variables for the CIA simulation. In addition, the SWOT analysis can provide the basic strategies prior to develop the internal decision making. In other words, the result of SWOT analysis helps to evaluate the decision criteria of AHP.

For the internal decision making in the product layer or service layer, decision making tools such as AHP, analytic hierarchy process (ANP), and scoring methods can be employed. Since the decision making in the product layer and service layer includes the assessment of relationships between product elements and technology elements, relationship-based evaluation methods such as linking grids, quality function deployment (QFD) can be employed (Phaal et al., 2005). Also, some matrix-liked structures such as design structure matrix (DSM) can be employed.

6. Conclusion

One of the most important issues in today's business is, inevitably, the use of scenarios. The fierce and dynamic environment makes firms more competitive, thus they are striving to deal with this uncertainty. As a remedy, scenario planning comes to the forefront. Therefore, the TRM, a prominent strategic planning tool, has vigorously employed the concept of scenarios. However, previous research on scenario-based technology roadmapping has neglected the issue of layer heterogeneity. To reflect this layer heterogeneity, this paper employs an approach of CIA and AHP as a tool for scenario-based roadmapping.

From the theoretical perspective, this paper is the first attempt to differentiate the planning characteristics of each layer, considering the layer heterogeneity in terms of scenario planning. The market layer is related to the changes in customer needs, environmental changes, and policy changes, i.e. external scenarios, whereas the product/technology layer is associated with the selection of a firm's strategy, i.e. internal scenarios. To differentiate the planning characteristics of each layer in TRM, this study employs CIA and AHP for the effective roadmapping procedures: CIA for the market layer, and AHP for the product and technology layers.

From the methodological perspective, this paper indicates how CIA and AHP can be employed for each layer of the TRM. First, CIA is highlighted in the technology roadmapping as an effective method for forecasting future scenarios in terms of external markets. Compared to the TRM without CIA integration, our approach can effectively consider the cross-impact of various scenario factors, including many social, economic, political, technological, and environmental issues. Considering the cross-impact is very important, since scenario factors generally reflect the business and market trends for the future, thus are generally interrelated one another. With the help of CIA, the cross-impact among scenario factors are effectively measured and used for selecting the most appropriate scenarios. Considering consistency value and impact score of CIA results, firms can select the most appropriate scenarios with high feasibility and high impact. These selected scenarios can be directly reflected to the market layer of TRM. Second, the use of AHP can help firm-specific decision making by considering internal scenario factors. Compared to the analysis linking grid, AHP can reflect various firm-specific decision making criteria such as R&D capability, R&D infrastructure, and commercialization capability. Even if linking grid is powerful to measure the relationship among market, product, and technology elements, it is hard to capture the practical consideration of firms. Since product planning and technology planning in TRM is closely related to the firms' internal situation such as strategic direction, budgeting problems, and resource allocation problems, AHP is suitable for developing the product and technology layers of TRM by reflecting various firms' internal conditions.

Despite the contribution, however, this paper is subject to some limitations. First, this paper employs different methodologies suitable for each layer, taking into account layer heterogeneity. However, the use of a simulation tool can also solve this problem by analyzing external market changes and internal decision making simultaneously. However, since a software-based approach is sometimes too sensitive for the initial setting, and it is hard to find the clear relationships between events. Therefore, it is important to leverage advantages and disadvantages of each method and make a decision using relevant methods. Second, when the number of alternatives or decision criteria increases, the number of required pairwise comparison significantly increases. This makes decision-making a significant problem for evaluators. Third, in a case

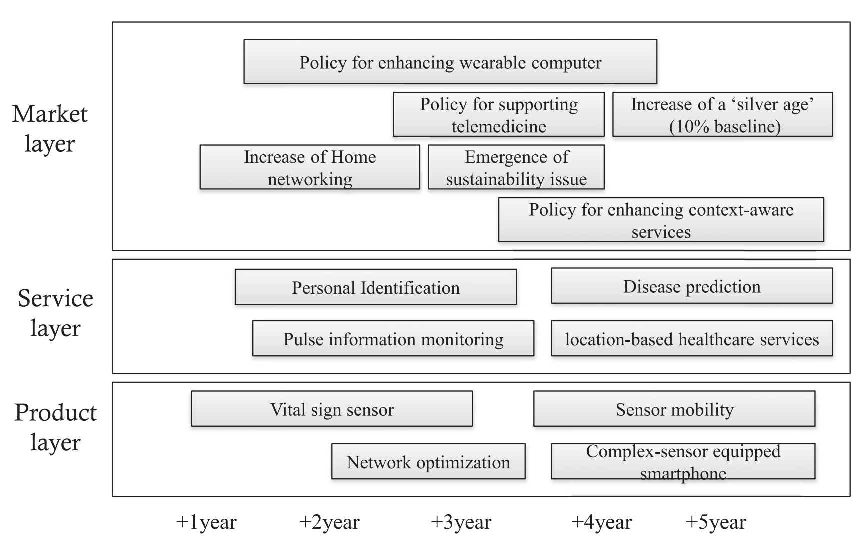

Fig. 7. The final TRM.

study, we considered four different events in terms of occurrence/non-occurrence. These events (future scenarios) could be considered in a more detailed way to enhance the accuracy of scenario planning. For example, we considered the scenario event 'increase of a "silver age" (10% baseline).' This event occurs when the increase of a silver age is more than 10% and does not occur when the rate is below 10%. However, this rate could be categorized as more detailed criteria, such as <5%, 5– 10%, 10– 20%, and >20%. This detailed description of external scenarios makes the analysis more profound. Finally, even though an illustrative case study was provided, the analysis of other practical cases, which are highly affected by government policy and environmental conditions, would benefit from the suggested methods.

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References

Alcamo, J., Kok, K., Busch, G., Priess, J., 2008. Chapter Four Searching for the Future of Land: Scenarios From the Local to Global Scale. Developments in Integrated Environmental Assessment. 2 pp. 67–103.

Amara, R., Lipinski, A.J., 1983. Business Planning for an Uncertain Future: Scenarios and Strategies. Pergamon, New York.

An, Y., Lee, S., Park, Y., 2008. Development of an integrated product-service roadmap with QFD: a case study on mobile communications. Int. J. Serv. Ind. Manag. 19 (5), 621–638.

Banuls, V.V., Salmeron, J.A., 2008. Foresighting key areas in the information technology industry. Technovation 28, 103–111.

Baughn, C.C., Osborn, R.N., 1990. The role of technology in the formation and form of multinational cooperative arrangements. J. High Technol. Managem. Res. 1 (2), 181–192.

Caetano, M., Amaral, D.C., 2011. Roadmapping for technology push and partnership: a contribution for open innovation environments. Technovation 31, 320–335.

Caytiles, R.D., Park, S., 2012. u-Healthcare: the next healthcare service paradigm. Int. J. Bio-Sci. Bio-Technol. 4 (2), 77–82.

Chen, H.H., Lee, A.H.I., Tong, Y., 2006. Analysis of new product mix selection at TFT-LCD technological conglomerate network under uncertainty. Technovation 26, 1210–1221.

Chermack, T.J., 2004. Improving decision-making with scenario planning. Futures 36 (3), 295–309.

Chermack, T.J., 2005. Studying scenario planning: theory, research suggestions, and hypotheses. Technol. Forecast. Soc. Chang. 72 (1), 59–73.

Chiesa, V., 2001. R R&D Strategy and Organization: Managing Technical Change in Dynamic Contexts. Imperial College Press, London.

Cho, D.H., Yu, P.I., 2000. Influential factors in the choice of technology acquisition mode: an empirical analysis of small and medium size firms in the Korean telecommunication industry. Technovation 20 (12), 691–704.

Choi, C., Kim, S., Park, Y., 2007. A patent-based cross impact analysis for quantitative estimation of technological impact: the case of information and communication technology. Technol. Forecast. Soc. Chang. 74 (8), 1296–1314.

Croisier, B., 1998. The governance of external research: empirical test of some transaction-cost related factors. R&D Manag. 28 (4), 289–298.

Dodgson, M., 1992. The strategic management of R&D collaboration. Tech. Anal. Strat. Manag. 4 (3), 227–244.

Dubin, R., 1978. Theory Building. Macmillan, New York.

Durand, T., 2003. Twelve lessons from Key Technologies 2005: the French technology foresight exercise. J. Forecast. 22 (2–3), 161–177.

Enzer, S., 1972. Cross-impact techniques in technology assessment. Futures 4 (1), 30–51.

Fenwick, D., Daim, T.U., Gerdsri, N., 2009. Value driven technology road mapping (VTRM) process integrating decision making and marketing tools: case of internet security technologies. Technol. Forecast. Soc. Chang. 76 (8), 1055–1077.

Ford, D., 1988. Develop your technology strategy. Long Range Plan. 21 (5), 85–95.

Forman, E., Peniwati, K., 1998. Aggregating individual judgments and priorities with the analytic hierarchy process. Eur. J. Oper. Res. 108 (1), 165–169.

Gausemeier, J., Fink, A., Schlake, O., 1998. Scenario management: an approach to develop future potentials. Technol. Forecast. Soc. Chang. 59 (2), 111–130.

Gerdsri, N., Kocaoglu, D.F., 2003, July. An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies: a case study of emerging electronic cooling technologies for computer servers. Management of Engineering and Technology, 2003. PICMET'03. Technology Management for Reshaping the WorldPortland International Conference on. IEEE, pp. 380–389.

Gerdsri, N., Kocaoglu, D.F., 2007a. Applying the analytic hierarchy process (AHP) to build a strategic framework for technology roadmapping. Math. Comput. Model. 46 (7), 1071–1080.

Gerdsri, N., Kocaoglu, D.F., 2007b. Applying the analytic hierarchy process (AHP) to build a strategic framework for technology roadmapping. Math. Comput. Model. 46 (7), 1071–1080.

Geum, Y., Lee, S., Kang, D., Park, Y., 2011. Technology roadmapping for technology-based product–service integration: a case study. J. Eng. Technol. Manag. 28 (3), 128–146.

Godet, M., 1987. Scenarios and Strategic Management (p. 210). Butterworths, London.

Gordon, T.J., 1994. Cross-Impact Method. United Nations University.(Part of Glenn 1994a), Washington, DC.

Gordon, T.J., Hayward, H., 1968. Initial experiments with the cross impact matrix method of forecasting. Futures 1 (2), 100–116.

Hamel, G., Doz, Y.L., Prahalad, C.K., 1989. Collaborate with your competitors and win. Harv. Bus. Rev. 67 (1), 133–139.

He, C., Shi, P., Chen, J., Li, X., Pan, Y., Li, J., ... Li, J., 2005. Developing land use scenario dynamics model by the integration of system dynamics model and cellular automata model. Sci. China Ser. D Earth Sci. 48 (11), 1979–1989.

Huss, W.R., Honton, E.J., 1987. Scenario planning—what style should you use? Long Range Plan. 20 (4), 21–29.

Ibarra, C.J., Ogliari, A., Back, N., 2008. Systematization of technology roadmapping. Product Management & Development 6 (2), 1–21.

Ibarra, G.C.J., Ogliari, A., Albertazzi, A., 2014. Application of technology roadmapping to the planning of new measurement systems. Engineering, Technology and Innovation (ICE)2014 International ICE Conference on. IEEE, pp. 1–11.

Ilevbare, I.M., Probert, D., Phaal, R., 2014. Towards risk-aware roadmapping: influencing factors and practical measures. Technovation http://dx.doi.org/10.1016/j.technovation.2014.05.006i.

Jin, G., Jeong, Y., Yoon, B., 2015. Technology-driven roadmaps for identifying new product/market opportunities: use of text mining and quality function deployment. Adv. Eng. Inform. 29 (1), 126–138.

Kahn, H., Wiener, A., 1967. The year 2000: a framework for speculation on the next thirty-three years. Macmillan, New York.

Kim, C., Kim, H., Han, S.H., Kim, C., Kim, M.K., Park, S.H., 2009. Developing a technology roadmap for construction R&D through interdisciplinary research efforts. Autom. Constr. 18 (3), 330–337.

Klein, H.E., Linneman, R.E., 1981. The use of scenarios in corporate planning—eight case histories. Long Range Plan. 14 (5), 69–77.

Kostoff, R.N., Schaller, R.R., 2001. Science and technology roadmaps. Eng. Manag. 48 (2), 132–143 (IEEE Transactions on).

Lee, S., Park, Y., 2005. Customization of technology roadmaps according to roadmapping purposes: overall process and detailed modules. Technol. Forecast. Soc. Chang. 72 (5), 567–583.

Lee, S., Kang, S., Park, Y., Park, Y., 2007. Technology roadmapping for R&D planning: the case of the Korean parts and materials industry. Technovation 27 (8), 433–445.

Lee, H., Lee, C., Seol, H., Park, Y., 2008. On the R&D priority setting in technology foresight: a DEA and ANP approach. Int. J. Innov. Technol. Manag. 5 (02), 201–219.

Lee, H., Lee, S., Park, Y., 2009a. Selection of technology acquisition mode using the analytic network process. Math. Comput. Model. 49 (5), 1274–1282.

Lee, H., Kim, C., Cho, H., Park, Y., 2009b. An ANP-based technology network for identification of core technologies: Aa case of telecommunication technologiesExpert Systems with ApplicationsExpert Syst. Appl. 36 (1), 894–908.

Lee, C., Song, B., Cho, Y., Park, Y., 2010. A Bayesian belief network approach to operationalization of multi-scenario technology roadmap. Technology Management for Global Economic Growth (PICMET)2010 Proceedings of PICMET'10. IEEE, pp. 1–6.

Lee, S., Mogi, G., Lee, S., Kim, J., 2011. Prioritizing the weights of hydrogen energy technologies in the sector of the hydrogen economy by using a fuzzy AHP approach. Int. J. Hydrog. Energy 36 (2), 1897–1902.

Lizaso, F., Reger, G., 2004. Linking roadmapping and scenarios as an approach for strategic technology planning. Int. J. Technol. Intell. Plan. 1 (1), 68–86.

Llerena, P., Wolff, S., 1994. Inter-firm agreements in telecommunications: elements of an analytical framework. Papers Presented to the Ninth International Telecommunications Society (ITS) on Global Telecommunications Strategies and Technological Changes. Elsevier Science Publishers BV, pp. 257–275.

Mahoney, J.T., 1992. The choice of organizational form: vertical financial ownership versus other methods of vertical integration. Strateg. Manag. J. 13 (8), 559–584.

Martin, B., 1993. Research Foresight and the Exploitation of the Science Base. HM Stationery Office.

Martin, H., Daim, T.U., 2012. Technology roadmap development process (TRDP) for the service sector: a conceptual framework. Technol. Soc. 34 (1), 94–105.

McCarthy, J.J., Haley, D.J., Dixon, B.W., 2001. Science and technology roadmapping to support project planning. Management of Engineering and Technology, 2001. PICMET'01Portland International Conference on. IEEE, pp. 637–649.

Millett, S., Randles, F., 1986. Scenarios for strategic business planning: a case history for aerospace and defense companies. Interfaces 16, 64–72.

Moenaert, R.K., Deschoolmeester, D., De Meyer, A., Barbé, J., 1990. Organizational strategy and resource allocation for technological turnaround. R&D Manag. 20 (4), 291–303.

Nelson, R.R., 1982. An Evolutionary Theory of Economic Change. Harvard University Press.

Pagani, M., 2009. Roadmapping 3G mobile TV: strategic thinking and scenario planning through repeated cross-impact handling. Technol. Forecast. Soc. Chang. 76 (3), 382–395.

Park, P., Lee, H.E., 2009. u-Healthcare aide system for ubiquitous wellbeing lifecare smart space. New Trends in Information and Service Science2009. NISS'09. International Conference on. IEEE, pp. 781–783.

Phaal, R., Muller, G., 2009. An architectural framework for roadmapping: towards visual strategy. Technol. Forecast. Soc. Chang. 76 (1), 39–49.

Phaal, R., Farrukh, C., Mitchell, R., Probert, D., 2003. Starting-up roadmapping fast. Res. Technol. Manag. 46 (2), 52–59.

Phaal, R., Farrukh, C., Probert, D., 2004a. Customizing roadmapping. Res. Technol. Manag. 47 (2), 26–37.
Phaal, R., Farrukh, C.J., Probert, D.R., 2004b. Technology roadmapping—a planning framework for evolution and revolution. Technol. Forecast. Soc. Chang. 71 (1), 5–26.
Phaal, R., Farrukh, C.J., Probert, D.R., 2005. Developing a Technology Roadmapping System, Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET '05), Portland.
Phaal, R., Farrukh, C.J., Probert, D.R., 2006. Technology management tools: concept, development and application. Technovation 26, 336–344.
Pisano, G.P., 1990. The R&D boundaries of the firm: an empirical analysis. Adm. Sci. Q. 35 (1), 153–176.
Postma, T.J., Liebl, F., 2005. How to improve scenario analysis as a strategic management tool? Technol. Forecast. Soc. Chang. 72 (2), 161–173.
Ramanathan, R., Ganesh, L.S., 1994. Group preference aggregation methods employed in AHP: an evaluation and an intrinsic process for deriving members' weightages. Eur. J. Oper. Res. 79 (2), 249–265.
Rinne, M., 2004. Technology roadmaps: infrastructure for innovation. Technol. Forecast. Soc. Chang. 71 (1), 67–80.
Robinson, D.K., Propp, T., 2008. Multi-path mapping for alignment strategies in emerging science and technologies. Technol. Forecast. Soc. Chang. 75 (4), 517–538.
Rosenbloom, R.S., Christensen, C.M., 1994. Technological discontinuties, organizational capabilities, and strategic commitments. Ind. Corp. Chang. 3 (3), 655–685.
Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. 48 (1), 9–26.
Sarin, R.K., 1978. A sequential approach to cross-impact analysis. Futures 10 (1), 53–62.
Schnaars, S.P., 1987. How to develop and use scenarios. Long Range Plan. 20 (1), 105–114.
Schoemaker, P.J., 1995. Scenario planning: a tool for strategic thinking. Sloan Manage. Rev. 36 (2), 25.
Schwartz, P., 1991. The art of the long view: planning for the future in an uncertain world. Doubleday, New York.
Shen, Y.C., Chang, S.H., Lin, G.T., Yu, H.C., 2010. A hybrid selection model for emerging technology. Technol. Forecast. Soc. Chang. 77 (1), 151–166.
Shengbin, H., Bo, Y., Weiwei, W., 2008. Research on application of technology roadmap in technology selection decision. Control and Decision Conference, 2008. CCDC 2008. Chinese. IEEE, pp. 2271–2275.
SQW/PREST, 1994. Prioritisation Criteria (A Paper to the UK Technology Foresight Steering Group).
Steenhof, P.A., Fulton, W., 2007. Scenario development in China's electricity sector. Technol. Forecast. Soc. Chang. 74 (6), 779–797.
Steensma, H.K., Corley, K.G., 2000. On the performance of technology-sourcing partnerships: the interaction between partner interdependence and technology attributes. Acad. Manag. J. 43 (6), 1045–1067.
Strauss, J.D., Radnor, M., 2004. Roadmapping for dynamic and uncertain environments. Res. Technol. Manag. 47 (2), 51–58.
Suharto, Y., 2013. Study of multi-scenario based technology roadmapping: Bayesian causal maps approach. 2013 Proceedings of PICMET'13: Technology Management in the IT-Driven Services (PICMET). IEEE, pp. 2212–2218.
Tegart, G., 1997. A Review of Australian Experience With Foresight Studies and Priority Setting. University of Canberra, Australian Network for Research and Technology Policy.
Tenaglia, M., Noonan, P., 1992. Scenario-based strategic planning: a process for building top management consensus. Strateg. Leadersh. 20 (2), 12–19.
Tyler, B.B., Kevin Steensma, H., 1995. Evaluating technological collaborative opportunities: a cognitive modeling perspective. Strateg. Manag. J. 16 (S1), 43–70.
Vaidya, O.S., Kumar, S., 2006. Analytic hierarchy process: an overview of applications. Eur. J. Oper. Res. 169 (1), 1–29.
Van der Heijden, K., 1997. Scenarios: The Art of Strategic Conversation. Wiley, New York.
Veugelers, R., 1997. Internal R & D expenditures and external technology sourcing. Res. Policy 26 (3), 303–315.
Walker, G., Weber, D., 1987. Supplier competition, uncertainty, and make-or-buy decisions. Acad. Manag. J. 30 (3), 589–596.
Weimer-Jehle, W., 2006. Cross-impact balances: a system-theoretical approach to cross-impact analysis. Technol. Forecast. Soc. Chang. 73 (4), 334–361.
Yoon, B., Phaal, R., Probert, D., 2008. Morphology analysis for technology roadmapping: application of text Mining. R Manag. 38 (1), 51–68.

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