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

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

A multiple correspondence analysis model for evaluating technology foresight methods

Majid Esmaelian[a], Madjid Tavana[b,c,*], Debora Di Caprio[d,e], Reza Ansari[f]

[a] Department of Management, University of Isfahan, Isfahan, Iran
[b] Business Systems and Analytics Department, La Salle University, Philadelphia, PA 19141, USA
[c] Business Information Systems Department, Faculty of Business Administration and Economics, University of Paderborn, D-33098 Paderborn, Germany
[d] Department of Mathematics and Statistics, York University, Toronto M3J 1P3, Canada
[e] Polo Tecnologico IISS G. Galilei, Via Cadorna 14, 39100 Bolzano, Italy
[f] Department of Management, University of Isfahan, Isfahan, Iran

ARTICLE INFO

Keywords:
Technology foresight
Multiple correspondence analysis
Technology development
Quantitative and qualitative criteria
Evaluation and selection
Extrapolation method

ABSTRACT

Technology foresight (TF) studies the appropriate extrapolation methodologies for predicting the most likely technology development scenarios in the future. Although there is a vast literature dealing with the classification and development of technology foresight methods (TFMs), the problem of selecting those that best reflect the characteristics of an organization is challenging and remains mostly overlooked. We propose a TFM evaluation procedure that allows decision makers and managers to successfully address this problem. The proposed procedure identifies the most relevant TFMs and organizational criteria and uses them in a multiple correspondence analysis (MCA) model to select the most suitable method(s) for implementation. The proposed MCA model combines the doubling data technique with a row principal scoring procedure to allow for the reduction of dimensionality and, consequently, the graphical analysis of the patterns of relationships among TFMs and evaluation criteria. We present a case study in a knowledge-based organization to demonstrate the applicability and efficacy of the proposed evaluation procedure. The results show that the proposed model can be properly adapted to allow for a wide range of applications involving business organizations and government agencies.

1. Introduction

Technology foresight (TF) is an important phase of a firm's development process of open innovation initiatives and it involves identifying technologies which are critical to the future success of the firm (Battistella, 2014; Rohrbeck and Gemünden, 2011; Tseng et al., 2009). The strategic management literature in general recommends managers to abandon maturing technologies and embrace new ones to stay competitive (Christensen, 2013). As a result, an increasing number of business organizations and government agencies have started using different technology foresight methods (TFMs) as research and development tools (Daim et al., 2006). One of the fundamental responsibilities of research and development managers is to decide between optimizing current technologies and planning new ones (İNtepe et al., 2013). Despite the large number of studies on TFMs and their classification, the complex and challenging problem of assessing the TFMs in order to select those that best reflect the characteristics of an organization remains mostly overlooked in the literature.

Only recently, there has been an increase in the number of studies on assessing TFMs. These studies in general agree on three main points: (1) any attempt to systematically evaluate foresight programs cannot ignore the complex interactive nature of foresight (Miles, 2012); (2) foresight cannot be fully evaluated independently from its context which makes impossible to find a "one-size-fits-all" evaluation method (Georghiou and Keenan, 2006); (3) new integrated approaches are necessary to combine the sophisticated solutions of the technology side with the real needs of the customers, that is, it is necessary to focus on both the market "pull" and technology "push" approach (Vishnevskiy et al., 2016).

Magruk (2011) developed a new approach for classifying TFMs based on their applicability. However, this approach cannot recommend the most suitable TFM for a particular technology development problem. İNtepe et al. (2013) used a multi-criteria interval-valued intuitionist fuzzy group decision making approach to select a TFM, but

* Corresponding author at: Business Systems and Analytics Department, La Salle University, Philadelphia, PA 19141, United States.
E-mail addresses: m.esmaelian@ase.ui.ac.ir (M. Esmaelian), tavana@lasalle.edu (M. Tavana), dicaper@mathstat.yorku.ca, debora.dicaprio@istruzione.it (D. Di Caprio), r.ansari@ase.ui.ac.ir (R. Ansari).
URL: http://tavana.us/ (M. Tavana).

http://dx.doi.org/10.1016/j.techfore.2017.07.022
Received 1 September 2016; Received in revised form 29 April 2017; Accepted 18 July 2017

Table 1
Technology foresight methods in the literature (characteristics and citations).

TFM	Exploratory	Normative	Expert based	Evidence based	Assumption based	Quantitative	Semi-quantitative	Qualitative	Citation
Environmental scanning	×	✓	✓	×	×	×	✓	×	Coates et al. (2001), Eto (2003), Firat et al. (2008), Lee and Sohn (2014), Meijering et al. (2013), Miles and Popper (2008), Nosella et al. (2008)
Expert panel	✓	×	✓	×	×	×	×	✓	Bengisu and Nekhili (2006), Chen et al. (2012), Coates et al. (2001), Daim et al. (2006), Kent and Saffer (2014), Miles and Popper (2008)
Brainstorming	✓	✓	×	✓	✓	×	✓	×	Chen et al. (2012), Dubarić et al. (2011), Garimella et al. (2013), Tseng et al. (2009), Daim et al. (2006)
Morphological analysis	✓	✓	✓	✓	×	×	✓	×	Chen et al. (2012), Dubarić et al. (2011), Garimella et al. (2013), Tseng et al. (2009), Daim et al. (2006), Cosmi et al. (2011)
Questionnaires/surveys	✓	✓	✓	✓	×	×	✓	×	Firat et al. (2008), Magruk (2011), Meijering et al. (2013), Garimella et al. (2013), Tseng et al. (2009)
Relevance trees	✓	✓	✓	✓	✓	×	×	✓	Coates et al. (2001), Firat et al. (2008), Lee and Sohn (2014), Magruk (2011), Meredith et al. (1995)
Scenarios	✓	×	×	×	✓	×	✓	×	Coates et al. (2001), Eto (2003), Firat et al. (2008), Magruk (2011), Meijering et al. (2013), Mahmud (2011)
SWOT	✓	×	✓	×	×	×	×	✓	Meijering et al. (2013), Meredith et al. (1995), Miles and Popper (2008)
Delphi	✓	✓	✓	×	×	×	✓	×	Coates et al. (2001), Firat et al. (2008), Magruk (2011), Meredith et al. (1995), Miles and Popper (2008)
Key technologies	×	✓	✓	×	×	×	✓	×	Grossman (2008), Miles and Popper (2008)
Trend impact analysis	✓	✓	✓	✓	×	✓	×	×	Miles et al. (2013), Miles and Popper (2008)
Technology roadmapping	✓	✓	✓	×	✓	×	✓	×	Meijering et al. (2013), Meredith et al. (1995), Miles and Popper (2008)
Modeling & simulation	✓	×	✓	×	×	✓	×	×	Magruk (2011), Meijering et al. (2013), Garimella et al. (2013), Tseng et al. (2009), Miles and Popper (2008)
Trend extrapolation	✓	×	×	✓	×	✓	×	×	Magruk (2011), Meijering et al. (2013), Garimella et al. (2013), Tseng et al. (2009)
Literature review	×	✓	×	✓	×	×	×	✓	Firat et al. (2008), Lee and Sohn (2014), Meijering et al. (2013), Meredith et al. (1995), Miles and Popper (2008)
Back casting	×	✓	×	×	✓	×	×	✓	Firat et al. (2008), Lee and Sohn (2014), Meijering et al. (2013), Meredith et al. (1995)
Cross-impact analysis	✓	×	✓	✓	×	×	✓	×	Daim et al. (2006), Kent and Saffer (2014), Schubert (2015), Garimella et al. (2013), Miles and Popper (2008)
Futures workshops	✓	✓	✓	×	✓	✓	×	×	Magruk (2011), Meijering et al. (2013), Garimella et al. (2013), Tseng et al. (2009)
Stakeholder mapping	×	✓	×	×	✓	×	✓	×	Grossman (2008)
Patent analysis	✓	×	×	✓	×	×	✓	×	Chen et al. (2012), Dubarić et al. (2011), Tseng et al. (2009), Daim et al. (2006), Miles and Popper (2008), Lee and Sohn (2014)
Multiscale analysis	×	✓	✓	×	×	✓	×	×	Miles et al. (2013), Miles and Popper (2008)
Text mining	✓	×	✓	×	×	×	✓	×	Grossman (2008)
System dynamic	✓	×	✓	×	×	✓	×	×	Grossman (2008)
Futures wheel	✓	✓	✓	×	✓	×	×	✓	Lee and Sohn (2014), Meijering et al. (2013), Meredith et al. (1995), Miles and Popper (2008)

their method is simply a ranking method and does not provide insightful information needed in the selection process (İNtepe et al., 2013). In this study, we propose a TFM evaluation procedure that allows decision makers, in general, and managers, in particular, to successfully address the problem of selecting the most suitable TFM for their organizations.

The proposed procedure consists of two phases: a qualitative (case-dependent) and a quantitative (case-independent) phase. In the qualitative phase, the set of most relevant TFMs for the organization and a set of appropriate evaluation criteria are identified. The Delphi method and the literature review method are suggested to identify the TFMs and the criteria, respectively. In the quantitative phase, a multiple correspondence analysis (MCA) model is defined to explore and visualize the patterns of relationships among the TFMs and the evaluation criteria. The MCA model combines the doubling data technique with a row principal scoring procedure in order to apply a reduction of dimensionality and perform a meaningful graphical evaluation of the TFMs with respect to the criteria.

The proposed TFM evaluation procedure is used to analyze a case study of a knowledge-based organization. The results obtained in the case study show that the procedure can be implemented by any other company with similar features. Indeed, the fact that the qualitative analysis is based on the Delphi method implies the choice of a specific design that depends on the research question defined by the analysts and varies significantly from one study to another (Hallowell and Gambatese, 2010). This is clearly an advantage when dealing with an organization depending on similar goals and contexts, but also imposes a limitation on the model since the qualitative phase must be carefully adapted (and possibly completely redesigned) to fit a different context.

On the other hand, the MCA model used in the quantitative phase depends only marginally on the characteristics of the organization. This fact allows for an expansion of the methodological framework to broader set of applications such as supplier selection, human resource management, project complexity evaluation and green product assessment.

This represents another advantage of the proposed model. That is, the two-phase structure of the evaluation procedure can be efficiently and effectively adapted so as to solve selection issues faced by a vast range of organizations and institutions.

Another merit of the proposed model is that it provides a valid alternative to integrated assessment approaches where consensus-based methods (i.e., the Delphi method) are combined with Analytic Hierarchy Process (AHP) and/or Analytic Network Process (ANP) models (Cho and Lee, 2013; Kim et al., 2013; Vidal et al., 2011; Yang et al., 2010). In fact, using a MCA in the quantitative phase can help to reduce the subjectivity of the evaluation process in situations where the hierarchy of criteria and sub-criteria could be prejudiced by a wrong weight assignment.

The remainder of this paper is organized as follows. Section 2 reviews some of the relevant literature on quantitative and qualitative TFMs, TF evaluation criteria, and MCA. Section 3, outlines the technical details of the proposed TFM evaluation procedure and the MCA model behind it. Section 4 presents the results of the case study discussing the practical implementation of the single steps comprised by the MCA model. Section 5 draws the conclusions, summarizes the advantages and limitations of the proposed method and presents some possible extensions.

2. Literature review

In this section, we present a review of the literature on quantitative and qualitative TFMs, TF evaluation criteria, and MCA.

2.1. TFMs and their classifications

There exists a large number of TFMs and several different classifications. Among the most recent studies, Daim et al. (2006) classified TFMs into three groups: Delphi-survey tradition; critical technology (or key technology) identification; and panel-based work. Miller and Swinehart (2010) categorized TFMs into three different groups: exploratory or normative methods; expert-based, evidence-based or assumption-based methods; and quantitative or qualitative methods. Moro et al. (2015) classified TFMs into quantitative, semi-quantitative, and qualitative methods.

Table 1 presents a comprehensive list of the TFMs proposed in the literature along with the relative relevant citations. This table also reports for each method if it is considered exploratory, normative, expert based, assumption based, quantitative, semi-quantitative, and/or qualitative.

For the case study, we have considered the three-tier classification proposed by Miles and Popper (2008). The corresponding list of TFMs has been used in the case study as the initial set of TFMs for the group of experts to evaluate. Please, refer to Phase 1 (Qualitative Analysis) of the TFM evaluation procedure in Section 4. Clearly, our choice of working with this particular list of TFMs is very much related to the case study and the firm involved in it. A different case study may require the analysis of a different set of TFMs on the basis of the goals and context of the organization being considered. The TFMs studied by Miles and Popper (2008), their descriptions and additional relevant references are outlined below.

2.1.1. Quantitative methods

These methods are largely based on numerical techniques.

a) Trend analysis: This method is grounded in forecasting techniques and uses statistical methods (such as exponential smoothing or moving averages) to predict time series data patterns. In the case of technology forecasting, trend analysis extrapolates the future trends of technology based on the past ones (Martin et al., 2012; Choi and Hwang, 2014; Dubarić et al., 2011; Kucharavy and De Guio, 2011).
b) Modeling and simulation: This method is used to reduce the uncertainty and the cost due to the application of a technology in the real world. Forecasters simulate the future state of a technology with respect to environmental conditions (Keller and Heiko, 2014; Technology Futures Analysis Methods Working Group, 2004; Im and Cho, 2013).
c) Trend extrapolation: This method uses statistical techniques such as moving average to forecast future trends and directions (Magruk, 2011; Meijering et al., 2013).
d) Multi-stage analysis: This method combines multiple models with different scales to describe the future of a technology based on a micro-model of technology. Multi-stage analysis is highly related to the mathematical content of the problems (Antonic et al., 2011).
e) Future workshops: This method uses workshops to interact with stakeholders and achieve applicable results (Martino, 2003).
f) System dynamics: This method forecasts the future of a technology by means of system dynamics tools such as neural networks. This method is also used to identify the dispersion of the technology in the future (Grossman, 2008; Tsai and Hung, 2014).

2.1.2. Semi-quantitative methods

a) Monitoring technology: This method uses systematic loops to find the ideal conditions by means of feedback information. This process subsumes all the stakeholders (Beddow, 2013; Davis et al., 2013; Miller and Swinehart, 2010; Tonn et al., 2012).
b) Brainstorming: This method collects a set of ideas about the future of a particular technology from an individual or a group of people (Daim et al., 2006; Dubarić et al., 2011; Garimella et al., 2013; Vanston, 2003).
c) Morphological analysis: This method studies the form and anatomy of the current technology and optimizes its use in the future by evaluating and examining all its aspects (Foray and Grübler, 1990).

Table 2
Evaluation criteria for technology foresight methods and relevant citations.

Marker	Criterion	Citation
C1	Discovering future opportunities to specify investment preferences in science and technology activities	Magruk (2011)
C2	Further setting of innovation and science system	Magruk (2011)
C3	Demonstrating the critical importance of science and innovation	Cheng et al. (2008)
C4	Introducing new actors into the policy dialogue	Magruk (2011)
C5	Generating networks and new connections between areas, sectors and markets	Magruk (2011)
C6	Time in hand	Keenan and Popper (2007), Rader and Porter (2008), Reger (2001)
C7	Project time horizons	Keenan and Popper (2007), Rader and Porter (2008), Reger (2001)
C8	Acquaintance of participants with foresight applications	Keenan and Popper (2007), Reger (2001)
C9	Data validity	Cheng et al. (2008), Firat et al. (2008), Levary and Han (1995), Mishra et al. (2002), Porter and Roper (1991)
C10	Data availability	Cheng et al. (2008), Firat et al. (2008), Levary and Han (1995), Mishra et al. (2002), Porter and Roper (1991)
C11	Implementation costs	Cheng et al. (2008), Levary and Han (1995), Firat et al. (2008)
C12	Predictability of technology development	Cheng et al. (2008)
C13	Ease of implementation	Cheng et al. (2008)

d) Questionnaire/surveys: This method uses survey results to predict the future of a particular technology (Firat et al., 2008; Magruk, 2011; Meijering et al., 2013).
e) Scenario planning: This method generates different scenarios about the future of a particular technology considering all the factors affecting the technology. (Amer et al., 2013; McPherson and Karney, 2014; Raford, 2015; Tseng et al., 2009).
f) Delphi: This method uses questionnaires conducted in successive rounds to collect ideas and opinions on a particular technology from a group of experts. The ideas and opinions collected at each round are shared with all the experts and the process is repeated until when consensus is reached (Förster and von der Gracht, 2014; Ishikawa et al., 1993; Kent and Saffer, 2014; Kolominsky-Rabas et al., 2015; Tang et al., 2014; Zimmermann et al., 2012).
g) Key technologies: This method focuses on the design of strategies related to a particular technology. These strategies are then used to develop a future plan for this technology (Bengisu and Nekhili, 2006; Tang et al., 2014; Wang et al., 2014).
h) Technology roadmapping: This method is based on the drawing of a plan, known as a technology roadmap, for a new product, process, or emerging technology. A technology roadmap provides a mechanism to help forecasting technology developments by specifying how the organization sees itself in the future. One of the most important advantages of using this method is the fact that it considers all the people who are directly or indirectly involved in the technology development (Barker and Smith, 1995; Phaal and Muller, 2009; Phaal et al., 2004; Vishnevskiy et al., 2015; Wancura et al., 2013; Weinberger et al., 2012).
i) Cross-impact analysis: This method focuses on the influences that a particular technology has on the environmental events and, vice versa, how the environment affects the technology (Kent and Saffer, 2014; Legendre and Legendre, 2012; Miles and Popper, 2008).
j) Stakeholder mapping: This method uses statistical techniques to predict who the future stakeholders for a particular technology are, where they are, and why they are interested in that technology (Grossman, 2008; Saritas et al., 2013; Schubert, 2015; van de Kerkhof et al., 2002).
k) Patent analysis: This method focuses on the information about a particular patent or technology. Technologists use statistical and visualization tools and data to predict the future of a given technology (Martin et al., 2012; Choi and Hwang, 2014; Dubarić et al., 2011; Kucharavy and De Guio, 2011).
l) Text/data mining: This method applies data mining techniques to investigate different aspects of a particular technology. Data mining techniques can search for hidden relations among events and uncover the future of the technology by surveying interactions between the technology and the environment (Grossman, 2008; Moro et al., 2015).

2.1.3. Qualitative methods

a) Expert panel: This method uses a group of experts with a common interest but from different areas in the organization. The experts thoroughly study a particular technology and argue its future trends (Bengisu and Nekhili, 2006; Chen et al., 2012; Coates et al., 2001).
b) Relevance trees: This method identifies the development phases of a particular technology. Experts break down the technological goals and identify the basic elements and structure of the technology (Coates et al., 2001; Daim et al., 2006; Firat et al., 2008).
c) Strengths, weaknesses, opportunities, and threats (SWOT) analysis: This method focuses on the strengths, weaknesses, opportunities, and threats associated with the application of a particular technology. The SWOT information is used to predict the future position of the technology (Gao and Low, 2014).
d) Literature review: This method uses references about a particular technology as the basis for decision making on that technology. One of the main objectives of this method is to foresee the knowns and unknowns about a particular technology (Grossman, 2008: Miles et al., 2013; Moro et al., 2015).
e) Back casting: This method hypothesizes a desirable future and uses back casting to create the assumed future (Firat et al., 2008; Meredith et al., 1995; Zimmermann et al., 2012).
f) Futures wheel: This method is similar to relevance trees and is often used to study the hierarchical effects of a particular technology. An event or a particular technology is considered as the core of a wheel, while the events which can influence the technology or be influenced by it are considered as vanes. (Meredith et al., 1995; Miles and Popper, 2008).

2.2. Evaluation criteria for TFMs

The TFMs must be evaluated according to relevant criteria and organizational characteristics. In Table 2, we present a comprehensive list of the most used criteria in the recent literature for the evaluation and selection of TFMs along with some corresponding relevant citations.

The criteria in Table 2 have also been used in the case study to evaluate the TFMs selected by the group of experts. Please, refer to Phase 1 (Qualitative Analysis) of the TFM evaluation procedure in Section 4. As for the TFMs, it must be noted that this choice of criteria and/or of criteria selection method (literature review) is strictly related to the case study and the firm involved in it and must necessarily be adapted to a different type of firm or study.

2.3. Multiple correspondence analysis (MCA)

MCA is a statistically-based visualization method that allows the user to graphically represent and analyze the associations among categorical variables (De Leeuw and Mair, 2009).

A data analysis using MCA requires first the construction of a two-way contingency table, that is, a cross-classification table containing the observations relative to two discrete variables (Tewari et al., 2008). MCA shows the similarities and underlines the differences among the variables by interpreting the corresponding rows and columns in the two-way contingency table as points of a low dimensional space. The positions of the row and column points depend on their associations in the table. This score representation provides a comprehensive interpretation for the assessment of the available data (Kazemzadeh and Reaziat, 2010).

MCA has proved to be useful in numerous applications to sociology, psychology, ecology, archeology, among others fields. Different types of MCA can be developed based on the type of input data (Greenacre, 2007). In fact, MCA can be applied to both quantitative and qualitative data (Kudlats et al., 2014).

In general, in a standard MCA the raw data are the frequencies of all the combinations of the responses and predictor levels. However, MCA is not restricted to frequency data. In particular, it can be used with the primal data rooted from applying the Delphi method with a series of simple changes. In this regard, one of the most common techniques to deal with rating data of many real-life problems is the so-called "doubling technique" (Greenacre, 2007). Hence, MCA offers several practical advantages when analyzing data from case studies such as the one considered in the current study. We will discuss this point further in the next two sections.

3. Proposed TFM evaluation procedure

In this section we outline the technical details of the procedure herein proposed to evaluate a set of TFMs relevant to an organization and select the most suitable ones. Further comments about the practical implementation of the single steps will be given in the Case study section.

The procedure consists of two phases, a qualitative analysis and a quantitative analysis, which are developed through five consecutive steps. The phases and the corresponding steps are described below. Fig. 1 provides a graphical representation of the proposed procedure.

3.1. Phase 1. Qualitative case-dependent analysis

Step 1. Identify the evaluation criteria and an initial set of TFMs

This can be done, for example, on the basis of a literature review. We will denote by m the number of identified evaluation criteria and by N the initial number of TFMs.

Step 2. Select the most relevant TFMs

This is usually done involving experts from the firm and using, for instance, the Delphi method. We will use n to denote the number of TFMs selected from the initial set of TFMs.

Remark. In the case study (Section 4), Steps 1 and 2 are implemented using a literature review and the Delphi method, respectively. However, it must be noted that these two methods do not necessarily represent the best way of identifying the TFMs and/or the evaluation criteria. Both the TFMs and the evaluation criteria must be identified so as to reflect (and account for) the complex interrelationships exiting among the long-term goals, the decision-making processes and the technology policies and strategies of the organization (Andersen and Andersen, 2014; Andersen and Rasmussen, 2014; Neij et al., 2004). That is, the methods used to perform the qualitative analysis (Phase 1) of the proposed evaluation procedure must be chosen and carried out considering the specific characteristics of the case study under analysis and both the endogenous and exogenous factors that may affect them.

Remark. Steps 1 and 2 do not display any explicit discussion on the important aspects or specific phases characterizing the TFMs against the interrelated and complex factors that allow for their actual implementation in an organization. However, such a discussion is an essential part of the literature review (Step 1) that aims to collect an initial set of TFMs and evaluation criteria. At the same time, it is the key for successfully choosing the experts' panel and correctly designing the consensus-based procedure to select the most relevant TFMs (Step 2). More details in this sense are provided in the Case study section (Section 4).

Step 3. Construct the two-way contingency matrix

The rows and columns of this matrix correspond to the TFMs obtained in Step 2 and the criteria identified in Step 1, respectively.

Experts are asked to rate each method according to all the evaluation criteria using a 1-M Likert scale, where M is an integer > 1. According to this rating scale, 1 means "strongly low" and M stands for "strongly high". Hence, a $n \times m$ matrix is obtained:

$$D = [x_{ij}]_{\substack{i=1,\dots,n \\ j=1,\dots,m}} \tag{1}$$

where x_{ij} is the rating value assigned to method i according to criterion j.

3.2. Phase 2. Quantitative case-independent analysis

Step 4. Double the columns of the two-way contingency matrix

The doubling technique is applied to define a new matrix from D. "Doubling" means to redefine each rating value x_{ij} as a pair of complementary values: the "positive" (or "high") pole c_{ij}^{+} and the "negative" (or "low") pole c_{ij}^{-}. Before performing the doubling, it is preferable to have rating scales with a lower endpoint of zero (Greenacre, 2007).

Thus, a $n \times 2m$ matrix is obtained:

$$F = [C_j^-, C_j^+]_{j=1,\dots,m}, \tag{2}$$

where, for every $j = 1, \dots, m$, C_j^{+} and C_j^{-} are column vectors of dimension n defined as follows:

$$C_j^+ = [c_{ij}^+]_{i=1,\dots,n} \text{ with } c_{ij}^+ = x_{ij} - 1, \tag{3}$$

and

$$C_j^- = [c_{ij}^-]_{i=1,\dots,n} \text{ with } c_{ij}^- = M - 1 - c_{ij}^+. \tag{4}$$

Step 5. Perform a MCA

The proposed MCA follows the so-called "row principal scoring" approach (Hayano et al., 2015; Yelland, 2010) in order to reduce the dimensionality of the problem and provide the graphical representation typical of a CA.

To simplify notations, denote by f_{ij} the generic element of the matrix F, that is:

$$F = [f_{ik}]_{\substack{i=1,\dots,n \\ k=1,\dots,2m}} \tag{5}$$

where, for every $i = 1, \dots, n$, we have $f_{i1} = c_{i1}^{-}$, $f_{i2} = c_{i1}^{+}$, $f_{i3} = c_{i2}^{-}$, $f_{i4} = c_{i2}^{+}$, and so on.

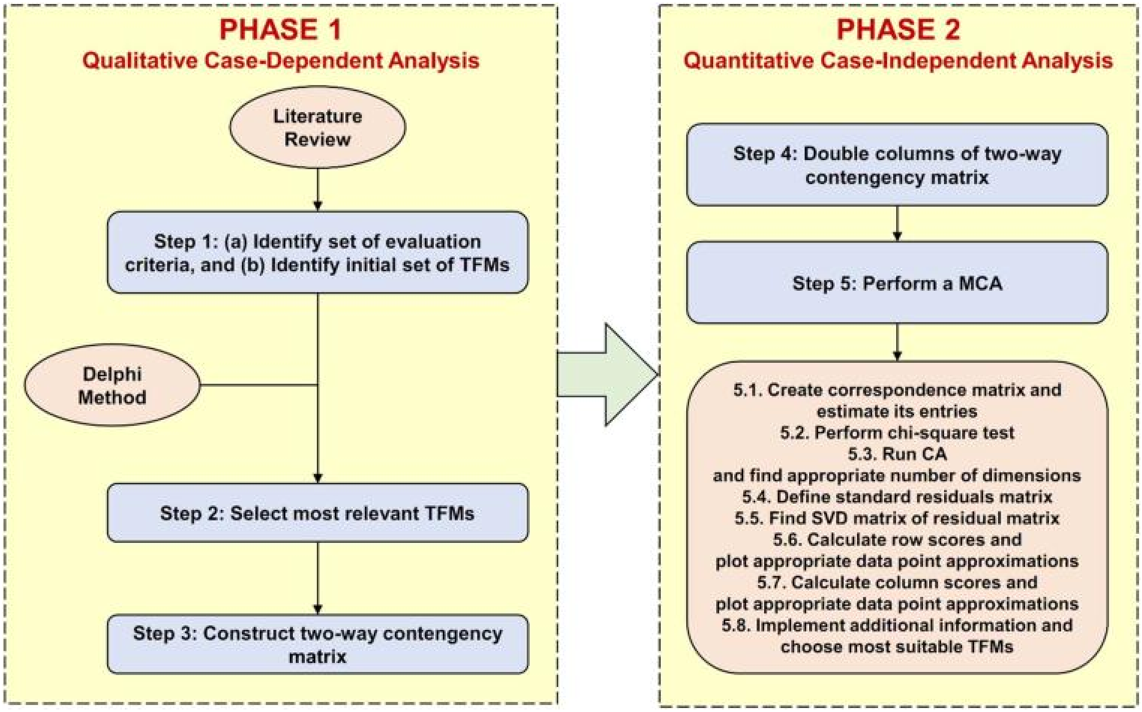

Fig. 1. Proposed TFM evaluation procedure.

Step 5.1.
Calculate the correspondence matrix and estimate its entries

The correspondence matrix P is a $n \times 2m$ matrix obtained from F as follows:

$$P = [p_{ik}]_{\substack{i=1,\dots,n\\k=1,\dots,2m}} \tag{6}$$

where $p_{ik} = {}^{f_{ik}}/_{N}$ and $N = \sum_{i=1}^{n} \sum_{k=1}^{2m} f_{ik}$.

Next, for every $i = 1, \dots, n$ and $k = 1, \dots, 2m$, calculate:

$$P_{i+} = \sum_{k=1}^{2m} p_{ik} \quad \text{(sum of the elements in the } i\text{-th row of } P) \tag{7}$$

$$P_{+k} = \sum_{i=1}^{n} p_{ik} \quad \text{(sum of the elements in the } k\text{-th column of } P) \tag{8}$$

$$\mu_{ik} = P_{i+} \cdot P_{+k} \quad \text{(estimation of the value of the entry } p_{ik} \text{ by assuming independence between rows and columns of the crosstab)} \tag{9}$$

Step 5.2.
Conduct a chi-square test

The χ^2 statistic relative to the $n \times 2m$ correspondence matrix P is defined as follows:

$$\chi^2 = \sum_{i=1}^{n} \sum_{k=1}^{2m} \frac{(p_{ik} - \mu_{ik})^2}{\mu_{ik}}. \tag{10}$$

This statistic conforms to the chi-square distribution with $(n - 1)(2m - 1)$ degrees of freedom. If the χ^2 statistic is significantly higher than the standard value, then *P-value* ≤ 0.05 and the rows and columns are dependent. Hence, the doubled data can be used in a MCA since there is a statistically significant difference in the distribution of the entries across the samples.

Step 5.3.
Run a correspondence analysis (CA) and determine the appropriate number of dimensions

The CA decomposes the overall inertia and identifies a small number of dimensions that allows for a good approximation of the locations of the data points. If the sum of the inertia of dimensions 1 and 2 accounts for > 50% of the total inertia, then the data points can be plotted as points of a two-dimensional perceptual map.

Step 5.4.
Define the standard residuals matrix

The elements of this matrix are the square roots of the terms comprised by the χ^2 statistic in Step 5.2:

$$\Omega = \left[{}^{(p_{ik} - \mu_{ik})}\Big/_{\sqrt{\mu_{ik}}} \right]. \tag{11}$$

This matrix has dimension $n \times 2m$.

Step 5.5.
Find the singular value decomposition (SVD) of the residual matrix

The SVD of a matrix breaks down the matrix into three matrices whose product returns the original matrix. That is:

$$\Omega = V \Lambda W^T \tag{12}$$

where V and W are two orthogonal matrices ($VV^T = WW^T = I$ with I representing the identity matrix) of dimension $n \times n$ and $2m \times 2m$, respectively, and Λ is a $n \times 2m$ diagonal matrix whose non-zero elements are the singular values of Ω. The super-index T denotes the transpose of the matrix.

Step 5.6.
Calculate the row scores and plot the appropriate data point approximations

We compute the scores relative to the rows of Ω using the following matrix R:

$$R = \sigma_r V \Lambda \tag{13}$$

where σ_r is the diagonal matrix comprising the reciprocals of the square roots of the sums P_{i+} $(i = 1, \ldots, n)$, that is:

$$\sigma_r = \begin{bmatrix} \frac{1}{\sqrt{P_{1+}}} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \frac{1}{\sqrt{P_{n+}}} \end{bmatrix} \tag{14}$$

The matrix R represents a SVD matrix. The number of columns corresponding to the number of dimensions retained by the CA is considered to be a good approximation of the data points corresponding to the rows (i.e., the TFMs). In the case study, two-dimensional solutions explained 72.1% of the total inertia, thus we were able to evaluate the TFMs using a two-dimensional scatter plot.

Step 5.7.
Calculate the column scores and plot the appropriate data point approximations

As in Step 5.6, we use the columns of a SVD matrix C. Differently from R, this matrix must provide an approximation for the locations of the data points corresponding to the columns of the standard residuals matrix Ω. Thus, Ω must be first transposed and then broken down by the SVD.

$$\Omega' = \Omega^T \tag{15}$$

$$\Omega' = V' \Lambda' W'^T \tag{16}$$

$$V' V'^T = W' W'^T = I \tag{17}$$

Hence,

$$C = \sigma_c V' \Lambda' \tag{18}$$

where σ_c is the diagonal matrix whose non-zero elements are the reciprocals of the square roots of the sums P_{+j} $(j = 1, \ldots, 2m)$, that is:

$$\sigma_c = \begin{bmatrix} \frac{1}{\sqrt{P_{+1}}} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \frac{1}{\sqrt{P_{+2m}}} \end{bmatrix} \tag{19}$$

Clearly, the number of columns providing a good approximation of the data points corresponding to the columns (i.e., the doubled evaluation criteria) must coincide with the one in Step 5.6. In particular, in the case study, the distances (i.e. correlations) among the evaluation criteria have been evaluated using a two-dimensional scatter plot.

Step 5.8.
Implement additional information and choose the most suitable TFMs

After collecting additional information about the organization, a new matrix R is needed in order to obtain the row scores. This matrix, denoted by R_{new}, could be obtained by simply appending the new data as new rows to the initial cross tab F and recalculating the scores and coordinates for all the rows (i.e., the TFMs) in the new table F_{new}. However, it is possible that the new entries overlap with existing ones and appending the new rows to the initial cross tab could distort the analysis by "double-counting" some of the rows. Thus, we prefer to use the following known equation (Yelland, 2010) that reflects the fact that the row scores obtained in Step 5.6 are weighted sums of the column scores computed in Step 5.7:

$$R_{new} = \sigma_{r,new}^2 \times P_{new} \times C_{new}. \tag{20}$$

The diagonal matrix $\sigma_{r,new}$ (Step 5.6), the correspondence matrix P_{new} (Step 5.1) and the matrix of column scores C_{new} (Step 5.7) are recalculated for F_{new}. After plotting the new two-dimensional data points approximating the real positions of the new rows of R_{new} (i.e., the organization conditions), the most suitable TFMs for the organization can be finally selected.

4. Case study

The case study presented in this section was conducted at Knowledgecare,[1] a knowledge-based organization in healthcare located in Phoenix, Arizona. Knowledgecare is in the forefront of creating and applying knowledge in healthcare. Healthcare delivery is a knowledge-driven process and Knowledgecare is specialized in clinical decision support systems and providing healthcare professionals with the knowledge needed to improve clinical practice. We used the proposed TFM evaluation procedure to identify and evaluate several TFMs and finally determine the most suitable ones for the technology development process of Knowledgecare.

4.1. Phase 1: qualitative analysis

Step 1: We started by identifying the most relevant TF evaluation criteria proposed in the literature. We used the 13 criteria collected through the literature review described in Section 2.2 and outlined in Table 2. Thus, in the case study, we have $m = 13$.

As for the most relevant TFMs, the literature review revealed the list of 25 TFMs considered by Miles and Popper (2008) to represent the TFMs commonly adopted by organizations similar in characteristics to Knowledgecare (see Section 2.1). Thus, in the case study, we have $N = 25$.

Step 2: We used the Delphi method to select n TFMs among the N initial ones that best match the needs of the organization.

The Delphi method is a well-known consensus technique where expert opinions are repeatedly obtained until there is a comprehensive consensus on selecting projects, predicting issues, and resolving problems (Delbecq et al., 1975). The Delphi method has been used in natural resources and environmental management research to facilitate the interaction among the stakeholders when investigating a variety of local, regional, and global issues (Linstone and Turoff, 2011).

Traditionally, this method consists of performing an anonymous survey within a panel of experts using consecutive rounds of questionnaires that include controlled feedback (Eastwood, 2011). The experts are expected to respond autonomously and anonymously. This is important in order to avoid an outspoken person or collective group thinking dominating the outcome, a common shortcoming in many consensus building methods (Kim et al., 2013).

The details relative to the selection process of the experts and how the Delphi questionnaires were conducted in the case study are described below.

a) Establishing the experts' panel

Twelve highly informed local experts were selected from academic and industrial research centers known for dealing with TF related issues. Note that the minimum number of experts suggested in the literature for a panel to be of appropriate size is seven (Sourani, 2015). The experts were invited to take part to the case study on the basis of their knowledge and experience in the field of study, ability and

[1] The name of the knowledge-based organization has been changed to protect its anonymity.

willingness to participate, adequate time to participate, and effective communication skills (Rådestad et al., 2013).

Remark. The expert selection is a critical component of the Delphi method, as the validity of the results relies on their judgements. The decisions regarding the panel size, characteristics, and composition should ensure that the expertise represented on the panel is congruent with the research issues in question (Donohoe, 2011). This represents both an advantage and a disadvantage of the method depending on whether or not the expert selection is performed correctly. The subjectivity characterizing this selection process as well as the interpretation of the data provided by both the managers (who conduct the selection procedure) and the experts is a limitation of the Delphi method unavoidably inherited by the qualitative analysis of our model.

b) Delphi procedure

Invitation letters were sent to the possible participants to complete a three-round rating process.

Twelve experts accepted to take part to the study and were asked to rate the importance of the TFMs composing the initial set using a 5-point Likert scale (1 = very low importance to 5 = very high importance). Recall that the initial set of TFMs consisted of the 25 TFMs outlined in Section 2.1 (Miles and Popper, 2008).

At each round, the questionnaire provided the participants with the option to add free-text comments. In the second and third round, the questionnaire was also accompanied by the feedback results relative to the previous round.

The questionnaire sent to experts is reported in Fig. 2 while Tables 3 to 5 show the results obtained in the three rounds of Delphi and accordingly used as feedbacks in the second and third round.

Remark. In the case study, the Delphi procedure applied to assess the initial set of TFMs was devised in a structured format and used a very straight-to-the-point questionnaire. The main reason behind this choice is the following. The proposed TFMs evaluation method aims at showing the applicability of MCA in combination with consensus-based managerial methods rather than to provide yet another application of the well-known Delphi method. This also represents the actual merit of the paper: counterbalancing the drawbacks inherent to a qualitative analysis (easily affected by a wrong choice of experts or inaccurate judgements) via a quantitative analysis that synthesizes criteria and alternatives in low dimensional data points. This synthesis correctly recovers a high percentage of the specific qualitative features and interrelationships thanks to a high total inertia threshold.

c) Consensus criteria

Consensus on the single indicator was assessed using the combination of three measures (Geist, 2010; Horner et al., 2009): the median score (MS), the inter quartile range (IQR) and the standard deviation (SD). That is, we assumed the consensus on retaining a certain TFM to be reached if:

$$\begin{cases} MS \geq 4 \ \text{('highly important' on a 5-Likert scale)} \\ IQR \leq 1 \\ SD < 1 \end{cases} \tag{21}$$

The level of agreement among the experts and, hence, the stability of the results was evaluated using the Kendall's Coefficient of Concordance (W). More precisely, the following stopping criterion was applied.

- If at the end of the second round $W \geq 0.5$, then STOP; else perform third round.
- If at the end of the third round $W \geq 0.5$, then STOP; else perform fourth round and STOP.

After three rounds of Delphi, the experts at Knowledgecare were able to identify 12 TFMs which are presented in Table 6 together with the corresponding acronyms. Thus, in the case study, $n = 12$.

Step 3: We constructed the two-way contingency table (the rows and columns are indexed by the methods and the criteria, respectively). We described the evaluation criteria to the experts at Knowledgecare and asked them to rate each method with respect to each criterion using a 1–20 Likert scale. That is, in the case study, $M = 20$ and:

$$1 \overset{def}{=} \text{strongly low};\ 2 \overset{def}{=} \text{very low};\ldots;19 \overset{def}{=} \text{very high};\ 20 \overset{def}{=} \text{strongly high}.$$

The experts' ratings were compiled in a 12×13 matrix, $D = [x_{ij}]_{\substack{i=1,\ldots,12\\ j=1,\ldots,13}}$, as described by Eq. (1). This matrix is presented in Table 7.

4.2. Phase 2: quantitative analysis

Step 4: We applied the doubling technique and created the matrix F as described by Eqs. (2) to (4). More precisely, the positive poles were obtained by subtracting 1 from each entry of the matrix D, while the negative poles were calculated by subtracting the positive pole values from $M - 1 = 19$. For example, using the doubling technique, a rating value of $x_{ij} = 6$ is redefined as the pair of values $c_{ij}^{+} = 6 - 1 = 5$ and $c_{ij}^{-} = 19 - c_{ij}^{+} = 19 - 5 = 14$. The resulting matrix is the 12×26 matrix represented in Table 8.

Step 5: As mentioned in Subsection 2.3, the reason behind using the doubling technique is the assimilation of rating data to frequency data which are the kind of data usually employed in a MCA. However, in order to apply a MCA to the data collected in Table 8, we had to conduct first a chi-square test to make sure that the variations of the data sets were large enough. The chi-square test examines a cross tab which deviates significantly from one in which rows and columns are independent.

Proceeding as described in Steps 5.1 to 5.3, we constructed the correspondence matrix P (see Eq. (6)) and computed the sums P_{i+} $(i = 1, \ldots, 12)$ and P_{+k} $(k = 1, \ldots, 26)$ of the rows and columns of the matrix P (see Eqs. (7) and (8)) as well as the estimation values $\mu_{ik} = P_{i+} \cdot P_{+k}$ (see Eq. (9)). Hence, we calculated the λ^2 statistic value (see Eq. (10)) and ran the CA.

Table 9 presents a summary of the CA showing, in particular, that:

- the value obtained for the χ^2 statistic was significantly higher than the standard value which confirmed a statistically significant difference in the distribution of entries across the sample data and allowed us to perform the MCA;
- the first two dimensions accounted for 72.1% (> 50%) of the total inertia and, hence, a two-dimensional perceptual map sufficed for a good approximation of the locations of the data points, i.e., the TFMs and the evaluation criteria.

Next, we constructed the residual matrix Ω and used the SVDs of Ω and Ω^T to obtain the matrices R and C, respectively. See Eqs. (11) to (19). On the basis of the appropriate number of dimensions determined by the CA, the first two columns of matrices R and C were read as the row and column scores, respectively. These scores and all the necessary statistics are shown in Tables 10 and 11. The scores appear in the columns labeled "Dimension 1" and "Dimension 2" to highlight their role as 2D coordinates.

The Delphi survey questionnaire

Please state to what extent each technology foresight method (TFM) can be use in Knowledgecare

TFM	Score Five points Likert scale 1 Low important	2	3	4	5 Very High important
Morphological Analysis					
Scenario Planning					
SWOT					
Delphi					
Key Technologies					
Technology Roadmapping					
Modeling & Simulation					
Literature Review					
Futures Workshops					
Patent Analysis					
Multi stage Analysis					
Monitoring Technology					
Environmental Scanning					
Expert Panel					
Brainstorming					
Questionnaires/Surveys					
Relevance Trees					
Trend Impact Analysis					
Trend Extrapolation					
Back Casting					
Cross-Impact Analysis					
Stakeholder Mapping					
Text Mining					
System Dynamic					
Futures Wheel					

Fig. 2. The Delphi survey questionnaire.

Fig. 3 shows the scatter plot obtained by plotting the scores of Table 10 as two-dimensional points. This perceptual map represents the TFMs and allows us to both visualize the distances and the variations between any two data sets and determine which TFMs are similar and which are not. Two methods corresponding to two nearby points in the map have similar rating values with respect to the criteria. Methods corresponding to points close to the origin have a somewhat common rating value with respect to all the criteria and they are close to the average profile of methods, while methods whose corresponding points are far from the origin have different rating values. We will discuss further the similarity among the TFMs in the rest of the current section.

From the initial graphical analysis of the TFMs based on Fig. 3, we could conclude that the Delphi (DE) and Scenario Planning (SP) methods are very similar. This is also true for Literature review (LR) and Patent Analysis (PA). On the other hand, the Foresight Workshops (FW) and Key Technologies (KT) methods are different from all the other TFMs. Moreover, the four methods positioned close to the origin, namely, Modeling and Simulation (M & S), Multi Scale Analysis (MSA), SWOT (SW) and Morphological Analysis (MA), are relatively similar since their applications might be different based on the situation and criteria considered in a specific foresight project.

Fig. 4 shows the scatter plot obtained by plotting the scores in Table 11. This chart represents both the positive and negative poles associated to each criterion as two-dimensional points.

Due to the doubling approach, each criterion C_k ($k = 1, \dots, 26$) is represented by two opposite vectors corresponding to the two poles $C_k{}^{+}$ and $C_k{}^{-}$ (both vectors start from the origin and lay along the same direction). Thus, we can draw 13 rating scale axes, one per each criterion, by joining with a line segment the positive and negative poles associated with the same criterion. These axes are represented in Fig. 5 as dashed line segments. They all pass through the origin of the perceptual map of the criteria and can be used to calculate the average ratings for the criteria as follows.

- Recreate the 1–20 scale on each rating scale axis: partition the axis into 19 equal intervals numbering the endpoints from 1 to 20, with 1 and 20 coinciding with the negative and positive pole, respectively.
- Interpret the origin as the average rating for each criterion: this can be done by weighting the negative and positive poles proportionally to the averages of the corresponding columns in Table 8. That is,

Table 3
Rating results after the 1st round of Delphi (feedbacks provided in the 2nd round).

TFM	Ex 1	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7	Ex 8	Ex 9	Ex 10	Ex 11	Ex 12	MS	IQR	SD	Consensus	min	max
Morphological analysis	4	4	4	4	5	4	4	4	4	3	4	4	4	0	0.4264	1	3	5
Scenario planning	4	4	2	4	3	4	4	3	4	4	3	4	4	1	0.66856	1	2	4
SWOT	3	5	5	3	4	3	5	4	3	2	3	5	3.5	2	1.05529	0	2	5
Delphi	4	4	4	2	5	4	5	3	4	4	4	4	4	0	0.79296	1	2	5
Key technologies	5	4	2	5	2	5	5	5	3	2	5	5	5	2.25	1.3484	0	2	5
Technology roadmapping	5	3	5	5	3	4	5	3	3	3	4	3	3.5	2	0.93744	0	3	5
Modeling & simulation	4	5	4	4	2	4	2	4	3	4	4	4	4	0.25	0.88763	1	2	5
Literature review	3	3	4	5	5	2	4	3	5	5	2	2	3.5	2.25	1.24011	0	2	5
Futures workshops	3	5	3	4	3	2	3	3	3	2	3	3	3	0	0.79296	0	2	5
Patent analysis	4	4	3	4	4	2	5	4	4	2	4	4	4	0.25	0.88763	1	2	5
Multiscale analysis	5	5	4	5	2	5	5	2	4	5	5	2	5	1.5	1.31137	0	2	5
Monitoring technology	2	3	3	5	5	3	3	3	5	3	5	3	3	2	1.08362	0	2	5
Environmental scanning	1	2	1	1	2	1	1	3	1	1	1	3	1	1	0.79772	0	1	3
Expert panel	2	3	2	2	2	4	2	3	2	2	3	2	2	1	0.66856	0	2	4
Brainstorming	2	2	2	2	2	2	3	2	2	3	2	2	2	0	0.38925	0	2	3
Questionnaires/surveys	1	3	3	3	2	3	1	3	3	4	3	3	3	0.25	0.88763	0	1	4
Relevance trees	2	4	4	2	2	2	2	2	1	2	3	2	2	0.25	0.88763	0	1	4
Trend impact analysis	1	2	1	1	2	5	1	4	1	4	1	1	1	1.5	1.4771	0	1	5
Trend extrapolation	5	2	3	1	3	1	3	1	3	3	3	2	3	1.25	1.16775	0	1	5
Back casting	2	2	1	2	2	4	3	2	2	5	2	1	2	0.25	1.1547	0	1	5
Cross-impact analysis	3	1	2	1	1	2	2	1	4	1	3	1	1.5	1.25	1.02986	0	1	4
Stakeholder mapping	1	2	4	2	2	3	2	2	3	2	2	2	2	0.25	0.75378	0	1	4
Text mining	3	3	3	2	3	3	4	3	3	2	3	3	3	0	0.51493	0	2	4
System dynamic	4	3	2	3	3	3	3	2	3	3	3	3	3	0	0.51493	0	2	4
Futures wheel	3	3	1	3	3	3	3	1	3	5	3	1	3	0.5	1.1547	0	1	5

MS = Median Score; IQR = inter quartile range; SD = Standard Deviation
Consensus = 1 if reached; 0 otherwise
Kendall's coefficient of concordance (W) = 0.396

MS = median score; IQR = inter quartile range; SD = standard deviation.
Consensus = 1 if reached; 0 otherwise.
Kendall's Coefficient of Concordance (W) = 0.396.

Table 4
Rating results after the 2st round of Delphi (feedbacks provided in the 3rd round).

TFM	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7	Ex8	Ex9	Ex 10	Ex 11	Ex 12	MS	IQR	SD	Consensus	min	max
Morphological analysis	4	4	4	4	5	4	4	4	4	3	4	4	4	0	0.426	1	3	5
Scenario planning	4	4	2	4	5	4	4	4	4	4	5	4	4	0	0.739	1	2	5
SWOT	3	5	3	5	4	5	5	4	3	3	5	5	4.5	2	0.937	0	3	5
Delphi	4	4	4	3	5	4	5	4	4	4	4	4	4	0	0.515	1	3	5
Key technologies	5	4	3	5	3	5	5	5	3	2	5	5	5	2	1.115	0	2	5
Technology roadmapping	5	3	5	5	3	4	5	3	4	3	4	3	4	2	0.900	0	3	5
Modeling & simulation	4	5	4	4	2	4	2	4	3	4	4	4	4	0.25	0.888	1	2	5
Literature review	3	3	4	5	5	2	4	3	5	5	3	3	3.5	2	1.055	0	2	5
Futures workshops	3	4	3	4	3	2	3	3	3	2	3	3	3	0	0.603	0	2	4
Patent analysis	4	4	3	4	4	2	5	4	4	2	4	4	4	0.25	0.888	1	2	5
Multiscale analysis	5	5	4	5	2	5	5	2	4	5	5	2	5	1.5	1.311	0	2	5
Monitoring technology	2	3	3	5	5	3	3	3	5	3	5	3	3	2	1.084	0	2	5
Environmental scanning	1	2	1	1	2	1	1	3	1	1	1	3	1	1	0.798	0	1	3
Expert panel	2	3	2	2	2	4	2	3	2	2	3	2	2	1	0.669	0	2	4
Brainstorming	2	2	2	2	2	2	3	2	2	3	2	2	2	0	0.389	0	2	3
Questionnaires/surveys	1	3	3	3	2	3	1	3	3	4	3	3	3	0.25	0.888	0	1	4
Relevance trees	2	4	4	2	2	2	2	2	1	2	3	2	2	0.25	0.888	0	1	4
Trend impact analysis	1	2	1	1	2	3	1	2	1	4	1	1	1	1	0.985	0	1	4
Trend extrapolation	5	2	3	1	3	1	3	1	3	3	3	2	3	1.25	1.168	0	1	5
Back casting	2	2	1	2	2	4	3	2	2	5	2	1	2	0.25	1.155	0	1	5
Cross-impact analysis	3	1	2	1	1	2	2	1	4	1	3	1	1.5	1.25	1.030	0	1	4
Stakeholder mapping	1	2	4	2	2	3	2	2	3	2	2	2	2	0.25	0.754	0	1	4
Text mining	3	3	3	2	3	3	4	3	3	2	3	3	3	0	0.515	0	2	4
System dynamic	4	3	2	3	3	3	3	2	3	3	3	3	3	0	0.515	0	2	4
Futures wheel	3	3	1	3	3	3	3	1	3	5	3	1	3	0.5	1.155	0	1	5

MS = Median Score; IQR = inter quartile range; SD = Standard Deviation
Consensus = 1 if reached; 0 otherwise
Kendall's Coefficient of Concordance (W) = 0.483

MS = median score; IQR = inter quartile range; SD = standard deviation.
Consensus = 1 if reached; 0 otherwise.
Kendall's Coefficient of Concordance (W) = 0.483.

Table 5
Rating results after the 3st round of Delphi.

TFM	Ex 1	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7	Ex 8	Ex 9	Ex 10	Ex 11	Ex 12	MS	IQR	SD	Consensus	min	max
Morphological analysis	4	4	4	4	5	4	4	4	4	3	4	4	4	0	0.426	1	3	5
Scenario planning	4	4	2	4	5	4	4	4	4	4	5	4	4	0	0.739	1	2	5
SWOT	4	5	5	5	4	5	5	4	3	3	5	5	5	1	0.793	1	3	5
Delphi	4	4	4	3	5	4	5	4	4	4	4	4	4	0	0.515	1	3	5
Key technologies	5	4	4	5	3	5	5	5	3	5	5	5	5	1	0.798	1	3	5
Technology roadmapping	5	5	5	5	4	4	5	3	4	4	4	3	4	1	0.754	1	3	5
Modeling & simulation	4	5	4	4	2	4	2	4	3	4	4	4	4	0.25	0.888	1	2	5
Literature review	3	3	4	5	5	4	4	4	5	5	4	5	4	1	0.754	1	3	5
Futures workshops	3	4	3	4	4	4	3	5	5	5	4	4	4	0.5	0.739	1	3	5
Patent analysis	4	4	3	4	4	2	5	4	4	4	4	4	4	0	0.718	1	2	5
Multiscale analysis	5	5	4	5	4	5	5	2	4	5	5	3	5	1	0.985	1	2	5
Monitoring technology	4	4	5	5	5	4	5	3	5	3	5	4	4.5	1	0.778	1	3	5
Environmental scanning	1	2	1	1	2	1	1	3	1	1	1	3	1	1	0.798	0	1	3
Expert panel	2	3	2	2	2	4	2	3	2	2	3	2	2	1	0.669	0	2	4
Brainstorming	2	2	2	2	2	2	3	2	2	3	2	2	2	0	0.389	0	2	3
Questionnaires/surveys	1	3	3	3	2	3	1	3	3	4	3	3	3	0.25	0.888	0	1	4
Relevance trees	2	4	4	2	2	2	2	2	1	2	3	2	2	0.25	0.888	0	1	4
Trend impact analysis	1	2	1	1	2	3	1	2	1	4	1	1	1	1	0.985	0	1	4
Trend extrapolation	5	2	3	1	3	1	3	1	3	3	3	2	3	1.25	1.168	0	1	5
Back casting	2	2	1	2	2	4	3	2	2	5	2	1	2	0.25	1.155	0	1	5
Cross-impact analysis	3	1	2	1	1	2	2	1	4	1	3	1	1.5	1.25	1.030	0	1	4
Stakeholder mapping	1	2	4	2	2	3	2	2	3	2	2	2	2	0.25	0.754	0	1	4
Text mining	3	3	3	2	3	3	4	3	3	2	3	3	3	0	0.515	0	2	4
System dynamic	4	3	2	3	3	3	3	2	3	3	3	3	3	0	0.515	0	2	4
Futures wheel	3	3	1	3	3	3	3	1	3	5	3	1	3	0.5	1.155	0	1	5

MS = Median Score; IQR = inter quartile range; SD = Standard Deviation
Consensus = 1 if reached; 0 otherwise
Kendall's Coefficient of Concordance (W) = 0.628

MS = median score; IQR = inter quartile range; SD = standard deviation.
Consensus = 1 if reached; 0 otherwise.
Kendall's Coefficient of Concordance (W) = 0.628.

Table 6
Relevant technology foresight methods identified in the case study.

TFM	Marker
Monitoring	MO
Morphological analysis	MA
Scenario planning	SP
SWOT	SW
Delphi	DE
Key technologies	KT
Multi-scale analysis	MSA
Technology roadmapping	TR
Modeling and simulation	M & S
Literature review	LR
Future workshops	FW
Patent analysis	PA

Table 7
Two-way contingency table reporting experts' ratings (matrix D).

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
MO	6	18	15	12	18	18	6	20	3	15	6	6	6
MA	18	12	12	12	12	15	15	9	20	9	9	9	9
SP	18	9	6	9	3	6	20	3	18	9	15	15	6
SW	12	12	9	9	18	18	15	12	12	15	12	9	12
DE	20	6	6	9	6	3	18	6	15	9	15	18	9
KT	18	3	3	3	6	9	15	9	12	9	9	12	9
MSA	12	3	9	9	15	18	12	15	15	9	12	9	12
TR	15	9	6	6	6	6	12	12	15	12	9	12	9
M & S	15	9	12	12	15	18	12	18	12	9	9	18	15
LR	9	12	9	9	18	18	9	15	9	6	6	12	6
FW	12	12	15	12	9	9	12	18	12	12	12	12	15
PA	9	12	6	9	18	18	6	18	9	6	6	6	9

C_k^+ being closer to (farther from) the origin than C_k^- means that C_k^+ weights more (less) than C_k^-.

For example, the average ratings for the criteria C1 and C6 are on the "strongly high" side of the scale (the actual average of criterion C1 is 14 and the one of criterion C6 is 13), while the average ratings for C2 and C3 are slightly on the "strongly low" side of the scale (the actual average of criterion C2 is 10 and the one of criterion C3 is 9).

The cosine of the angle between two of the 13 rating scale axes in Fig. 5 can be used to approximate the correlation between the two corresponding criteria. The angle between two axes indicates the smallest angle to use in a counterclockwise rotation about the origin for the positive pole of one axis to align with the positive pole of the other axis. The closer the angle gets to 90° the closer the cosine gets to 0 and the less correlated the two criteria are.

This allows us to establish the correlations among the criteria. For instance, we could conclude that criteria C5, and C6 are positively correlated but uncorrelated with C13. For the sake of completeness, we have performed the correlation test for each pair of criteria. The correlation values are reported in Table 12.

Note that the correlations are not exactly recovered by the computation of the cosines since the two-dimensional map does not explain 100% of the inertia (it explains 72.1% of the inertia). A more accurate evaluation of the correlations among the criteria would be provided by a three-dimensional view of the rating scale axes.

Next, we plotted the positive and negative poles of the criteria and the TFMs on the same two-dimensional chart. This chart is represented in Fig. 6 and allows for a graphical evaluation of the methods with respect to the criteria. For instance, Fig. 6 shows that method KT has a strongly low score with respect to criteria C2, C3 and C4. At the same time, method MO has a strongly high score with respect to criteria C2 and C8 and a strongly low score with respect to criterion C1.

Having a visual of the position of the TFMs with respect to the criteria can be used to determine whether there exist groups of TFMs

Table 8
Doubled two-way contingency table (matrix F).

	C1		C2		C3		···	C11		C12		C13	
	C1 −	C1 +	C2 −	C2 +	C3 −	C3 +	···	C11 −	C11 +	C12 −	C12 +	C13 −	C13 +
MO	14	5	2	17	5	14	···	14	5	14	5	14	5
MA	2	17	8	11	8	11	···	11	8	11	8	11	8
SP	2	17	11	8	14	5	···	5	14	5	14	14	5
SW	8	11	8	11	11	8	···	8	11	11	8	8	11
DE	0	19	14	5	14	5	···	5	14	2	17	11	8
KT	2	17	17	2	17	2	···	11	8	8	11	11	8
MSA	8	11	17	2	11	8	···	8	11	11	8	8	11
TR	5	14	11	8	14	5	···	11	8	8	11	11	8
M & S	5	14	11	8	8	11	···	11	8	2	17	5	14
LR	11	8	8	11	11	8	···	14	5	8	11	14	5
FW	8	11	8	11	5	14	···	8	11	8	11	5	14
PA	11	8	8	11	14	5	···	14	5	14	5	11	8

Table 9
Correspondence analysis summary.

Dimension	Singular value	Inertia	Chi square	Sig.	Proportion of inertia		Confidence singular value	
					Accounted for	Cumulative	Standard deviation	Correlation 2
1	0.348	0.121			0.619	0.619	0.016	− 0.020
2	0.141	0.020			0.102	0.721	0.018	
3	0.137	0.019			0.096	0.817		
4	0.119	0.014			0.072	0.890		
5	0.088	0.008			0.040	0.929		
6	0.080	0.006			0.033	0.962		
7	0.055	0.003			0.016	0.978		
8	0.044	0.002			0.010	0.988		
9	0.033	0.001			0.005	0.994		
10	0.029	0.001			0.004	0.998		
11	0.020	0.000			0.002	1.000		
Total		0.195	579.340	0.000[a]	1.000	1.000		

[a] 275 degrees of freedom; degrees of freedom = $(n - 1)\,(2m - 1) = (12 - 1)\,(2 * 13 - 1) = 11 * 25 = 275$.

Table 10
Appropriate dimensionality of a perceptual map for technology foresight methods.

Alternative	Mass	Score in dimension		Inertia	Contribution				
					Of point to inertia of dimension		Of dimension to inertia of point		
		1	2		1	2	1	2	Total
MO	0.083	1.030	− 0.183	0.038	0.254	0.020	0.821	0.010	0.831
MA	0.083	− 0.160	− 0.227	0.010	0.006	0.030	0.077	0.063	0.140
SP	0.083	− 0.949	− 0.041	0.029	0.216	0.001	0.894	0.001	0.895
SW	0.083	0.263	− 0.124	0.008	0.017	0.009	0.236	0.021	0.258
DE	0.083	− 0.912	− 0.104	0.026	0.199	0.006	0.919	0.005	0.924
KT	0.083	− 0.560	0.606	0.016	0.075	0.216	0.573	0.273	0.846
MSA	0.083	0.155	0.172	0.008	0.006	0.017	0.087	0.044	0.131
TR	0.083	− 0.391	0.121	0.009	0.037	0.009	0.498	0.019	0.518
M & S	0.083	0.249	− 0.405	0.011	0.015	0.097	0.161	0.174	0.335
LR	0.083	0.523	0.385	0.012	0.066	0.087	0.646	0.142	0.788
FW	0.083	0.079	− 0.748	0.010	0.001	0.330	0.018	0.646	0.664
PA	0.083	0.672	0.549	0.018	0.108	0.177	0.724	0.196	0.920
Active total	1.000			0.195	1.000	1.000			

which are assigned similar scores with respect to a fixed subset of criteria. This is important when introducing further conditions (i.e. additional data points) in order to identify the best methods for a specific organization.

Finally, we calculated the row scores under some specific organization conditions and selected the most suitable methods (Step 5.8). We used the matrix R_{new} of Eq. (20) to obtain the scores relative to one organization condition, namely, the performance, and plot it on the perceptual map of the TFMs. Tables 13 and 14 report the experts' ratings of the performance of Knowledgecare with respect to all the criteria and the corresponding doubled data, respectively.

Fig. 7 presents the MCA map of the TFMs to which it has been added the organization condition of performance. The performance scores correspond to the point denoted by “Real”. Based on the position of “Real” on the map, we could conclude that the most suitable TFMs to implement at Knowledgecare are SWOT (SW), morphological analysis (MA) and MSA.

Table 11
Appropriate dimensionality of a perceptual map for criteria.

Criteria	Mass	Score in dimension		Inertia	Contribution				
					Of point to inertia of dimension		Of dimension to inertia of point		
		1	2		1	2	1	2	Total
C1 +	0.051	− 0.520	− 0.063	0.006	0.040	0.001	0.860	0.005	0.866
C1 −	0.026	1.041	0.127	0.011	0.080	0.003	0.860	0.005	0.866
C2 +	0.035	0.508	− 0.438	0.008	0.026	0.048	0.413	0.124	0.537
C2 −	0.041	− 0.434	0.373	0.007	0.022	0.041	0.413	0.124	0.537
C3 +	0.032	0.450	− 0.935	0.007	0.019	0.200	0.334	0.586	0.919
C3 −	0.045	− 0.327	0.680	0.005	0.014	0.145	0.334	0.586	0.919
C4 +	0.033	0.236	− 0.620	0.003	0.005	0.091	0.197	0.554	0.751
C4 −	0.044	− 0.181	0.476	0.003	0.004	0.070	0.197	0.554	0.751
C5 +	0.045	0.776	0.104	0.011	0.077	0.003	0.845	0.006	0.851
C5 −	0.032	− 1.067	− 0.142	0.015	0.106	0.005	0.845	0.006	0.851
C6 +	0.049	0.690	0.126	0.011	0.067	0.005	0.746	0.010	0.756
C6 −	0.028	− 1.183	− 0.216	0.019	0.114	0.009	0.746	0.010	0.756
C7 +	0.047	− 0.539	− 0.179	0.006	0.039	0.011	0.813	0.036	0.849
C7 −	0.030	0.857	0.284	0.009	0.063	0.017	0.813	0.036	0.849
C8 +	0.048	0.652	− 0.176	0.009	0.059	0.011	0.801	0.024	0.825
C8 −	0.029	− 1.098	0.296	0.015	0.099	0.018	0.801	0.024	0.825
C9 +	0.047	− 0.478	− 0.134	0.006	0.031	0.006	0.588	0.019	0.607
C9 −	0.030	0.761	0.213	0.010	0.049	0.010	0.588	0.019	0.607
C10 +	0.036	0.086	− 0.427	0.004	0.001	0.047	0.026	0.261	0.287
C10 −	0.040	− 0.078	0.384	0.003	0.001	0.042	0.026	0.261	0.287
C11 +	0.036	− 0.435	− 0.342	0.004	0.020	0.030	0.562	0.141	0.703
C11 −	0.040	0.392	0.308	0.004	0.018	0.027	0.562	0.141	0.703
C12 +	0.043	− 0.407	− 0.271	0.006	0.020	0.022	0.430	0.078	0.508
C12 −	0.034	0.502	0.335	0.007	0.025	0.027	0.430	0.078	0.508
C13 +	0.035	0.039	− 0.489	0.004	0.000	0.060	0.004	0.282	0.286
C13 −	0.041	− 0.033	0.417	0.004	0.000	0.051	0.004	0.282	0.286
Active total	1.000			0.195	1.000	1.000			

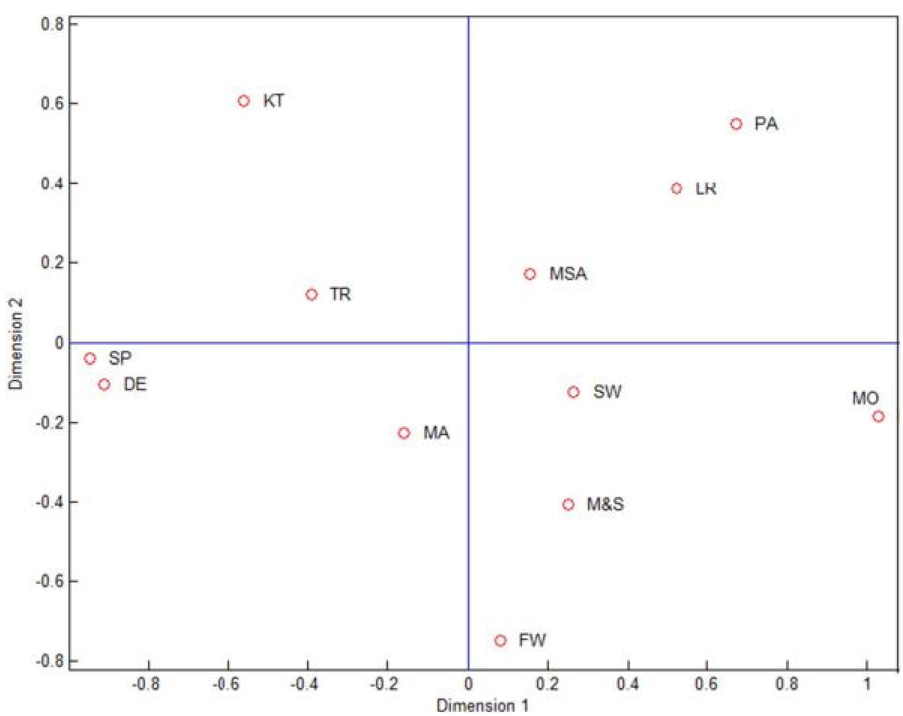

Fig. 3. MCA perceptual map of the technology foresight methods. The first and second axes account for 61.9% and 10.2% of the explained variance, respectively.

5. Conclusions

We have proposed an evaluation procedure to identify the most suitable technology foresight methods (TFMs) for the technology development process of an organization. This procedure consists of two phases, a qualitative case-dependent analysis and a quantitative case-independent analysis that are developed through five consecutive steps. The first three steps correspond to the qualitative phase where the relevant evaluation criteria and TFMs are identified via a literature review and the Delphi method, respectively. The remaining two steps correspond to the quantitative phase and assess the TFMs obtained in first phase by means of a multiple correspondence analysis (MCA) that follows a row principal scoring approach to allow for the reduction of dimensionality and the use of two-dimensional perceptual maps. One of

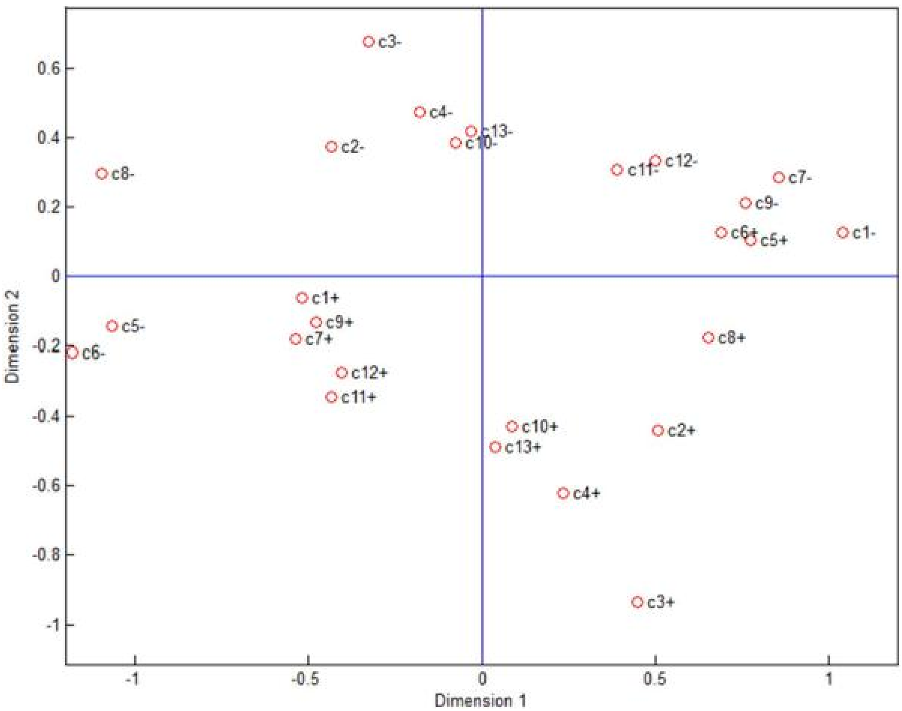

Fig. 4. MCA perceptual map of the doubled criteria (positive and negative poles). The first and second axes account for 61.9% and 10.2% of the explained variance, respectively.

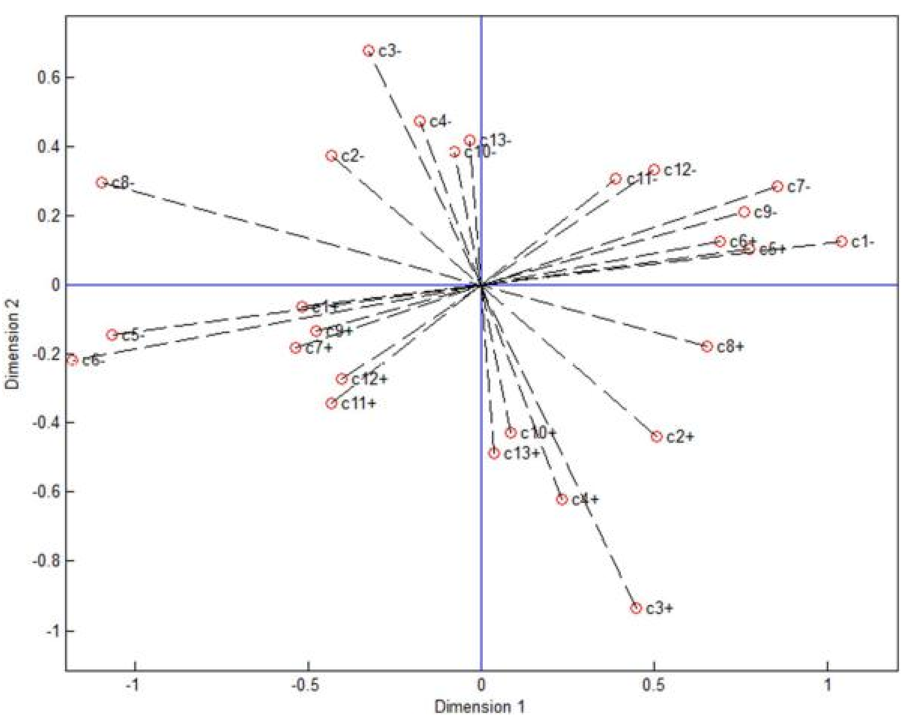

Fig. 5. MCA map of criteria: positive and negative poles and rating scales.

the important steps of the procedure is the application of the doubling data technique to the rating data. Thanks to this technique rating data are assimilated to frequency data which are the kind of data usually employed in a MCA.

We have focused on the applicability of the proposed procedure and its practical value. More precisely, we have presented the results obtained by implementing the proposed procedure in a case study of a knowledge-based organization very active in creating and applying knowledge in healthcare. In particular, the use of doubled data for the two-way contingency matrix of the MCA turned out to be essential in order to perform a meaningful graphical analysis of the TFMs versus the criteria.

The main limitations of the proposed approach are related to the qualitative phase.

In the case study, we used a literature review to identify the relevant evaluation criteria and the initial set of TFMs, and the Delphi method to refine the set of TFMs after selecting the experts' panel. However, these two methods do not necessarily represent the best way of identifying the TFMs and/or the evaluation criteria. As remarked through the paper, both the TFMs and the evaluation criteria must be chosen so as to reflect (and account for) the complex interrelationships exiting among the long-term goals, the decision-making processes and the

Table 12
Correlations among criteria.

	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	− 0.628	− 0.471	− 0.315	− 0.795	− 0.703	0.879	− 0.828	0.815	− 0.204	0.645	0.673	0.079
C2		0.650	0.621	0.503	0.389	− 0.521	0.469	− 0.514	0.389	− 0.477	− 0.454	− 0.227
C3			0.868	0.447	0.433	− 0.381	0.611	− 0.301	0.433	− 0.199	− 0.213	− 0.253
C4				0.424	0.393	− 0.227	0.417	− 0.105	0.171	− 0.031	− 0.063	0.263
C5					0.944	− 0.733	0.731	− 0.607	0.048	− 0.622	− 0.570	0.090
C6						− 0.652	0.676	− 0.471	− 0.016	− 0.617	− 0.564	0.131
C7							− 0.896	0.783	0.007	0.855	0.623	0.040
C8								− 0.733	0.161	− 0.660	− 0.447	0.358
C9									− 0.240	0.630	0.400	0.135
C10										0.143	− 0.230	0.175
C11											0.549	0.241
C12												0.225

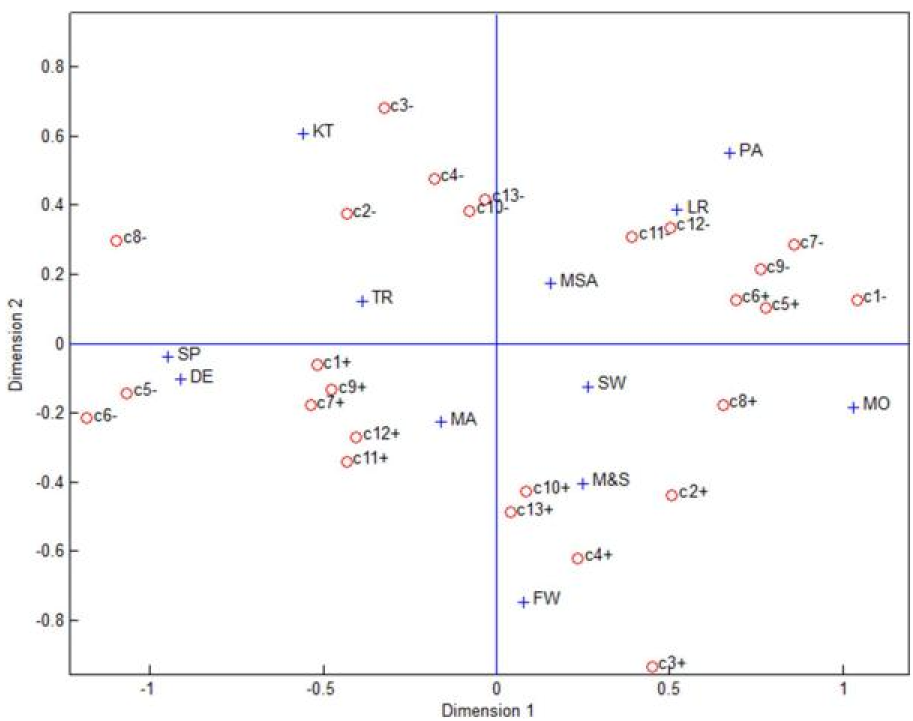

Fig. 6. MCA perceptual map of both technology foresight methods and criteria.

Table 13
Organizational performance ratings under evaluation criteria.

	Criterion												
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Performance	12	9	9	9	12	12	12	12	9	9	12	12	12

Table 14
Organizational performance ratings under doubled criteria.

	Doubled criterion								
	C1		C2		…	C12		C13	
	C1 −	C1 +	C2 −	C2 +	…	C12 −	C12 +	C13 −	C13 +
Performance	8	11	11	8	…	8	11	8	11

technology policies and strategies of the organization.

It follows that our procedure can be surely implemented by any company similar in features (goals and context) to the one considered in the case study, but the qualitative phase must be carefully adapted (and possibly completely redesigned) to fit a different context.

In particular, as any semi-quantitative method, the Delphi method is affected by the quality of the experts selected to compose the panel since the validity of the results clearly relies on their judgements. The subjectivity characterizing the expert selection as well as the interpretation of the data provided by both the manager (conducting the selection procedure) and the experts is a limitation of the Delphi method unavoidably inherited by the qualitative analysis of our model.

As for the advantages of the proposed evaluation procedure, they are to be found in its quantitative phase.

The MCA performed in the quantitative phase depends only marginally on the characteristics of the organization. This fact not only shows the applicability of a MCA in combination with consensus-based managerial methods such as the well-known Delphi method, buts also represents the actual merit of the paper. The proposed two-phase procedure allows one to counterbalance the drawbacks inherent to a qualitative analysis (easily affected by a wrong choice of experts or inaccurate judgements) via a quantitative analysis that synthesizes criteria and alternatives as data points of a low dimensional space based on the level of total inertia.

As a consequence, our framework can be extended to a variety of assessment situations, from those dealing with supplier selection

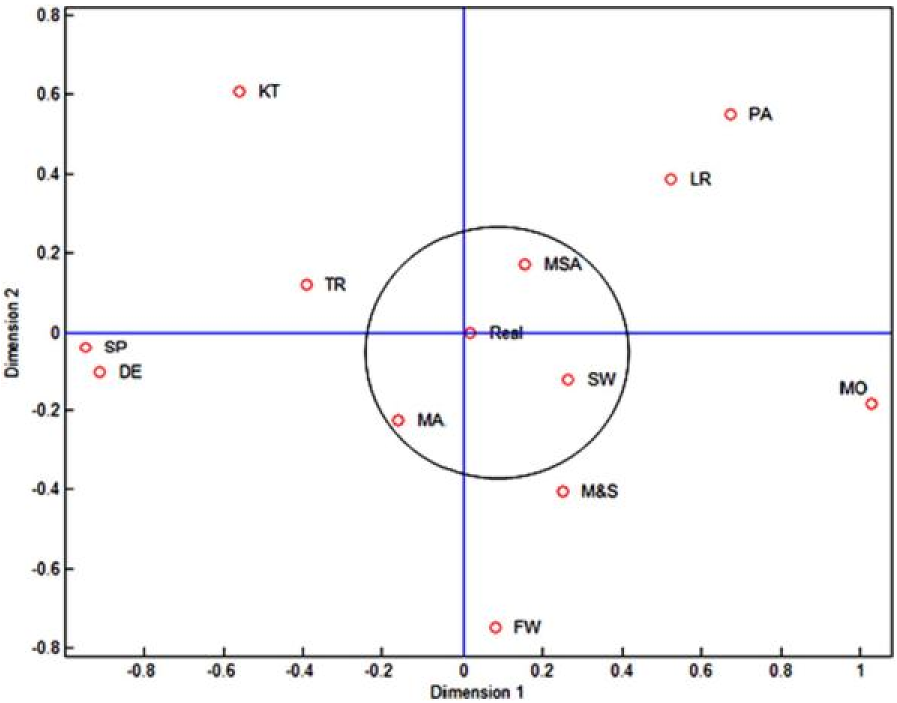

Fig. 7. Technology foresight methods to choose under the organization conditions.

problems or human resource management to those focusing on project assessment or product evaluation problems.

Another merit of the proposed model is that it provides a valid alternative to integrated assessment approaches combining consensus-based methods with Analytic Hierarchy Process (AHP) and/or Analytic Network Process (ANP) models. Indeed, using a MCA in place of AHP for the quantitative analysis can help to reduce the subjectivity of the evaluation process in situations where the definition of the hierarchical structures involved in the process might not fit the problem at hand due to an inaccurate assignment of weights to criteria and alternatives.

Finally, regarding the specific drawbacks and advantages due to the way the MCA has been applied in the case study, we would like to underline the following points.

The correlations among the evaluation criteria were not recovered completely by the data point approximations obtained by the MCA. This is due to the fact that the two-dimensional perceptual map of the case studies does not explain 100% of the inertia, but 72.1% of it. To provide a more accurate evaluation of the correlations among the criteria it would have been necessary to provide a three-dimensional view of the rating scale axes. This limitation could represent a serious disadvantage in studies where the correlations among criteria must be exact, since a three or higher dimensional representation of the rating scales involves a level of abstraction usually difficult to deal with.

The doubling data step, Step 4, has been performed using a discrete scale, but it could have been redefined so as to use an initial continuous scale by means of a simple discretization process. This is a technical advantage that can be exploited to perform the MCA described here in many real life situations where the items to assess are naturally rated on a continuous scale rather than on a discrete one.

The last step of the MCA, Step 5.8, allows one to refine the final selection of TFMs by implementing additional information relative to the organization in the last stage. Apart from providing a term of comparison on the basis of which it is possible to choose the best TFMs, this last step also allows the manager and the experts' panel to take in account factors and relationships that may have not been known or considered important at the beginning of the study. That is, should some essential data about the organization become available at any time after the evaluation procedure has started, the manager does not need to restart the procedure. He/she can conveniently adapt the MCA step, Step 5, by requesting to repeat Step 5.8 for each additional information received.

Acknowledgement

The authors would like to thank the anonymous reviewers and the editor for their insightful comments and suggestions.

References

Amer, M., Daim, T.U., Jetter, A., 2013. A review of scenario planning. Futures 46, 23–40.
Andersen, A.D., Andersen, P.D., 2014. Innovation system foresight. Technol. Forecast. Soc. Chang. 88, 276–286.
Andersen, P.D., Rasmussen, B., 2014. Introduction to Foresight and Foresight Processes in Practice: Note for the PhD Course Strategic Foresight in Engineering. Department of Management Engineering, Technical University of Denmark.
Antonic, N., van Duijn, C.J., Jäger, W., Mikelic, A. (Eds.), 2011. Multiscale Problems in Science and Technology: Challenges to Mathematical Analysis and Perspectives. Springer Science & Business Media.
Barker, D., Smith, D.J., 1995. Technology foresight using roadmaps. Long Range Plan. 28 (2), 21–28.
Battistella, C., 2014. The organisation of corporate foresight: a multiple case study in the telecommunication industry. Technol. Forecast. Soc. Chang. 87, 60–79.
Beddow, J.K., 2013. Morphological analysis of particles and surfaces. In: Production and Processing of Fine Particles: Proceedings of the International Symposium on the Production and Processing of Fine Particles, Montreal, August 28–31, 1988. Elsevier, pp. 25 (October).
Bengisu, M., Nekhili, R., 2006. Forecasting emerging technologies with the aid of science and technology databases. Technol. Forecast. Soc. Chang. 73 (7), 835–844.
Chen, S.H., Huang, M.H., Chen, D.Z., 2012. Identifying and visualizing technology evolution: a case study of smart grid technology. Technol. Forecast. Soc. Chang. 79 (6), 1099–1110.
Cheng, A.C., Chen, C.J., Chen, C.Y., 2008. A fuzzy multiple criteria comparison of technology forecasting methods for predicting the new materials development. Technol. Forecast. Soc. Chang. 75 (1), 131–141.
Cho, J., Lee, J., 2013. Development of a new technology product evaluation model for assessing commercialization opportunities using Delphi method & fuzzy AHP approach. Expert Syst. Appl. 40, 5314–5330.
Choi, J., Hwang, Y.S., 2014. Patent keyword network analysis for improving technology development efficiency. Technol. Forecast. Soc. Chang. 83, 170–182.
Christensen, C., 2013. The innovator's Dilemma: When new Technologies Cause Great Firms to Fail. Harvard Business Review Press.
Coates, V., Farooque, M., Klavans, R., Lapid, K., Linstone, H.A., Pistorius, C., Porter, A.L., 2001. On the future of technological forecasting. Technol. Forecast. Soc. Chang. 67 (1), 1–17.
Cosmi, F., Bernasconi, A., Sodini, N., 2011. Phase contrast micro-tomography and morphological analysis of a short carbon fibre reinforced polyamide. Compos. Sci. Technol. 71 (1), 23–30.

Daim, T.U., Rueda, G., Martin, H., Gerdsri, P., 2006. Forecasting emerging technologies: use of bibliometrics and patent analysis. Technol. Forecast. Soc. Chang. 73 (8), 981–1012.
Davis, P., Sullivan, E., Marlow, D., Marney, D., 2013. A selection framework for infrastructure condition monitoring technologies in water and wastewater networks. Expert Syst. Appl. 40 (6), 1947–1958.
De Leeuw, J., Mair, P., 2009. Simple and canonical correspondence analysis using the R package anacor. J. Stat. Softw. 31 (5), 1–18.
Delbecq, A.L., van de Ven, A.H., Gustavson, D.H., 1975. Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes. Scott Foresman and Company, Glenview, Illinois.
Donohoe, H.M., 2011. Defining culturally sensitive ecotourism: a Delphi consensus. Curr. Issue Tour. 14 (1), 27–45.
Dubarić, E., Giannoccaro, D., Bengtsson, R., Ackermann, T., 2011. Patent data as indicators of wind power technology development. World Patent Inf. 33 (2), 144–149.
Eastwood, J.L., 2011. The paradox of scientific authority: the role of scientific advice in democracies. Sci. Educ. 95 (2), 380–382.
Eto, H., 2003. The suitability of technology forecasting/foresight methods for decision systems and strategy: a Japanese view. Technol. Forecast. Soc. Chang. 70 (3), 231–249.
Firat, A.K., Woon, W.L., Madnick, S., 2008. Technological Forecasting–A Review. Composite Information Systems Laboratory (CISL), Massachusetts Institute of Technology.
Foray, D., Grübler, A., 1990. Morphological analysis, diffusion and lockout of technologies: ferrous casting in France and the FRG. Res. Policy 19 (6), 535–550.
Förster, B., von der Gracht, H., 2014. Assessing Delphi panel composition for strategic foresight—a comparison of panels based on company-internal and external participants. Technol. Forecast. Soc. Chang. 84, 215–229.
Gao, S., Low, S.P., 2014. The last planner system in China's construction industry—a SWOT analysis on implementation. Int. J. Proj. Manag. 32 (7), 1260–1272.
Garimella, S.V., Persoons, T., Weibel, J., Yeh, L.T., 2013. Technological drivers in data centers and telecom systems: multiscale thermal, electrical, and energy management. Appl. Energy 107, 66–80.
Geist, M.R., 2010. Using the Delphi method to engage stakeholders: a comparison of two studies. Eval. Program Plan. 33 (2), 147–154.
Georghiou, L., Keenan, M., 2006. Evaluation of national foresight activities: assessing rationale, process and impact. Technol. Forecast. Soc. Chang. 73 (7), 761–777.
Greenacre, M.J., 2007. Correspondence Analysis in Practice. Chapman & Hall/CRC Press, London.
Grossman, R., 2008. Literature Review: Impact of Technology Change on Issue Areas Relevant to Connectivity in Remote and Indigenous Communities. Centre for Community Informatics Research Development and Training and Northern Indigenous Community Satellite Network.
Hallowell, M.R., Gambatese, J.A., 2010. Population and initial validation of a formal model for construction safety risk management. J. Constr. Eng. Manag. 136 (9), 981–990.
Hayano, R.S., Masaharu Tsubokura, M., Miyazaki, M., Satou, H., Sato, K., Masaki, S., Sakuma, Y., 2015. Whole-body counter surveys of Miharu-town school children for four consecutive years after the Fukushima NPP accident. Proc. Jpn. Acad. B Phys. Biol. Sci. 91 (3), 92–98.
Horner, K., Islam, M., Flygare, L., Tsiklakis, K., Whaites, E., 2009. Basic principles for use of dental cone beam computed tomography: consensus guidelines of the European Academy of Dental and Maxillofacial Radiology. Dentomaxillofac. Radiol. 38 (4), 187–195.
Im, K., Cho, H., 2013. A systematic approach for developing a new business model using morphological analysis and integrated fuzzy approach. Expert Syst. Appl. 40 (11), 4463–4477.
İNtepe, G., Bozdag, E., Koc, T., 2013. The selection of technology forecasting method using a multi-criteria interval-valued intuitionistic fuzzy group decision making approach. Comput. Ind. Eng. 65 (2), 277–285.
Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., Mieno, H., 1993. The max-min Delphi method and fuzzy Delphi method via fuzzy integration. Fuzzy Sets Syst. 55 (3), 241–253.
Kazemzadeh, R., Reaziat, A., 2010. Positioning of industries in cyberspace; evaluation of web sites using correspondence. Int. J. Ind. Eng. Prod. Res. 20 (4).
Keenan, M., Popper, R., 2007. RIF (Research Infrastructures Foresight). European Commission, Brussels.
Keller, J., Heiko, A., 2014. The influence of information and communication technology (ICT) on future foresight processes—results from a Delphi survey. Technol. Forecast. Soc. Chang. 85, 81–92.
Kent, M.L., Saffer, A.J., 2014. A Delphi study of the future of new technology research in public relations. Public Relat. Rev. 40 (3), 568–576.
van de Kerkhof, M., Hisschemoller, M., Spanjersberg, M., 2002. Shaping diversity in participatory foresight studies: experiences with interactive backcasting in a stakeholder assessment on long-term climate policy in The Netherlands. Greener Manag. Int. 85–100.
Kim, M., Jang, Y.C., Lee, S., 2013. Application of Delphi-AHP methods to select the priorities of WEEE for recycling in a waste management decision-making tool. J. Environ. Manag. 128, 941–948.
Kolominsky-Rabas, P.L., Djanatliev, A., Wahlster, P., Gantner-Bär, M., Hofmann, B., German, R., Sedlmayre, M., Reinhardtd, E., Schüttler, J., Kriza, C., 2015. Technology foresight for medical device development through hybrid simulation: the ProHTA project. Technol. Forecast. Soc. Chang. 97, 105–114.
Kucharavy, D., De Guio, R., 2011. Logistic substitution model and technological forecasting. Procedia Eng. 9, 402–416.
Kudlats, J., Money, A., Hair, J.F., 2014. Correspondence analysis: a promising technique to interpret qualitative data in family business research. J. Fam. Bus. Strateg. 5 (1), 30–40.
Lee, W.J., Sohn, S.Y., 2014. Patent analysis to identify shale gas development in China and the United States. Energy Policy 74, 111–115.
Legendre, P., Legendre, L.F., 2012. Numerical Ecology. Vol. 24 Elsevier.
Levary, R.R., Han, D., 1995. Choosing a technological forecasting method. Ind. Manag. 37 (1), 14.
Linstone, H.A., Turoff, M., 2011. Delphi: a brief look backward and forward. Technol. Forecast. Soc. Chang. 78 (9), 1712–1719.
Magruk, A., 2011. Innovative classification of technology foresight methods. Technol. Econ. Dev. Econ. 17 (4), 700–715.
Mahmud, J., 2011. City foresight and development planning case study: implementation of scenario planning in formulation of the Bulungan development plan. Futures 43 (7), 697–706.
Martin, Ben R., Nightingale, Paul, Yegros-Yegros, Alfredo, 2012. Science and technology studies: exploring the knowledge base. Res. Policy 41 (7), 1182–1204.
Martino, J.P., 2003. A review of selected recent advances in technological forecasting. Technol. Forecast. Soc. Chang. 70 (8), 719–733.
McPherson, M., Karney, B., 2014. Long-term scenario alternatives and their implications: LEAP model application of Panama' s electricity sector. Energy Policy 68, 146–157.
Meijering, J.V., Kampen, J.K., Tobi, H., 2013. Quantifying the development of agreement among experts in Delphi studies. Technol. Forecast. Soc. Chang. 80 (8), 1607–1614.
Meredith, J.R., Mantel, S.J., Samuel, J., 1995. Project Management: A Managerial Approach. John Wiley & Sons, New York, pp. 1.
Miles, I., 2012. Dynamic foresight evaluation. Foresight 14 (1), 69–81.
Miles, I., Popper, R., 2008. The Handbook of Technology Foresight. MPG Books, Cornwall.
Miles, M., Ryman, T.K., Dietz, V., Zell, E., Luman, E.T., 2013. Validity of vaccination cards and parental recall to estimate vaccination coverage: a systematic review of the literature. Vaccine 31 (12), 1560–1568.
Miller, P., Swinehart, K., 2010. Technological forecasting: a strategic imperative. JGBM 6 (2), 1–5.
Mishra, S., Deshmukh, S.G., Vrat, P., 2002. Matching of technological forecasting technique to a technology. Technol. Forecast. Soc. Chang. 69 (1), 1–27.
Moro, S., Cortez, P., Rita, P., 2015. Business intelligence in banking: a literature analysis from 2002 to 2013 using text mining and latent Dirichlet allocation. Expert Syst. Appl. 42 (3), 1314–1324.
Neij, L., Andersen, P.D., Durstewitz, M., 2004. Experience curves for wind power. Int. J. Energy Technol. Policy 2 (1–2), 15–32.
Nosella, A., Petroni, G., Salandra, R., 2008. Technological change and technology monitoring process: evidence from four Italian case studies. J. Eng. Technol. Manag. 25 (4), 321–337.
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.J., Probert, D.R., 2004. Technology roadmapping – a planning framework for evolution and revolution. Technol. Forecast. Soc. Chang. 71 (1), 5–26.
Porter, A.L., Roper, A.T., 1991. Forecasting and Management of Technology. Vol. 18 John Wiley & Sons.
Rader, M., Porter, A.L., 2008. Fitting future-oriented technology analysis methods to study types. In: Future-Oriented Technology Analysis. Springer, Berlin Heidelberg, pp. 25–40.
Rådestad, M., Jirwe, M., Castrén, M., Svensson, L., Gryth, D., Rüter, A., 2013. Essential key indicators for disaster medical response suggested to be included in a national uniform protocol for documentation of major incidents: a Delphi study. Scand. J. Trauma Resuscitation Emerg. Med. 21 (68), 1–11.
Raford, N., 2015. Online foresight platforms: evidence for their impact on scenario planning & strategic foresight. Technol. Forecast. Soc. Chang. 97, 65–76.
Reger, G., 2001. Technology foresight in companies: from an indicator to a network and process perspective. Tech. Anal. Strat. Manag. 13 (4), 533–553.
Rohrbeck, R., Gemünden, H.G., 2011. Corporate foresight: its three roles in enhancing the innovation capacity of a firm. Technol. Forecast. Soc. Chang. 78 (2), 231–243.
Saritas, O., Pace, L.A., Stalpers, S.I., 2013. Stakeholder participation and dialogue in foresight. In: Borch, Kristian, Dingli, Sandra M., Jørgensen, Michael Søgaard (Eds.), Participation and Interaction in Foresight: Dialogue, Dissemination and Visions. Edward Elgar Publishing Limited, Cheltenham, UK, pp. 35–69.
Schubert, C., 2015. Situating technological and societal futures. Pragmatist engagements with computer simulations and social dynamics. Technol. Soc. 40, 4–13.
Sourani, A., 2015. The Delphi method: review and use in construction management research. Int. J. Constr. Educ. Res. 11 (1), 54–76.
Tang, Y., Sun, H., Yao, Q., Wang, Y., 2014. The selection of key technologies by the silicon photovoltaic industry based on the Delphi method and AHP (analytic hierarchy process): case study of China. Energy 75, 474–482.
Technology Futures Analysis Methods Working Group, 2004. Technology futures analysis: toward integration of the field and new methods. Technol. Forecast. Soc. Chang. 71 (3), 287–303.
Tewari, J.C., Dixit, V., Cho, B.K., Malik, K.A., 2008. Determination of origin and sugars of citrus fruits using genetic algorithm, correspondence analysis and partial least square combined with fiber optic NIR spectroscopy. Spectrochim. Acta A Mol. Biomol. Spectrosc. 71 (3), 1119–1127.
Tonn, B., Scheb, J., Fitzgerald, M., Stiefel, D., 2012. Future of governance workshop summary. Futures 44 (9), 773–777.
Tsai, J.M., Hung, S.W., 2014. A novel model of technology diffusion: system dynamics perspective for cloud computing. J. Eng. Technol. Manag. 33, 47–62.
Tseng, F.M., Cheng, A.C., Peng, Y.N., 2009. Assessing market penetration combining scenario analysis, Delphi, and the technological substitution model: the case of the OLED TV market. Technol. Forecast. Soc. Chang. 76 (7), 897–909.

Vanston, J.H., 2003. Better forecasts, better plans, better results. Res. Technol. Manag. 46 (1), 47–58.
Vidal, L.A., Marle, F., Bocquet, J.C., 2011. Using a Delphi process and the analytic hierarchy process (AHP) to evaluate the complexity of projects. Expert Syst. Appl. 38 (5), 5388–5405.
Vishnevskiy, K., Karasev, O., Meissner, D., 2015. Integrated roadmaps and corporate foresight as tools of innovation management: the case of Russian companies. Technol. Forecast. Soc. Chang. 90, 433–443.
Vishnevskiy, K., Karasev, O., Meissner, D., 2016. Integrated roadmaps for strategic management and planning. Technol. Forecast. Soc. Chang. 110, 153–166.
Wancura, H., Montignac, F., Mazzucchi, C., Spirig, M., e Costa, J. B., 2013. Creating a solid base for technology road mapping using an integrated technology monitoring and assessment tool. Procedia Soc. Behav. Sci. 75, 370–382.
Wang, Z.G., Wang, Y., Zhang, J.Q., Zhang, B.C., 2014. Overview of the key technologies of combined cycle engine precooling systems and the advanced applications of micro-channel heat transfer. Aerosp. Sci. Technol. 39, 31–39.
Weinberger, N., Jörissen, J., Schippl, J., 2012. Foresight on environmental technologies: options for the prioritisation of future research funding–lessons learned from the project “Roadmap Environmental Technologies 2020 + ”. J. Clean. Prod. 27, 32–41.
Yang, C., Liu, T., Kao, C., Wang, H., 2010. Interpreting AHP & Delphi methods to construct a green product assessment hierarchy for early stages of product design & development. Int. J. Oper. Res. 7 (3), 35–43.
Yelland, P.M., 2010. An introduction to correspondence analysis. Math. J. 12. http://dx.doi.org/10.3888/tmj.12-4.
Zimmermann, M., Darkow, I.L., Heiko, A., 2012. Integrating Delphi and participatory backcasting in pursuit of trustworthiness—the case of electric mobility in Germany. Technol. Forecast. Soc. Chang. 79 (9), 1605–1621.