TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT
2022, VOL. 34, NO. 8, 859–875
https://doi.org/10.1080/09537325.2021.1931672

A technology development framework for scenario planning and futures studies using causal modeling

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ABSTRACT
Planning for the future plays a pivotal role in a competitive business world. Scenario analysis is a popular tool for exploring plausible futures and planning. However, the practice of scenario planning is often qualitative, unstructured, and time-consuming. We propose a structured technology development framework by categorising the qualitative variables impacting technology development and identifying their causal relationships. We then use causal loops and expert opinions and the Decision Making Trial and Evaluation Laboratory (DEMATEL) method for scenario planning and futures studies. We present a case study in the communications industry to demonstrate the applicability of the proposed framework.

ARTICLE HISTORY
Received 6 April 2020
Revised 7 May 2021
Accepted 11 May 2021

KEYWORDS
Technology development; causal modelling; scenario planning; DEMATEL; futures studies

1. Introduction

Technology is the dominating force in creating organisational change, and it is imperative for managers to forecast technological changes and their impact on organisational longevity. The word technology emphasises the importance of machines (non-human) and human-machine interactions (Mintzberg 1993; Ramanathan 1994). In addition, a technological system is expected to integrate a material transformation subsystem with an information processing subsystem to accomplish the desired operations that the technology has been designed to perform (Ramanathan 1994). This paper closely follows Tschirky's (2003) definition of technology that states, 'Technology constitutes specific knowledge, abilities, methods, and equipment, facilitating the deployment of scientific and engineering knowledge.' Technology is the leading force in creating technical, economic, social, and organisational changes. Managers must forecast technological changes and their impact on corporate longevity. Futures studies expose as a helpful tool to plan for the future. Developing a technology plan detailing where an organisation is and where it wants to be concerning technology requires sizeable and high-quality information (Gelle and Karhu 2003; Vojak and Suarez-Nunez 2004). This information should be collected from different internal and external sources. Technology foresight and planning require a comprehensive and interactive process to study the dynamic relationship among the key internal and contextual factors and formulating future scenarios (Reger 2001). This study synthesises the current body of knowledge in futures studies and the relationship among the key elements to investigate possible scenarios and recommend viable future pathways. We focus on the communication industry, which is continually struggling with the rapid pace of

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technological changes and improvements. Technological change is a powerful source of competitive advantage and a significant ingredient of long-term economic growth. Technological innovation and change present both threats and opportunities characterised by a high degree of uncertainty. Understanding the nature of these uncertainties in the communications industry and the obstacles to overcome them is not a trivial matter. Failure to manage these uncertainties puts companies' short-term profitability at risk and impacts long-term growth and survival. Scenario planning and futures studies using causal modelling are highly beneficial to the communications industry due to uncertainties and rapid technological changes.

Causal modelling is a conceptual framework used to describe the causal mechanism of a technological system and predict its behaviour (Pearl and Mackenzie 2018). Bayesian networks and event trees have played an important role in technology research and causal modelling (Bollen and Pearl 2013). Bayesian networks were initially introduced by Pearl (1988) to capture interdependencies among system components using conditional probabilities. They are preferred tools for capturing causal relationships among random variables in complex technologies and systems with dependencies (Dai and Deng 2020; Zhang and Mahadevan 2020). Bayesian networks are designed to graphically model systems with uncertainty and intertwined casual relationships (Fenton and Neil 2013; Qazi and Akhtar 2020). The Bayesian network's qualitative (graphical) aspects can effectively model systems for evidence-based policy (Carriger, Dyson, and Benson 2018). Causality is essential for understanding complex technological systems with causal dependencies (Pearl and Mackenzie 2018). Event trees can also represent causality and interdependencies in probabilistic systems with binary trees (Rasmuson 1992). Compared with event trees, the Bayesian network has a distinctive advantage. The Bayesian network is more effective in supporting our belief on the system state by propagating information on random variables such as data or evidence in both forward and backward inference.

Previous studies have extensively researched the role of foresight and scenario building in improving strategic planning (Kononiuk and Glinska 2015; Peter and Jarratt 2013; Ruff 2014) and understanding technology development (Vishnevskiy, Karasev, and Meissner 2014; Gershman, Bredikhin, and Vishnevskiy 2016; Förster 2014). However, little attention has been paid to how the technology foresight goals can form strategic plans. We explain how causal loops, implemented via the Decision Making Trial and Evaluation Laboratory (DEMATEL) technique, can assist companies in their technology planning efforts. The causal loops explain the relationships between the key technological factors and their interactions, which leads to scenario planning and generating a suitable technology development path.

This study aims to conceptualise a technology development framework supported by an analysis of the intertwined and causal relationship among the system's components. Most previous studies on technology development are based on statistical relationships between influencing parameters, limiting the conclusions to previously observed patterns instead of the system's underlying causal relationships. Our goal is to establish an evidence-based framework supported by experts' knowledge and experience.

The remainder of this paper is organised as follows. Section 2 reviews the literature in technology foresight, technology development, and scenario building. Section 3 presents the proposed framework and the DEMATEL method. In Section 4, we present a case study in the communications industry to demonstrate the applicability of the proposed framework. Section 5 concludes with our conclusions.

2. Literature review

2.1. Technology foresight

Technology foresight, also known as 'futures studies' or 'future research,' is the process of speculating about the future of science, technology, the economy, and society to discover emerging technologies for substantial economic and social advantages (Martin 1995). This process involves establishing an advantageous connection between society and technology (Meissner 2012). Technology foresight, coupled with subjective methods (e.g. Delphi), can suggest critical technological development opportunities over the long term. Any company can benefit from technology foresight as it provides insights into how the industry is evolving and what technologies are needed to remain competitive in the marketplace.

Previous studies on technology foresight can be divided into two categories. The first category reports and discusses the process and results of numerous national-level foresight exercises achieved by different nations worldwide (Wonglimpiyarat 2007; Georghiou and Keenan 2006; Ruff 2014; Rongping et al. 2008). The effect of such exercises on a nation's policy-making in technology, research, innovation, and entrepreneurship is widely studied (Fuller and Warren 2006; Chan and Daim 2012; Meissner 2012; and Rhisiart and Jones-Evans 2016). The purpose of these studies is usually identifying a positive impact and discussing factors pivotal in making these impacts. While an industry or a company level foresight tends to be more focused on a certain technology area, a national level foresight covers a wide range of technologies. The second category includes those studies that explore the key factors for making the foresight exercises more effective (Gelle and Karhu 2003; Linstone 2011; Andersen and Rasmussen 2014), using various suggested methodologies (Jørgensen, Jørgensen, and Clausen 2009; Battistella and De Toni 2011; Johnston and Cagnin 2011; Smith and Saritas 2011; Chen, Wakeland, and Yu 2012; Van der Steen and Van der Duin 2012; Cagnin, Havas, and Saritas 2013). These studies are intended to provide advice on when and how one can opt or combine several methods within one project or focus area to gain the best outcomes.

Scenario techniques and technology foresight are regularly used to identify technology requirements and futures planning (Liu et al. 2011; Andersen et al. 2014). Saritas, Taymaz, and Tumer (2007) suggest a technology foresight programme should consider the effects of external contexts and the structural factors from these contextual levels. At this level, technology foresight is frequently referred to as technology monitoring, technology watch, or technology scouting (Reger 2001). There is also a slight overlap between technology foresight and strategic planning or technology road mapping (Reger 2001). Various tools and techniques such as the analytic hierarchy process (AHP) (Gerdsri and Kocaoglu 2007), the opinion survey, Delphi, and expert workshops (Rhisiart and Jones-Evans 2016), have been instrumental in identifying potential technologies along the planning horizon.

The value of large-scale and reliable information from external sources is highlighted in the technology planning literature (Gelle and Karhu 2003; Vojak and Suarez-Nunez 2004). Technology foresight can be used as an external source of information to assess and determine key technologies associated with the company's missions, goals, strategies, and capabilities (Chen, Ho, and Kocaoglu 2009). This practice can also generate business value by increasing a company's technology 'power zone' and offering new techno-based business opportunities (Carlson 2004).

The current literature in technology foresight and technology planning tends to concentrate on the evaluation and selection of potential technologies (Farrukh, Phaal, and Probert 2003; Chen, Ho, and Kocaoglu 2009), recognition of unforeseen changes and failure mechanism (Vojak and Suarez-Nunez 2004; Chen, Ho, and Kocaoglu 2009), and forecasting the technology development path (Kostoff and Schaller 2001; Gerdsri and Kocaoglu 2007; Yoon and Park 2007). In spite of recent advances in technology foresight, there is a lack of a comprehensive structure and technical framework for developing technology plans. Next, we briefly review the literature on technology development, focusing on identifying key technology development factors. These factors will then be used in the framework proposed in this study for scenario planning and futures studies. It is noteworthy to clarify the identification of new factors is not within the scope of this study.

2.2. Technology development

In the late twentieth century, there was an increasing tendency in using conventional methods for technology development. Howells (1991) explains this behaviour as a return to the nineteenth-century technology development era before the advent of the internal R&D in organisations. In that period, there was a growth in the technology market placed on gathering inventions from private inventors and supporting independent laboratories and universities by companies (Lamoreaux and Sokoloff 1999). Although internal R&D did not completely replace conventional methods, it had a significant impact on many companies (Grueber and Studt 2009). At that time, companies used asymmetrical approaches to technology development by preferring external sources to supplement internal R&D (Arora and Gambardella 1990).

In this study, we focus on the 'technology development' concept defined by Bostrom (2014), where technology is derived from human wisdom, and developing technology requires innovation and devising new products or procedures. New technologies usually are developed to address societal needs. This objective is achieved by using the knowledge, skills, and experience gained from the technology transfer process and the internal R&D.

Changes in technology growth and the global economy lead to a structural transformation, which has major impacts on the economy. Accordingly, after the market's disequilibrium in the 1970s, attention was drifted from mass production to customers' special needs and flexibility. Because this fundamental change led to falling transaction costs, a new branch of the economy (microeconomics) emerged (Thurik 2003). This economy, which is called 'entrepreneurial economics,' is concerned with ideas and knowledge rather than the traditional inputs for economies such as natural resources, workforce, and capital. Such fundamental change contains technological changes, the globalisation, the knowledge condensation, deregulations, labor-supply movement, a variety of demands, and the uncertainty. As a reaction to these factors, the industrial structure was formed to pay attention to small and medium-sized enterprises (SME) (Thurik 2003).

Previous studies have identified various downfalls for SMEs' such as limited resources, the absence of strategic directions, and financial barriers. These downfalls hamper technology development in SMEs, mainly because they necessitate short-term solutions and remedies to the day-to-day operations (Klewitz and Hansen 2014; Del Brìo and Junquera 2003). Technology development requires long-term devotion and vision. This is while the SMEs' progress requires a long-term pathway to creating value and promoting operational and strategic sustainability (Jenkins 2004; Jenkins 2009). A robust and sustainable strategic plan for technology development enables SMEs to improve their services/products and reduce their costs to survive in a competitive environment (Mephkee and Ruengsrichaiya 2005).

In technology management, especially in futuristic technology management, recognising and analysing factors influencing technology development play a pivotal role (Halicka 2016). These factors can be technological, economic, social, legal, ecological, or political (Nazarko et al., 2017a).

2.3. Scenario building

A scenario is 'a set of hypothetical events set in the future constructed to clarify a possible chain of causal events as well as their decision points' (Kahn and Wiener 1968). To be both acceptable and practical, scenarios have to satisfy five conditions: pertinence, coherency, likelihood, importance, and transparency (Durance and Godet 2010). There are, in general, three main approaches to scenario planning: (i) the approach proposed by Herman Kahn at the Rand Corporation in the 1960s, (ii) the approach developed by Hasan Ozbekhan, and (iii) the approach introduced by a French governmental regional foresight department (named DATAR) from the late 1960s to early 1970s (Durance and Godet 2010).

A scenario can be narrated as a storyline containing an array of intertwined and uncertain events and their possible consequences. They often can be used to support decision-making, especially when several parameters are uncertain or imperfectly defined (Godet, 2000). Thus, scenarios can provide insights about alternative outcomes that can take place according to each decision made (Brightman et al. 1999). Scenarios can be an instrument for dealing with prediction unreliability (Godet, 2000; Berkhout, Hertin, and Jordan 2002; De Kok, Uhlaner, and Thurik 2006; Rotmans et al. 2000). Such a state of future methodologies supports the main philosophy of seeking different and uncertain futures, allowing for qualitative factors, considering valuable information and relevant forecasts, choosing among various methods, and selecting a global and systemic approach (Godet, 2000). Providing three to four alternative descriptions of the future is typical in scenario building (Goodier et al. 2010).

In summary, most of the previous research on technology development has focused on recognising the factors influencing the development of technology with little or no attention to the causal relationship among these factors. While it is shown that the experts' experience and insight can uncover the intertwined and causal relationships between the underlying factors in technology development, the previous studies are limited to statistical analysis. Establishing a framework grounded in historical observations and data will limit the framework's scope to an antiquated and backward-looking view instead of a futuristic and forward-looking perspective. This study fills this gap by adding a casual aspect to the technology development framework by capitalising on experts' knowledge and insight. This study presents a technology development framework for scenario planning and futures studies using causal modelling. We propose a structured framework by categorising qualitative variables and finding the causal relationships among them by using causal loops, expert opinions, and the Decision Making Trial and Evaluation Laboratory (DEMATEL) method.

3. Methodology

3.1. Conceptual framework

Figure 1 presents the conceptual framework proposed in this study. Initially, we review the previous research to exploit a comprehensive list of relevant factors influencing technology development regardless of their importance. A questionnaire is developed to analyse these factors. The responses collected from a group of experts are used to build a causal model along with a DEMATEL model. DEMATEL can uncover the interdependencies among the factors and develop the causal relationship map within them. This method is used for analysing and investigating complex systems with intertwined components. The most important features of DEMATEL are the ability to map the interdependencies in a cause and effect map and pinpoint the critical factors in a complex structure with the help of an impact relation diagram (Si et al. 2018). Next, the interactions among the factors and the intensity of these interactions are depicted graphically. We then graphically depict the key factors and the essential interlinks among them. A causal model is built next based on the key factors and their interlinks. We then build scenarios by exploring the entire model and the causal loop. Finally, a technology development path to the desired future is selected by analysing the scenarios concerning the technology foresign and organisational mission and objectives.

3.2. DEMATEL technique

The DEMATEL method is used to estimate the direct and indirect causal relationships between a set of factors based on individual or group perceptions. The first step is establishing a matrix (A) depicting the direct impact between pairs of factors. DEMATEL then obtains a total influence matrix (T), which includes both the direct and indirect influence of the factors. Finally, DEMATEL builds an impact-relation map (IRM), considering both the direct and indirect impact of the factors.

The input is the direct influence matrix (A), which includes the impact of every factor on all other factors. The scale used ranges from 0 (no influence) to 4 (strong influence). The DEMATEL method

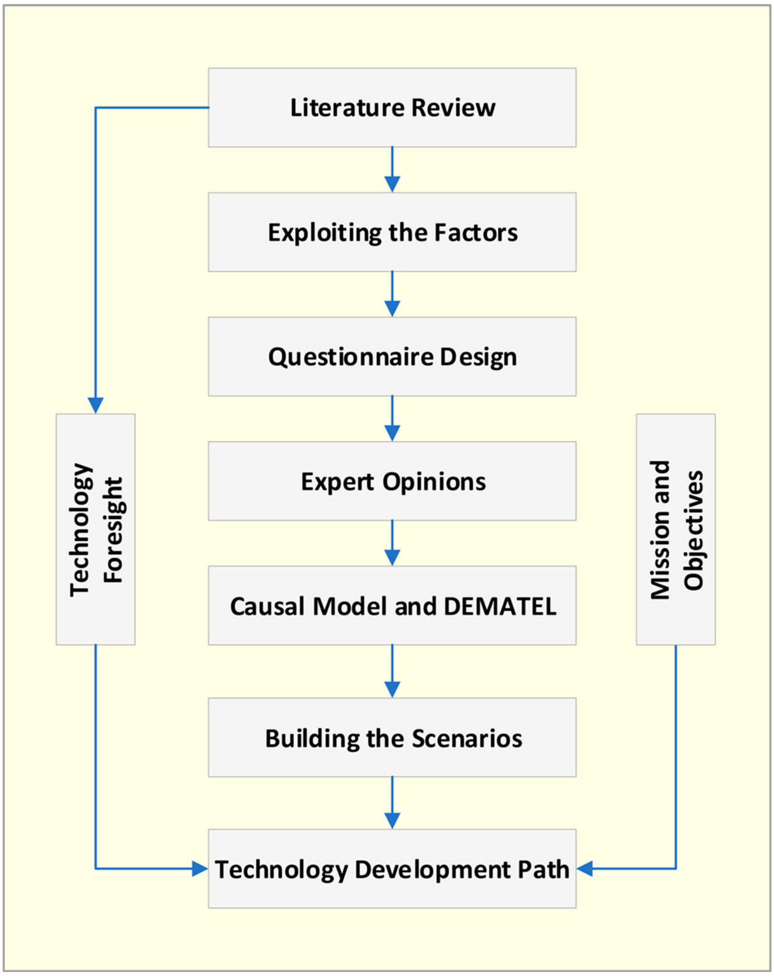

Figure 1. Proposed framework.

generates the full direct/indirect influence matrix (T). The procedure can be mathematically described as follows:

Step 1. Establish direct causal relationships:

$$A = [a_{ij}]_{j=1,\ldots,n}^{i=1,\ldots,n} \tag{1}$$

where a_{ij} = Direct influence of factor i on factor $j \; \forall \; i, j$ and n = Number of factors.

Step 2. Normalize Matrix A:

$$s = \min\left[\frac{1}{Max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}, \frac{1}{Max_{1 \le j \le n} \sum_{i=1}^{n} a_{ij}}\right] \tag{2}$$

$$X = s \times A \tag{3}$$

Step 3. Calculate the direct/indirect impact of Matrix T:

$$T = [t_{ij}]_{j=1,\ldots,n}^{i=1,\ldots,n} \tag{4}$$

$$T = X(1 - X)^{-1} \tag{5}$$

Calculate the following two related values:

$$r_i = \sum_{j=1}^{n} t_{ij} \ = \text{sum of row } i \quad \forall i \tag{6}$$

$$c_j = \sum_{i=1}^{n} t_{ij} = \text{sum of colum } j \quad \forall j \tag{7}$$

For each factor, if *r-c* is positive, then the factor as a whole affects other factors, and if *r-c* is negative, then the factor as a whole is influenced by other factors. On the other hand, $r + c$ calculates the degree of relationships of each factor with other factors (receiving and affecting). Finally, a threshold value is set to obtain the impact-relation map (IRM). Those entries of the matrix T lower than that value are set to 0. The IRM is built with those entries that are positive

4. Case study

Inter-world Communication Systems (ICS)[1] is a relatively new Internet service provider company with 4300 employees providing WiMAX and Wireless Internet services in Iran. With a 65% market share, ICS is the largest internet service provider in Iran.

4.1. Exploiting the factors

In this step, we obtained a comprehensive list of factors impacting technology development at ICS by conducting a comprehensive literature review on the studies in this area. We identified 16 factors that are shown by previous studies to have a significant impact on technology development. Neshati and Daim (2017) categorised technology development factors into four categories: economic, strategic, organisational, and legal. Nazarko et al. (2017) categorised nanotechnology development factors into seven categories: social, technical, economic, ecological, political, values, and legal groups. We considered the more comprehensive approach proposed by and identified a list of 16 factors influencing technology development at ICS. These factors presented in Table 1 include human resources potential (HR); access to the world of technology (WT); research and development potential for technology (RT); regional cooperation networks of entities: science-business-administration (CO); expenditure on R&D (RD); the economic potential of the region (EP); impact of products and technologies on humans and the environment (IM); state Innovation policy (IP); openness to

Table 1. Influencing technology development factors.

Factor	Description
1	Human resources potential (HR)
2	Access to the world of technology (WT)
3	Research and development potential for technology (RT)
4	Regional cooperation networks of entities: science-business-administration (CO)
5	Expenditure on R&D (RD)
6	The economic potential of the region (EP)
7	Impact of products and technologies on humans and the environment (IM)
8	State Innovation policy (IP)
9	Openness to new products, the value of progress (ON)
10	Regulations regarding the cooperation between public authorities, business, and science (RG)
11	Regulations protecting intellectual property (RI)
12	Legal regulations in the field of technology
13	Market expansion (ME)
14	Opportunity cost (OC)
15	Grow expertise (GE)
16	Product (service) alignment (PA)

new products, the value of progress (ON); regulations regarding the cooperation between public authorities, business, and science (RG); regulations protecting intellectual property (RI); legal regulations in the field of technology; market expansion (ME); opportunity cost (OC); grow expertise (GE); and Product (service) alignment (PA).

4.2. Finding relationships

Five experts, all technology managers from ICS, completed a questionnaire based on the 16 factors presented in Table 1. The IRM matrix presented in Table 2 is constructed by analysing the questionnaire results with the DEMATEL method. The threshold value used in this study is the average score of the entries in the direct/indirect impact matrix (T).

This step is the first level of refinement used to eliminate unimportant relations. In Table 2, 1 indicates that the horizontal factor influences the vertical factor, and 0 indicates that the horizontal factor has no impact on the vertical factor.

4.3. Highlighting the key factors

The second level of refinement is the most important and eliminating the less important ones. In the DEMATEL technique, $r + c$ is used to show the degree of relationship between the factors (receiving and affecting). Table 3 shows the $r + c$ values for the 16 factors.

In this step, the factors with the $r + c$ less than average are eliminated to identify the key factors. Table 4 shows the key factors and the interactions between them. Figure 2 is a visual representation of the key factors and their relationships.

4.4. Developing the model

The process begins by answering the following questions:

(a) Which link or effect is more important when analysing the system?
(b) Which intermediate factors there may be in the system?
(c) What is the polarity of the links?
(d) Where are the delays?
(e) Is there any factor that is eliminated before while it should remain?

After applying this process, we were able to reveal the early version of the feedback loops. It is important to note that the literature review and expert opinion support the process. We present

Table 2. Impact-relation map.

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0
2	1	0	1	1	1	1	0	0	0	0	0	0	1	1	1	0
3	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0
4	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	0
5	1	1	1	1	1	1	0	1	1	0	0	0	1	1	1	0
6	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	0
7	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
8	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0
9	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	0
10	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1
11	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1
12	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1
13	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
14	0	1	1	1	1	0	0	0	0	0	0	0	1	0	1	0
15	1	1	1	1	1	1	0	0	1	0	0	0	1	1	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Value of *r+c* for the 16 identified factors.

Factor Number	*r+c*
1	7.6689
2	9.5071
3	8.8701
4	9.0280
5	8.4946
6	8.2692
7	8.3445
8	9.5947
9	9.1347
10	8.8317
11	10.0419
12	10.2108
13	9.3399
14	9.6035
15	10.2183
16	7.5023

three causal loops presented in Figures 3–5 to illustrate how a causal loop is extracted from the preliminary relationship diagram shown in Figure 2. These loops are based on three key factors: grow expertise (GE), market expansion (ME), and state innovation policy (IP). Studying such examples can help develop the final model. However, the list of detected causal loops from Figure 2 is not limited to these three. While many more causal loops can be detected in this figure, only the causal loops relevant to the SMEs are selected and included in the final model.

Finally, it is necessary to build one integrated and comprehensive model with all critical loops and their interactions. To that end, several causal loops are extracted from the key factors and relationships in Table 4 and Figure 2. These causal loops are presented to the five ICS experts, and they are asked to select the most relevant and important ones to the SMEs for inclusion in the overall causal model. For example, although the IP loop (presenting the relationships between the regulation-related factors) can help policymakers, this loop was excluded from the overall causal model since this causal loop is considered irrelevant to the SMEs. Figure 6 presents the overall causal map. This causal map is analysed further in the next section.

4.5. Analysis of the overall causal map

This subsection discusses the causal model presented in Figure 6. We first review and explain the causa loops and then identify the external factors over which SMEs' decision-makers would have little or no control.

4.5.1. The causal loops

The proposed model, depicted in Figure 6, encompasses four main causal loops: accessibility loop, human resources loop, R&D loop, and expertise and market loop. These factors illustrate that the three first loops (accessibility, human resources, and R&D) are concerned with decision-making,

Table 4. Key factors and their relationships.

Factor	Description	WT	IP	ON	RI	RT	ME	OC	GE
2	Access to the world of technology (WT)	0	0	0	0	0	1	1	1
8	State Innovation policy (IP)	1	0	1	1	1	1	1	1
9	Openness to new products, the value of progress (ON)	1	1	0	1	0	1	1	1
11	Regulations protecting intellectual property (RI)	1	1	1	0	1	1	1	1
12	Legal regulations in the field of technology (RT)	1	1	1	1	0	1	1	1
13	Market expansion (ME)	1	0	0	0	0	0	0	0
14	Opportunity cost (OC)	1	0	0	0	0	1	0	1
15	Grow expertise (GE)	1	0	1	0	0	1	1	0

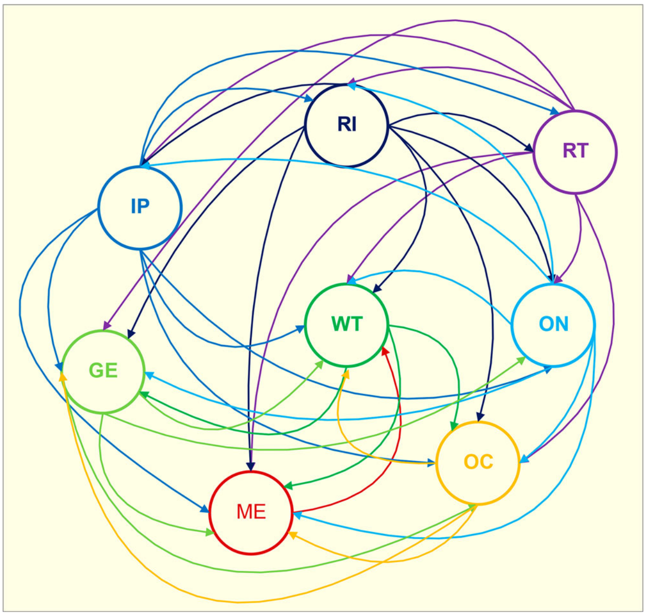

Figure 2. Key factors and their relationships.

and another loop (expertise and market) is related to the result of the decisions. In other words, the managers tend to adjust the factors in the accessibility, human resources, and R&D loops and expect to observe the result of their adjustments in the expertise and market loop.

It is noteworthy to mention that expenditure is an essential component when it comes to decision-making. As shown in Figure 4, there is one expenditure-related factor in each of the accessibility, human resources, and R&D loops; such factors separate the routes.

4.5.2. The legal factors

Technology managers and planners have little or no control over uncontrollable variables such as government regulations. In this study, regulations dealing with technology (RT), including

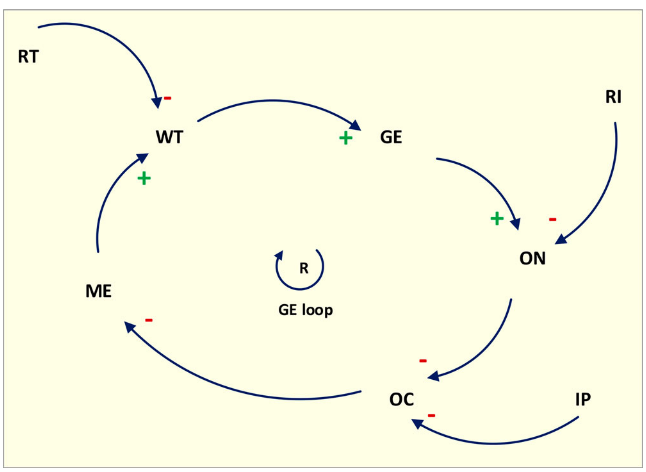

Figure 3. Grow expertise loop.

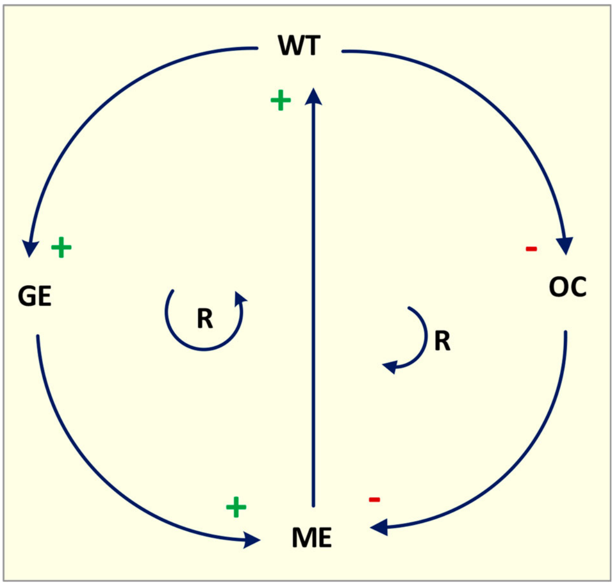

Figure 4. Market expansion loop.

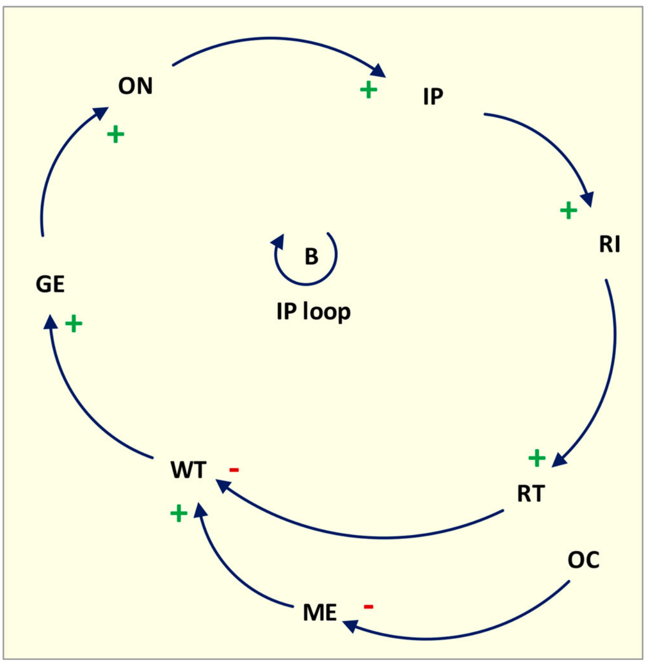

Figure 5. State Innovation policy loop.

regulations concerning the protection of intellectual property (RI) and innovation policy (IP), reflect regulations imposed by the government agencies. Regulations protecting technology (RT) refers to the laws on technology-related violations (e.g. introducing new technology without appropriate approvals and licensing). Regulations protecting intellectual property (RI) are related to copyright laws. The state innovation policy (IP) is related to innovation policy initiatives. These policies typically

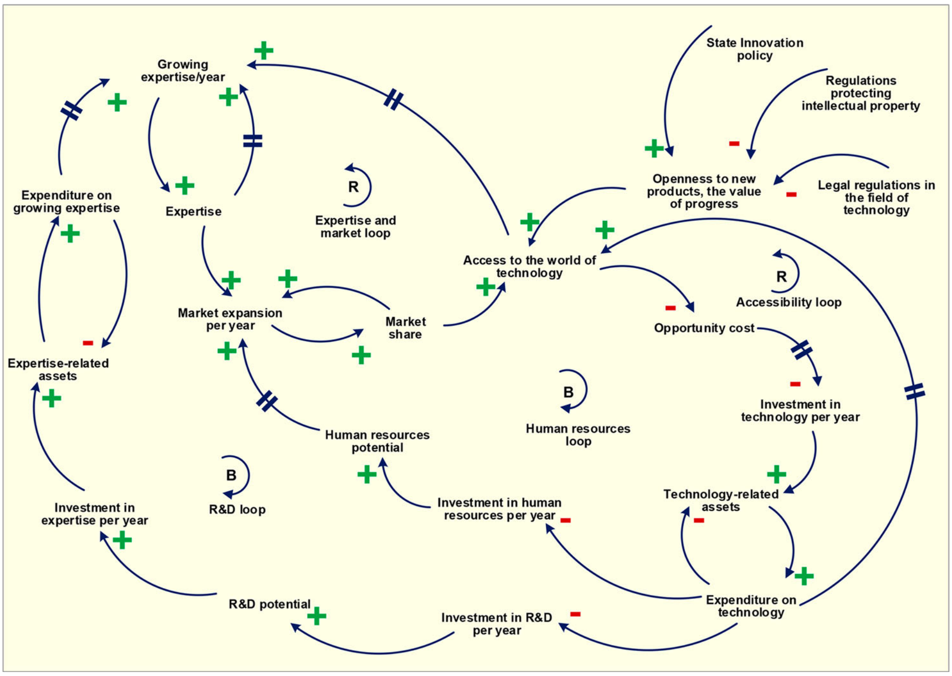

Figure 6. The overall causal model.

direct and oversee the state and regional business and economic development efforts. These factors can influence openness to new products (ON). Increasing RI and RT create more legal barriers and discourage ON. On the other hand, IP encourages ON.

4.6. Scenario building

Several stories will be narrated where each one pictures a possible future, and the proposed causal model is used to assess each scenario.

Scenario 1 (balanced scenario): This is our base scenario where nothing is changed. Analysing this scenario provides a holistic overview of the system. The balance, in this scenario, means the balance in spending money in each field. In this scenario, two decision-making-loops balance the system (human resources and R&D), and another one reinforces the system (accessibility). This balancing effect can overcome the existing reinforcement effect in the result-related-loop (expertise and market). In other words, regardless of whether the system is in the desired state (expertise-wise and market-wise) or not, it will remain unchanged.

Scenario 2 (technology spending scenario): This scenario represents increasing expenditures on technical issues while decreasing expenditure on other issues (human resources and R&D) in the field of technology (because of the limitation in technology-related assets). In this scenario, there will be a short-term growth in 'access to the world of technology' as the delay is higher in human resources, expertise, and market, and R&D loops compared to the accessibility loop. It will directly increase the growing expertise and, by a reinforcing loop, it will consequently increase 'expertise' and 'market share,' which are desired outcomes. However, this increase will be flattened over time because of the impact of the balancing loops (human resources and R&D) on 'growing expertise' and 'market expansion.'

Scenario 3 (fundamental spending scenario): This scenario represents spending most of the technology-related assets on the fundamental parts (human resources and R&D). As shown in Figure 6, by funding for human resources and R&D, 'expertise' and 'market share' will become stronger.

However, the direct outcome of decreasing expenditure on technical elements is a drop in 'access to the world of technology'; in that situation, managers may decide to reduce 'investing in technology' (because of the growth in 'opportunity cost'). The ultimate outcome is a drop in 'technology-related assert' (a fall in expenditure on the fundamental elements has been made possible).

Scenario 4 (market orientation scenario): In this scenario, the goal is to increase 'market share' by spending, symmetrical, money on technical parts ('expenditure on technology'), and the part of the human resources ('investing in human resources'). This strategy is effective until it is stopped by 'expertise.' By decreasing the expenditure on R&D, there will be no growth in expertise, therefore eventually, 'expertise' will play a role as a limiting factor.

Scenario 5 (expertise spending scenario): This scenario is similar to Scenario 4; however, in this scenario, the expenditure on technical parts ('expenditure on technology') and the development part ('investing in R&D') in total is more than the amount of money which were spent on the part of the human resources ('investing on human resources'). In this scenario, 'expertise' can reinforce 'market share,' and 'human resources potential' will be a limiting factor.

All five scenarios examined in this study are listed in Table 5. In this table, the first column shows the scenario name; the second column indicates the area that needs further investment; the third identifies the growing area, and the fourth column lists the limiting factors in each scenario.

4.7. The suggested plan for technology development in ICS

The scenarios formulated in Section 4.6 are used to study the ICS current state and develop a long-term strategic plan for technology development in this company. The proposed plan contains three phases, where each phase is established based on one of the five scenarios presented in Section 4.6.

Phase 1: From the technology point of view, ICS, is currently in a happy place. It has the biggest global network in Iran, and it uses TD-LTE and WiMAX, which are considered advanced technologies in Iran. In this case, Scenario 4 is more relevant since it focuses on the market alignment with ICS's goals of expanding the market. As mentioned earlier, one important factor in increasing the market share is 'human resources potential.'

However, there can be other elements (e.g. competition, economy, etc.) which can influence 'market share' (in the model such effects are referred to as 'market expansion'), 'human resources' can also affect 'market expansion,' which means, the company can develop its market by improving 'human resources.'

Phase 2: This phase begins when the former process is no more effective due to the limiting factor of 'expertise.' In this phase, the company should concentrate on 'expertise,' which is the primary focus in Scenario 5. When the current technologies become outdated, ICS may even lose some of its existing market shares.

Futures studies can help the managers to estimate the exact time for changing the strategic direction of the company. There are many tools for determining the changing course (e.g. analysing the

Table 5. Scenario listing.

	Scenario	Increasing expenditures on	Growth in	Limiting factor
1	The balance in spending money in each field	System will remain unchanged	System will remain unchanged	The system will remain unchanged
2	Technical issues	Expertise and Market share	Human resources and R&D loops	Human resources and R&D loops
3	Human resources and R&D	Expertise and Market share	Opportunity cost	Opportunity cost
4	Technical parts and the part of the human resources	Market share	Expertise	Expertise
5	Technical parts and the development part	Market share	Human resources potential	Human resources potential

current technology life cycle). To increase the expertise, ICS should work on R&D-related courses of action. In general, there are two main approaches: (i) working with international companies for knowledge transfer, or (ii) working with universities and research institutions for education and developing expertise.

Phase 3: Ultimately, the company needs to balance their expenditures, which are the focus of Scenario 1. In this phase, monitoring plays a pivotal role. ICS should constantly monitor its current state against its desired state in conjunction with the state of the communication technology market in the country.

5. Conclusion and future research directions

This study proposed a technology development framework for scenario planning and futures studies using causal modelling. The DEMATEL method was used to deal with the uncertain and dynamic business environment, and causal loops were used to support scenario planning. This research's main theoretical contribution to technology management is developing a comprehensive and evidence-based causal modelling framework for SMEs by using DEMATEL to uncover the interdependencies among the factors and using a causal map to analyse the intertwined relationships. Three causal loops were developed to study the GE, ME, and IP factors. These causal loops were then used to determine the most relevant and essential factors for inclusion in the SMEs' overall causal model.

The causal model was used in scenario planning for generating a technology development framework for ICS. The causal model suggested that ICS's most effective strategy is to invest in human resources and increase its market share. However, according to the developed causal model, this strategy is effective only until expertise becomes a limiting factor. At that point, ICS would need to adopt strategies to strengthen organisational expertise. Strong organisational expertise should trigger and encourage R&D activities, and increasing R&D activities will require additional financial resources. An analysis of these cause and effect relationships allows for proactive and interactive planning strategies based on the internal strengths and weaknesses and external opportunities and threats.

This research can be expanded in two directions. First, a systematic method can be devised to develop causal loops. In this study, the causal loops are defined based on experts' opinions and the literature review. Future works should suggest a systematic method for developing causal loops. Second, external parameters influencing the model (e.g. competitors' role, advantages of transferring the same technologies, etc.) can be included in the causal model.

Note

1. The name of the company is changed to protect their anonymity.

Acknowledgment

Dr. Madjid Tavana is grateful for the partial financial support he received from the Czech Science Foundation (GACR 19-13946S).

Disclosure statement

The above authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This work was supported by Czech Science Foundation: [Grant Number GACR 19-13946S].

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