Journal of Engineering and Technology Management 77 (2025) 101902

Contents lists available at ScienceDirect

Journal of Engineering and Technology Management

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

Critical success factors for the implementation of technology roadmapping in small-medium enterprises clusters

Cinzia Battistella *, Giovanna Attanasio, Roberto Pillon

All at the University of Udine, Polytechnic Department of Engineering and Architecture, via delle Scienze 206, Udine 33100, Italy

ARTICLE INFO

Keywords:
Technology roadmapping
Critical success factors
SMEs
Clusters
Intermediary
Framework
Model

ABSTRACT

This paper investigates the critical success factors influencing technology roadmapping within small and medium-sized enterprises (SMEs). Since this type of analysis is resource-intensive, SMEs often need to join in clusters coordinated by an intermediary. By conducting a comprehensive literature review and longitudinal case studies, we propose the "Framework of Technology Roadmapping in SMEs clusters". This innovative framework identifies and categorizes 19 critical success factors, organizing them into six main areas: organization (motivation and management), intelligence ability (resources and competences), and process management (architecture and method). These six areas collectively represent the primary parameters and levers essential for the design and implementation of technology roadmapping activities in SMEs clusters. By addressing these factors, SMEs clusters can more effectively navigate technological advancements, align their strategies with future market demands, and sustain competitive advantage. The framework not only serves as a guide for SMEs and SMEs clusters embarking on technology roadmapping but also provides a foundation for further research and refinement in this critical area of literature.

1. Introduction

The knowledge and technology possessed by an organization and its members are among the most critical and important resources for businesses today (Bergh et al., 2024; Fitzgerald et al., 2014; Akhavan et al., 2006; Kogut and Zander, 1995; Kogut and Zander, 1993). They are central to the functioning of organizations but inherently challenging to manage because they are constantly evolving, often in ways that cannot be predicted (Allee, 2012; Grodal et al., 2023; Tsoukas and Vladimirou, 2001). Assumptions such as clear delineation of company boundaries (internal vs external), strong internal localization of the innovation process within the company, a clear distinction between technology creation and its commercialization (first development then market), and the consequent temporal gap between technology creation and reproduction, must be re-evaluated based on emerging drivers (among which the increasing pressure to speed up the development and commercialization of new products) and lead to overcoming the traditional view of technology transfer (Battistella et al., 2023; Bozeman et al., 2015). A clear distinction is thus made between the traditional outward-oriented transfer model and a new model, where the main focus is on the progressive building of competencies that allow for the development of technologies that do not yet exist or the possibility of acquiring them from outside and having the potential to create radical changes or discontinuities (inward-oriented) (e.g., Shon et al., 2022;Caner et al., 2014) According to this perspective, it is crucial to establish and maintain the connections between technological resources and business objectives with appropriate tools

* Corresponding author.
E-mail address: cinzia.battistella@uniud.it (C. Battistella).

https://doi.org/10.1016/j.jengtecman.2025.101902
Received 23 September 2024; Received in revised form 4 July 2025; Accepted 30 July 2025
Available online 5 August 2025

and processes (Phaal et al., 2001a; Gerdsri et al., 2013; Geum et al., 2023). Therefore, technology management should focus on the intersection between technological and business aspects (including not only technology creation but also its application, diffusion, and valorization), integrating technological considerations into business decision-making at various levels, from strategy to operations (Beerepoot et al., 2023; Verbano and Crema, 2016; Farrukh et al., 2003). Given these circumstances, corporate strategy and planning should incorporate technology strategy as a fundamental component (Attanasio et al., 2025;Tsou and Chen, 2023; Buczacki and Laporte, 2016; Metz, 1996; Matthews, 1992). However, in order to coordinate business operations and assets to create a competitive and sustainable market position, it is necessary to have a thorough awareness of how the medium- to long-term context—which includes customers, competitors, and regulations—is evolving (Bozeman et al., 2015).

Johnston et al. (2012) argue that in a constantly changing environment, a company must have relevant information on which to base decisions, establishing an adaptive understanding of the environment (Fergnani, 2022). In this context, technology roadmapping (TRM) functions as a method to facilitate strategic and long-term planning, explicitly allowing the examination of dynamic relationships between technological resources, organizational goals and a changing environment (Kerr & Phaal, 2021; Phaal et al., 2004a). This method provides a systematic framework for analyzing and conveying the dynamic relationships between emerging or established markets, products and technologies over time. This process seeks to create technology roadmaps, which are structured, temporal, and graphical instruments that illustrate and analyze the concurrent relationships among markets, products, and technologies (Kerr and Phaal, 2021; Carvalho et al., 2013; Phaal et al., 2004a). By offering a point of reference for examining the outside world, looking for opportunities, and monitoring the performance of potentially disruptive individual technologies, road mapping can help businesses survive turbulent environments (Kerr and Phaal, 2021, 2020; Bower and Christensen, 1995). TRM can also help separate less-promising technologies from more promising ones (Kerr and Phaal, 2021; Kostoff and Schaller, 2001). As a technology intelligence tool assisting front-end decision-making, TRM supports creating and advancing innovation and technology transfer pathways (Phaal et al., 2001a; Phaal and Muller, 2009). It helps decision-makers evaluate opportunities and understand the development context to make better decisions (Kerr and Phaal, 2021). Companies of all sizes could apply TRM processes to derive relevant information regarding events and trends in their technological and competitive environment (Gholipoor and Mozaffari, 2020; Linares-Barbero and De La Vega, 2024). Small and medium-sized enterprises (SMEs) could benefit from TRM processes (Escoz Barragan et al., 2025; Hermann et al., 2024; Arshed et al., 2012). The strong environmental dynamism characterizing today's context demands SMEs' technological response speed, stemming from accelerated operational processes and rapid decision-making, combined with the relational and productive efficiency advantages typical of large companies (Mubarak et al., 2025; Faruque et al., 2024; Agyapong et al., 2020). In this way, if appropriately supported through TRM processes, SMEs can seize the opportunities offered by the evolution of the global context and effectively compete with larger enterprises (Jun et al., 2013). Despite the economic significance of SMEs, there is a lack of targeted studies on the application of TRM (e.g., Carvalho et al., 2013; Battistella et al., 2015; Jun et al., 2013; Park et al., 2013; Arshed et al., 2012), primarily due to the existence of "action gaps" concerning the implementation of TRM methodologies in SMEs.

Due to their restricted resources, knowledge, and skills, SMEs encounter challenges in implementing decision-making and strategic support activities (Linares-Barbero and De La Vega, 2024; Kim and Seo, 2023), which have limited the diffusion of TRM in SMEs (Carvalho et al., 2013; Arshed et al., 2012). Even though TRM has a straightforward structure and set of concepts, businesses still face significant challenges when implementing it because the results depend on a detailed strategy and planning process (Ahumada-Tello et al., 2023; Vishnevskiy et al., 2016; Buczacki and Laporte, 2016; Lee et al., 2007; Phaal et al., 2001). In addition to operational difficulties, SMEs find themselves in a "grey area" in TRM research, which primarily focuses on large enterprises (Battistella et al., 2015). Such considerations are also supported by authors studying technology transfer, such as Nazarenko et al. (2022), Meydanli and Polat (2020) and Lichtenthaler and Ernst (2008). In these contexts, technology roadmaps have been used to support technology management, improving the integration between the different technologies developed by a firm and their exploitation in the existing product platforms (Ozcan et al., 2021; Yoon et al., 2019).

Such technology roadmaps limited their diffusion to large firms, which more frequently carry out multiple projects for technology development and product platforms (Arshed et al., 2012; Caetano and Amaral, 2011). Only in the last years technology roadmaps have been applied even to better connect a firm's strategies with the most promising emerging technologies through the definition of the alternative technological pathways that a firm can adopt (Park et al., 2020; Phaal and Muller, 2009).

To overcome implementation difficulties, TRM analyses can be conducted on clusters of SMEs. Clusters are acknowledged as means to address SMEs' constraints and serve as vital ways to enhance their productivity, innovation, and competitiveness (Karaev et al., 2007). Clusters are characterised by a sectoral or geographical aggregation of organizations that produce and sell related or complementary goods while encountering shared challenges and opportunities (UNIDO, 2000). These SME clusters can be coordinated by intermediary organizations providing technology transfer services (Battistella et al., 2015; Rinkinen and Mäkimattila, 2015). Intermediaries for SME clusters facilitate and promote knowledge transfer between local and external industry and knowledge institutions, and through coordinated joint actions, they support small producers(Clarke and Ramirez, 2014). Furthermore, intermediaries play the essential function of facilitating interactions, enabling firms to create, transfer and implement knowledge (Parker and Hine, 2014), fundamental capabilities to apply TRM activities. However, TRM studies of SME clusters coordinated by an intermediary offering technology transfer services are more complex than those of large organizations because of the inherent variety present in the cluster (Battistella et al., 2015); moreover, applications of TRM to SME clusters coordinated by an intermediary have been minimally addressed in the literature (e.g., Battistella et al., 2015; Buczacki and Laporte, 2016).

To summarize, it is challenging to implement TRM in SMEs due to their lack of resources and some strategic and organizational activities. Analysis of SME clusters coordinated by an intermediary can help overcome the implementation barrier. However, few studies have identified precisely how this process occurs, and which are the critical success factors. Only Park et al. (2013) identify

critical success factors for implementing TRM. However, it does not make the process generalizable by considering clusters of SMEs coordinated by an intermediary that allows them to overcome the typical constraints of SMEs.

The main aim of this paper is to identify the critical factors that guarantee the success of TRM application in SMEs clusters coordinated by an intermediary. Accordingly, the research question is: *What are the critical success factors for TRM implementation in SMEs clusters coordinated by an intermediary?*

The paper is organized as follows. Section 2 describes the theoretical background of TRM adoption in SMEs and related critical success factors in the literature. Section 3 explains the methodology. Section 4 identifies the critical success factors from the case studies, and Section 5 discusses them about literature. Section 6 draws conclusions.

2. Theoretical background

2.1. Adoption of technology roadmapping in SMEs

TRM aims to support identifying and implementing the most promising technologies for a firm (Chakraborty et al., 2022; Battistella et al., 2015; Jun et al., 2013; Kostoff and Schaller, 2001). An effective TRM should be based on a systemic approach that considers both the future evolution of science and technologies that could be applied in a targeted market and the firm's needs, resources, and competencies (Kim et al., 2020; Garcia and Bray, 1997). At this aim, firms should not only effectively forecast future trends in science and technology but also identify the existing gaps in their current technology levels, define reliable plans to fill these gaps and exploit the achieved competencies into new products and services (Amati et al., 2020; Lee et al., 2007).

The literature often argues that the process of creating a roadmap is more valuable than the roadmap itself, as the main benefit lies in communication and consensus building between functions and organizations, which is linked to the stakeholder-centred process (Amati et al., 2020; Lee et al., 2013; Phaal and Muller, 2009). The stakeholder-centred approach emphasizes the importance of stakeholder involvement and integration in TRM for the methodology's success. Collaboration with various stakeholders facilitates the representation of different organizational perspectives and acquiring knowledge essential for developing the roadmap. Chakraborty et al. (2022) outlined three dimensions to characterize the quality and nature of stakeholder engagement. The dimensions include breadth, which refers to the variety of stakeholder roles; depth, which assesses the quality of the methods employed; and time, which reflects the duration and stage of stakeholder involvement. The TRM process must be carefully analyzed and organized to maximize strategic and foresight benefits. Gerdsri et al. (2009) describe a strategy that emphasizes key stakeholders' roles and engagement during roadmapping and outlines requirements and actions to implement the methodology. Hirose et al. (2020) propose a six-stage maturity model for implementing TRM to help organizations integrate it into their strategic processes. The TRM process contributes to knowledge management within an organization by facilitating the transformation of tacit knowledge into explicit knowledge and enabling the exchange of technical knowledge between departments (de Weck, 2022; Stig, 2013; Gerdsri et al., 2009). The TRM process generates the "roadmap," which offers the "big picture view" of the developed strategic plan and all the most relevant information and insights needed for the communication requirements. At the highest level, the general architectural understanding consists of three main layers: the top layer, the middle layer, and the bottom layer (Phaal and Muller, 2009; Phaal et al., 2004). From a visual standpoint, the roadmap canvas is a crucial communication tool whose design should be carefully planned (Phaal and Muller, 2009). The adoption of this systematic approach to TRM may be more difficult for SMEs that, compared to large firms, are characterized by fewer resources (Robson et al., 2022;Carvalho et al., 2013; Arshed et al., 2012; Yusuf and Saffu, 2005). In this sense, the capacity to identify the most promising technologies to invest in requires the involvement of several experts characterized by various backgrounds and competencies, from those related to science and technology to those related to the evolution of the market (Arshed et al., 2012). SMEs' capacity to effectively implement TRM may be significantly hindered by their human resources, which are too limited, scarcely qualified for technology intelligence activities, and excessively involved in operational activities, to the detriment of strategic planning (Ednie et al., 2023; Battistella et al., 2015). The limitations in human resources provoke another significant issue that may affect the implementation of TRM by SMEs, which is their lack of a formalized planning process, especially for long-run strategies (Battistella et al., 2015; Stonehouse and Pemberton, 2002). The effectiveness of TRM depends on the firm's capacity to define and plan an overall strategy (Jun et al., 2013; Amer and Daim, 2010), establishing and monitoring the integration between technology development and organizational goals (de Alcantara and Martens, 2019; Strauss and Radnor, 2004). Only this integration can keep TRM alive, guaranteeing an up-to-date analysis of the technological evolution and a constant adjustment of organizational strategies and resources (Gerdsri et al., 2019). Besides, this integration is necessary to translate the results of TRM into strategic plans and operative actions that can improve the innovation outcomes of SMEs (de Alcantara and Martens,2019; Geum et al., 2013; Jannek and Burmeister, 2007). SMEs' capacity to integrate TRM into the overall strategic planning is further reduced by the large variety of methods and configurations for TRM (Vinayavekhin et al., 2023; de Alcantara and Martens, 2019; Phaal et al., 2004a), which prevents a clear identification of the best practices that an SME should adopt. This lack is due to the current status of the literature on TRM, which provides empirical evidence from case studies, lessons learned, and qualitative questionnaires (Ding and Ferràs Hernández, 2023) without a systematic theoretical framework. In particular, implementing TRM is specifically challenging for SMEs because most studies in this literature have been based on analyzing corporate processes in large companies (Meydanli and Polat, 2020). This may reduce SMEs' capacity to exploit the lessons learned in the literature on TRM, forcing them to re-invent approaches that could meet their specific needs (Jun et al., 2013; Arshed et al., 2012; Phaal et al., 2004b). The main studies in management literature that analyze the adoption of TRM in SMEs are summarised in Table 1. These studies have been published from 2003 onwards, indicating how the interest in implementing TRM in SMEs has peaked in the last twenty years because of the rising need for these managerial tools and the availability of support systems necessary to develop them correctly. These papers describe the implementation of TRM in SMEs from different countries,

Table 1
Literature studying TRM in SMEs.

Year	Authors	Research method	Number of SMEs	Industry	Country	Partners involved in TRM	TRM method	TRM output	Level	Topic of the paper
2003	Probert, D.R., Farrukh, C.J., and Phaal, R.	Action research	2	Security systems - Software	United Kingdom	1 research center	T-Plan with workshops	Multi-layered roadmaps	Technology planning	Description of TRM applications to enable organizations to evaluate its use
2005	Holmes, C., and Ferrill, M.	Survey	33, mostly SMEs	Not indicated	Singapore	Technology specialists	Modified T-Plan with initial assessment and external experts	Operation and Technology Roadmap	Technology planning	Description of the background of TRM and benefits of its application
2007	Lee, S., Kang, S., Park, Y., and Park, Y.	Case study	Not indicated	Parts and materials	South Korea	1 technology transfer organization	TechStrategy	Science-technology roadmaps	Industry	Description of the TRM for R&D purposes and identification of a framework for R&D planning, detailing specific procedures for constructing the TRM
2009	Gindy, N.N.Z., Arman, H., and Cavin, S.	Case study	1	Aerospace	United Kingdom	University researchers	Strategic Technology Alignment Roadmapping (STAR)	STAR software	Strategy	Development of the STAR integrated framework for technology requirements planning, investment and acquisition and technology acquisition strategy
2010	Oliveira, M.G., and Rozenfeld, H.	Case study	1	Nanotechnology	Brazil	University researchers	Integrated, Technology roadmapping and Portfolio management	Roadmaps and project portfolio	R&D	Development of a new method based on combining project portfolio management and TRM to assist the development of front-end activities
2013	Jun, S.P., Seo, J.H., and Son, J.K.	Survey	148, mostly SMEs	Not indicated	South Korea	1 technology transfer organization	SME Technology Roadmap	Market-based product-technology roadmap	R&D	Examination of the contents and impacts of the successful Korean SME Roadmapping Support Programme to clarify its various implications for future policies.
2013	Nimmo, G.	Case study	Not indicated	Grocery	Canada	1 technology transfer organization and industry champions	Visioning, product, technology, roadmap workshops	Lean Logistics Technology Roadmap	Logistics	Description of technology roadmapping providing expert knowledge on the framing/ inclusion of TRM, TRM processes, TRM implementation and linking technology TRM with other strategic planning tools
2013	Park, S.Y., Son, J. K., Seo, J.H., and Seo, J.	Survey	146, mostly SMEs	Not indicated	South Korea	1 technology transfer organization	Support Program for Individual Company	Market-based market-product roadmap	R&D	Analysis of the critical success factors of TRM regarding input and process, providing substantial insights into TRM performance concerning output.
2015	Battistella, C., De Toni, A.F., and Pillon, R.	Action research	Cluster of 9 SMEs	Coffee	Italy	1 technology transfer organization	Extended Map methodology	Industry technological map	Industry	Proposal for a new methodology to implement TRM
2016	Buczacki, A., and Laporte, C.Y.	Case study	Consortium of SMEs	Electric vehicles	Poland	Research institutes	Workshops supplemented with	Market-based product-	Technology planning	Use of the TRM for product development

(*continued on next page*)

Table 1 (*continued*)

							surveys and questionnaires	technology roadmaps		
2017	Abbasi, M., Vassilopoulou, P., and Stergioulas, L.	Case study	Not indicated	Creative industries	United Kingdom	1 research institute and industry champions	Workshops, interviews, think thank events to define a roadmap based on visions, scenario, and gap analysis	Technology roadmap emphasizing different technological future challenges	Technology planning	Presentation of a roadmap built on the basis of contributions from the creative and ICT expert communities gathered during the consultation and validation phases of the research.
2018	Vicente Oliva, S., and Martinez-Sanchez, A.	Case study and content analysis	3	Security and defence	Spain	1 technology transfer organization	Workshops	Technology roadmaps	Technology planning	Application of TRM to Spanish National Defence
2019	Schimpf, S., and Abele, T.	Survey	9	Several industries	Germany	Not indicated	Not indicated	Not indicated	Not indicated	Identification of TRM practices in German industrial companies
2021	Baabdullah A.M.; Alalwan A.A.; Slade E.L.; Raman R.; Khatatneh K.F.	Survey	392	Several industries	Middle East countries	Not indicated	Not indicated	Not indicated	Technology acceptance	TRM as enabler to accept and then implement AI practices

especially Europe, Korea, Singapore, Canada, and Brazil. Most studies are focused on high-tech industries, such as software, defence, nanotechnology, and electric vehicles or energy (Vicente Oliva and Martinez-Sanchez, 2018; Buczacki and Laporte, 2016; Amer and Daim, 2010; Probert et al., 2003), which are characterized by high R&D expenditures and the continuous creation of advanced products and services (Castellacci, 2008). Nevertheless, some papers analyze SMEs operating in industries characterized by a lower technological content, such as grocery and coffee (Battistella et al., 2015) or creative industries (Abbasi et al., 2017), thus showing how TRM can be customized to be effectively adopted even in these industries. Apart from these differences, all the studies show that the success of the implementation of TRM in SMEs depends on the participation of some specialists, such as university researchers and technology transfer organizations, and the support from influential stakeholders operating in the same industry. These partners can support SMEs by offering the competencies and resources to implement TRM correctly. Besides, the implementation of TRM together with the partners in the supply chain may favour the definition of a more convincing and shared view of the future market needs, which is a prerequisite to selecting which technologies can better satisfy them (Vinayavekhin et al., 2023; Kwon et al., 2022; Gindy et al., 2006).

We found little indication of how to customize the technique for SMEs and the critical success factors in the literature. Technology roadmaps are helpful and flexible. Its potential benefit may not be fully realized if modifying it to meet specific needs is difficult (Lee and Park, 2005). In practice, it is crucial, and at times imperative, to adapt the generic TRM process flexibly to address specific management requirements and environmental circumstances (Kerr and Phaal, 2021). Although customization is critical, the current literature focuses on simplifying the TRM process, with minimal emphasis on customizing the technology roadmap. Academic interest in this topic is increasing, with research beginning to investigate the critical success factors for implementing TRM (Daim and Oliver, 2008). Yet coherent and structured answers still need to be discovered (Carvalho et al., 2013).

Adopting a TRM approach in collaboration with external actors could represent a viable way to overcome existing SME constraints. Notably, the literature suggests that applying TRM in SMEs requires clusters of SMEs coordinated by an intermediary (e.g., Battistella et al., 2015; Buczacki et al., 2016). This is also aligned with the most recent approaches of foresight in SMEs (Carayannis et al., 2025; Dörr et al., 2024), which emphasize the need for a more collaborative, networked, and open way to plan an adequate answer to environmental dynamics (Vecchiato et al., 2024; Marinković et al., 2022; Milshina and Vishnevskiy, 2018; Heger and Boman, 2015; Battistella and De Toni, 2011).

2.2. SME clusters

Clusters are a practical approach to overcoming SMEs' limitations (in size and resources) and improving their productivity and competitiveness (Karaev et al., 2007). Clusters have been generally defined as sectoral and geographic concentrations of firms that produce related or complementary goods and share common challenges and opportunities (UNIDO, 2000), forming cooperative and competitive networks at the same time (European Commission, 2002; Gancarczyk, 2015; Porter, 1998; Vanhaverbeke, 2001). However, no univocal definition in the literature explains a cluster and its basic elements. According to Porter (1998), one of the key elements of a cluster is geographical proximity, as it ensures knowledge transmission and development. Scholars as Rosenfeld (1997) emphasize that clusters must include active channels of exchange, communication and cooperation between geographically interdependent enterprises. Without these channels, the mere concentration of enterprises does not constitute a cluster. Clusters differ from industrial districts: districts are oriented towards local sourcing, whereas clusters aim at creating optimal competitive conditions for enterprises (Preissl and Solimene, 2003).

The cluster approach is often used to conduct analyses and describe the behaviour of SMEs, but it would be impossible to do so if only one were considered. The literature reports examples of SME clusters as a means to achieve internationalization (Gancarczyk and Gancarczyk, 2018), to describe relationships that lead to increased performance (Lamprinopoulou and Tregear, 2011), to study the development strategies of manufacturing SMEs (Lorentz et al., 2016) and how they behave to global trends in corporate responsibility (von Weltzien Høivik and Shankar, 2011). Furthermore, SME clusters have been used as strategic tools to promote innovation, as they optimize the use of resources and reduce the associated costs (Faisol et al., 2022; Jacob et al., 2022). Consequently, the cluster approach is a crucial element for TRM in SMEs.

2.3. Critical success factors of TRM in SMEs

Critical factors are elements that directly or indirectly influence the efficacy of the TRM exercise, either facilitating and promoting (success factors) or hindering the execution of the activity.

We note that recently, the literature has begun to address the issue of critical success factors of TRM but does not present structured contributions; in fact, it provides the results of case studies, lessons learned, and qualitative questionnaires drawn mainly from operational experience (Li et al., 2024; Ding and Hernández, 2023; Gerdsri et al., 2010; Phaal and Farrukh, 2000; Kostoff and Schaller, 2001; Bruce and Fine, 2004; Abe et al., 2009; Cosner et al., 2007; Phaal and Muller, 2009). This is not surprising, considering that research is guided by the experience of practitioners and, to a lesser extent, by theoretical studies. Most studies on TRM processes are self-reported descriptions of experiences in a given organization (e.g., Meydanli and Polat, 2020; Gerdsri et al., 2010; Lee and Park, 2005). Furthermore, since the methods and possible configurations for carrying out a TRM process are numerous, the nature of the empirical findings is quite heterogeneous, unstructured, and complex to compare. The majority of studies on TRM focus on corporate processes within large enterprises (Ding and Hernández, 2023; Meydanli and Polat, 2020; Albright and Kappel, 2003; Garcia and Bray, 1997; Bruce and Fine, 2004), while others address inter-organizational processes involving significant associations within specific categories or sectors (More et al., 2015; Kajikawa et al., 2013; Phaal et al., 2004a; McCarthy, 2003; Kostoff and Schaller, 2001). Very

few studies specifically examine small and medium-sized enterprises, with the sole exception being Holmes and Ferrill, 2005, which does not analyze the critical implementation issues pertinent to SMEs.

However, interest in this topic is also growing academically, and research is starting to ask what the critical success factors are in implementing TRM. Phaal and Farrukh (2000) conducted a significant survey on TRM within large UK companies, identifying crucial factors for successful TRM. These include clarity of business needs, effective business processes, involvement of key personnel, and senior management commitment. Conversely, obstacles include initiative overload and lack of necessary data. Kilkis (2014), Vatananan and Gerdsri (2012), Groenveld (2007), Garcia and Bray (1997), and Strauss et al. (1998) emphasize the importance of commitment and a shared vision for successful TRM, highlighting challenges in launching and sustaining the process. Gerdsri (2013), Gerdsri et al. (2009), Lee et al. (2007) stress the significance of senior management commitment and project manager motivation for quality TRM. They also emphasize the need for diverse skill sets among participants and strong top management support.

Integration of TRM with overall business processes is essential, with initial activities treated as integral to company operations (Ateetanan and Shirahada, 2016; Geum et al., 2011; Lee et al., 2007). The process can only be more effective when not isolated from other management tools. Consequently, integration must be designed prior to the beginning of the activities. Cost and time constraints are important considerations, along with efficiency and effectiveness. According to research, long-term projects risk losing participants' interest (Ding and Hernández, 2023; Caetano and Amaral, 2011; Lee et al., 2007). Most organizations have discovered that quickly carrying out the TRM process is ideal. Research on standardizing processes and gathering data efficiently is still in progress, requiring accurate input data and professional opinion (da Silveira Junior et al., 2018; Hansen et al., 2016; Yoon et al., 2008). Furthermore, most organizations have found that to characterize the components and contents of roadmaps, a standard taxonomy, or a standard set of keywords, is required.

Another factor hindering the adoption of the method is the lack of quality input data (da Silveira Junior et al., 2018; Yoon et al., 2008; Phaal et al., 2005), which often relies on knowledge from the experts participating in workshops. The roadmap's structure should balance detail and complexity with a clear temporal dimension and alignment across multiple organizations (Kerr and Phaal, 2021; Carvalho et al., 2013; Lee et al., 2011; Phaal and Farrukh, 2000). The role of experts is crucial, as the map contents primarily rely on expert judgment, although objective data such as market statistics or patent information will enhance their assessments. Therefore, choosing the expert committee is a crucial step in TRM (Gerdsri et al., 2010; Lee et al., 2007). To facilitate inter-organizational TRM, participants must perceive value and trust, with identified champions accountable for process ownership (Kim et al., 2023; Abe et al., 2009; Phaal and Muller, 2009). Feedback from stakeholders is crucial for continuous improvement and developing a common visual language aid understanding and communication (Gerdsri et al., 2010; Bruce and Fine, 2004).

TRM's success hinges on commitment, effective communication, integration with business processes, and ongoing feedback refinement based on stakeholder feedback.

The proposed contributions in the literature focusing on critical success factors of TRM in SMEs are not presented in a structured form; they are qualitative and derive from the experiences gained in case studies of a varied nature mainly oriented towards applications carried out in large companies or significant trade associations. Only Park et al. (2013) identify critical success factors for evaluating TRM performance in SMEs. Few studies focus specifically on critical success factors (Lee et al., 2013; Pataki et al., 2010; Daim et al., 2018; Daim and Oliver, 2008) and still without making generalizable contributions, considering clusters of SMEs coordinated by an intermediary.

Indeed, in literature, although the presence of a coordinating partner or of a knowledge transfer partner (see Table 1) is often mentioned, it is not systematically analyzed or considered a central element in the TRM process for SMEs. In practice, the implementation of TRM requires a coordinating actor or transfer partner, but this perspective is largely absent from the literature, especially when associated with the specific context of SMEs.

3. Methodology

This study aims to shed light on the critical success factors for TRM implementation in SME clusters. As the literature suggests, these TRM studies can be conducted on SME clusters coordinated by service intermediaries. These intermediaries have insight into the TRM process in SME clusters. Therefore, to answer the research question and identify the critical success factors in SME clusters, we adopted the viewpoint of the intermediaries who coordinate this process. The intermediary viewpoint facilitates a more nuanced understanding of the dynamics that regulate TRM, as well as a comprehensive overview of its essential components. Furthermore, embracing this perspective enables a more precise identification of the processes through which knowledge is generated, disseminated, and applied, thereby enhancing the comprehension of how the outcomes produced by TRM are solidified within the relevant contexts (Smedlund, 2006).

We chose to structure the analysis in three steps following the indication of Tranfield et al. (2003) and Linnenluecke et al. (2020), which consist of three steps: (1) planning the review, (2) conducting the review, (3) reporting the review.

3.1. Planning the review

We first identified the purpose of the review, as stated in the introduction, and theoretical background. This article aims to identify the critical success factors that ensure the successful adoption of TRM in clusters of SMEs that an intermediary coordinates. The role of the intermediary is critical in that it helps SMEs overcome the limitations these organizations inherently have and ensure that the critical success factors are present during the TRM process.

Accordingly, the following research question was formulated:

What are the critical success factors for TRM implementation in SMEs clusters coordinated by an intermediary?

3.2. Conducting the review

We further reviewed the literature to identify the critical success factors for a TRM analysis. We conducted two separate literature reviews.

We conducted a first literature review using Scopus and Google Scholar as databases to identify seminal publications in the field of TRM to find general categories for TRM implementation. The articles were organized in an Excel file. Categories were extracted for each article, which were then aggregated considering conceptual similarity. The derived framework of critical success factors categories for TRM implementation (Fig. 1) is proposed to be structured around three categories: *TRM Organization, TRM Intelligence capabilities, and TRM Process management.* These categories represent the areas where the critical success factors influencing the TRM process operate. The factors that have been identified represent the set of primary elements that either facilitate or impede the success of the initiative. Thus, the coding framework (Fig. 1) is based on the topics reported in Table 2. From the coding framework, interview questions were developed.

A second literature analysis conducted enabled the identification of critical factors that influence the TRM process and determine the initiative's success. To identify critical success factors, a systematic literature review was conducted. Scopus was used as the database for the search. The keywords 'technology roadmapping' and its acronym 'TRM' were used to search for articles with TRM. The search was limited to the subject area "Business Management and Accounting," articles and reviews, and the English language. The search returned 223 articles. Each article was evaluated considering the inclusion and exclusion criteria in Table 3, by first considering the title and abstract and then an entire article. Articles were selected by considering whether the article addressed TRM as its primary focus. This selection resulted in the inclusion of 38 articles. Subsequently, an additional search was conducted on Google Scholar. The same keywords were used to integrate additional articles. The same selection criteria were used, which led to the selection of an additional 4 articles. In the end, 42 articles were considered. These articles were then analyzed to extract the critical success factors of TRM. Eventually, these critical success factors were aggregated according to the criteria of conceptual similarity, resulting in a list. Next, considering the previously identified coding framework, these critical success factors were grouped.

A second literature analysis conducted enabled the identification of critical factors that influence the TRM process and determine the initiative's success. To identify critical success factors, a systematic literature review was conducted. Scopus was used as the database for the search.

The keywords 'technology roadmapping' and its acronym 'TRM' were used to search for articles with TRM. The search was limited to the subject area "Business Management and Accounting," articles and reviews, and the English language. The search returned 223 articles. Each article was evaluated considering the inclusion and exclusion criteria in Table 3. We specifically selected studies focused on TRM as the primary topic, research on novel TRM methodologies, and studies that implemented TRM in various case studies. Conversely, we excluded studies that employed TRM alongside other methodologies, as this could complicate the identification of critical success factors. This methodological approach facilitated a precise selection of sources, concentrating on a comprehensive analysis of TRM. The articles were chosen by initially evaluating the title and abstract, followed by a review of the complete article. Articles were selected by considering whether the article addressed TRM as its primary focus. This selection resulted in the inclusion of 38 articles. Subsequently, an additional search was conducted on Google Scholar. The same keywords were used to integrate additional articles. The same selection criteria were used, which led to the selection of an additional 4 articles. In the end, 42 articles were considered. These articles were then analyzed to extract the critical success factors of TRM. Eventually, these critical success factors were aggregated according to the criteria of conceptual similarity, resulting in a list. Next, considering the previously identified coding framework, these critical success factors were grouped.

3.3. Reporting the review

To synthesize the results, a qualitative analysis based on examining the content of the selected articles was conducted to identify critical success factors and answer the research question. Specifically, the articles were read, and relevant data were extracted and

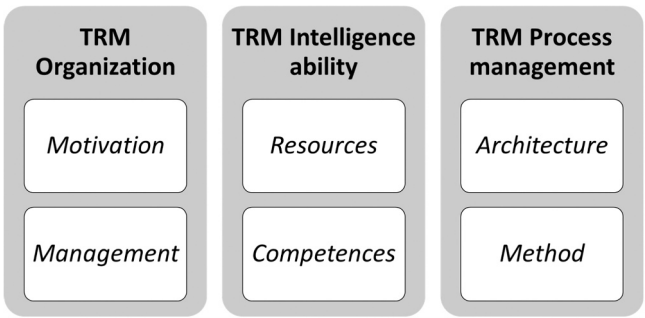

Fig. 1. TRM coding framework.

Table 2
Summary of the coding framework.

Categories of the coding framework	Topics for the categories of the coding framework	References
TRM organizations	***Motivation:*** The drive and incentives that encourage organizations to adopt and pursue TRM. ***Management:*** The leadership, governance, and administrative practices that support TRM initiatives.	Phaal and Farrukh (2000); Kostoff and Schaller (2001); McMillan (2003); Bruce and Fine (2004); Cosner et al. (2007); Gerdsri et al., (2010); Groenveld (2007); Lee et al.(2007); Abe et al. (2009)
TRM Intelligence Ability	***Resources:*** The availability and allocation of financial, human, and technological resources necessary for effective TRM. ***Competences:*** The skills, knowledge, and expertise within the organization that enable the successful development and implementation of technology roadmaps.	Phaal and Farukh (2000); Kostoff and Schaller (2001); McMillan, (2003); Bruce and Fine (2004); Phaal et al., (2004b); Cosner et al. (2007); Groenveld (2007); Lee et al. (2007); Yoon et al. (2008); Abe et al. (2009)
TRM Management Process	***Architecture:*** The structural design and framework of the TRM process, ensuring it is well-organized and coherent. ***Method:*** The methodologies and techniques employed to carry out TRM, including the tools and processes used to gather, analyze, and apply information.	Phaal and Farukh (2000); Phaal et al. (2004b); Groenveld (2007); Lee et al. (2007); Yoon et al. (2008); Gerdsri et al. (2010)

Table 3
Inclusion and Exclusion criteria.

Inclusion criteria	Exclusion criteria
TRM as primary focus TRM as methodology TRM case studies	TRM used in combination with other methodologies

systematically organized in an Excel spreadsheet. Then, the collected information was aggregated based on its conceptual similarity and categorized according to the framework identified earlier.

3.4. Longitudinal cases

To address the research question, we designated AREA Science Park in Trieste, Italy as an intermediary.

AREA is the leading multisectoral Science and Technology Park in Italy. We purposefully selected AREA as a distinctive and significant innovation intermediary within the European framework. AREA offers technology transfer services, mainly to SMEs in the national territory. Among the technology transfer services, there are services of foresight and TRM analysis and support. Table 4 reports the three case studies followed in AREA. Together with the intermediary, we identified three clusters of SMEs that AREA had coordinated for TRM analyses. The selected clusters belong to coffee, cultural and blue economy industry and they are located in the region Friuli Venezia Giulia, Italy (see Table 4 for other details). The clusters were selected for this analysis because they are considered as the most relevant concerning the trajectories outlined by the Regional Innovation Scoreboard. We analyzed the clusters by identifying critical factors on success for SMEs by cross-referencing them with those identified in the literature.

The project implementation of TRM in the companies was developed by AREA in the following phases:

- Kick-off and Orientation (objectives, topics to be addressed, available material and information sources, planning of activities and meetings, planning of project timelines, cluster work team).
- External Research and Opportunity Profiles (description of the opportunity, products, and services; market attractiveness and critical success factors; case studies on reference players).
- Sectoral Technological Map (main business factors and requirements, innovative products/services, functionalities and technologies, potential indicators - elements to monitor - on businesses, society, market, and technology).
- Final Presentation and Discussion on the results of the project (presentation of the main results of the Opportunity Profiles; presentation of the Sectoral Technological Map; discussion on how to use the roadmap as a tool to support the decision-making process for cluster organizations; discussion on how to build paths individual specifications to define product and business development plans).

According to Battistella et al. (2013), the method was based on creating Opportunity Profiles for the sector using secondary research, direct interviews with industry leaders, and case studies. This was followed by developing a sectoral Strategic Technological Map that identifies new product and service opportunities, necessary functionalities and technologies, and related business considerations, allowing the cluster and member organizations to make their own strategic decisions.

AREA developed strategic technological roadmaps that foresights possible future trajectories (5–7 years) in some relevant themes for the global industries. The methodology applied by AREA is characterized by the typical elements that distinguish TRM analyses. The TRM used is organised into five layers: products, services, supply chain, technologies, and business parameters. These maps allow SMEs to evaluate the possible impact of these themes on the firms' businesses. Thanks to the implementation of this TRM system, SMEs in the clusters were able to identify over 150 possible new products/services.

In this analysis, data were acquired through AREA's coordination experience for the three SME clusters. Twelve semi-structured interviews lasting approximately 60 min, were initially conducted with the *Foresight Manager* and the project manager that supervised AREA Science Park's foresight projects to obtain a direct and comprehensive understanding of the processes adopted during the coordination of TRM activities for SME clusters. For triangulation purposes, 3 representatives for each SME cluster related to the specific layers (products/services/supply chain, layer technologies layer, and business layer) with 10 + years of experience were interviewed. The interviewees were respectively the product and supply chain manager, the chief technology officer, and the strategy manager. Then a documentary analysis was conducted utilizing official reports, technical documentation, and internal materials provided by AREA, specifically focusing on the initiatives implemented under the TRM framework. The integration of primary and secondary sources facilitated data triangulation (Yin, 2003).

Starting from the information provided by AREA regarding case study TRM studies through semi-structured interviews, we were able to map critical success factors and compare them with those derived from literature. This allowed us to identify the complete list of critical success factors for TRM analyses for SMEs clusters.

4. Results: critical success factors for TRM implementation in SMEs clusters from case studies and literature

Table 5 synthesizes critical success factors in relation to supporting literature and relevance in SMEs. The following section discussed and generalized the results in relation to the literature.

Table 4
TRM case studies.

TRM	Cluster	SMEs involved	TRM context Aim	Participation scope	Specific focus	Alignment and organizational decision making	TRM architecture Layers	Timeframe	TRM process Time for realisation
1	Trieste Coffee Cluster	9	Industry Strategic Technology Roadmap	Industry	Genetics, supply chain traceability, shelf-life and packaging, sensorial branding and customer co-creation, pharmacy and nutraceutics	Connected to decision making of the single SMEs	Products, services, supply chain, technologies, and business parameters	5–7 years	1 year
2	Cultural and creative regional cluster	12	Foresight study and roadmap	Industry	Technologies impacting on cultural and creative industry	Connected to decision making of the single SMEs	Products, services, supply chain, technologies, and business parameters	5–7 years	1 year
3	Blue economy companies	15	Foresight study and Technology and market roadmap	Industry	Alternative fuels, robotics, ICT, waterborne transport, and aquaculture	Not connected	Technologies and business parameters	5–7 years	1 year

Table 5
Critical success factors for TRM in SME clusters.

Category		TRM critical success factor in SMEs clusters	References in TRM literature
Organization *(motivation and management)*	1	Presence of a business owner/stakeholder involvement	Meydanli and Polat, 2020; Buczacki and Laporte, 2016; Pataki et al., 2010; Arshed et al., 2012; Phaal and Muller, 2009
	2	Relevance for future actions	Kilkiş, 2014; Tugrul, et al., 2011; Kostoff and Schaller, 2001
	3	Senior management commitment	Meydanli and Polat, 2020; Hou et al., 2010; Pataki et al., 2010; Lee et al., 2007
	4	Clear definition of the objectives of the initiative	More et al., 2015; Lee et al., 2013; Arshed et al., 2012; Pataki et al., 2010; Gerdsri et al., 2009; Lee et al., 2007
	5	Defining a precise focus	Daim et al., 2018; Lee et al., 2013; Pataki et al., 2010; Gerdsri, and Kocaoglu, 2007; Phaal et al., 2004b
	6	Integration with management tools and strategic/decision-making processes	Meydanli and Polat, 2020; Buczacki and Laporte, 2016; Gershman et al., 2016, Lee et al., 2007; Probert et al., 2003
	7	Guarantee process continuity (startup - maintenance – rolling out)	Arianto and Surendro, 2017; Vatananan and Gerdsri, 2012; Pataki et al., 2010; Phaal et al., 2001
Intelligence capability *(resources and competences)*	8	Project costs	Ding and Hernández, 2023; Lee et al., 2007; Albright and Kappel, 2003
	9	Project timing	Pataki et al., 2010; Cosner et al., 2007
	10	Data/information	Kerr and Phaal, 2021; Caetano and Amaral, 2011; Pataki et al., 2010; Yoon et al., 2008; Kostoff and Schaller, 2001
	11	Support Tools	Kerr and Phaal, 2021; Meydanli and Polat, 2020; Yoon et al., 2008
	12	Necessary interdisciplinary skills	Meydanli and Polat, 2020; Battistella et al., 2015; Caetano and Amaral, 2011; Abe et al., 2009; Castellacci, 2008
	13	Facilitation/training	Meydanli and Polat, 2020; Cosner et al., 2007
Process management *(architecture and method)*	14	Clear/effective/robust/efficient process	Alcantara and Martens, 2019; Arianto and Surendro, 2017; Buczacki and Laporte, 2016; Lee et al., 2013; Vatananan and Gerdsri, 2012; Phaal et al., 2001
	15	Definition of roles	Meydanli and Polat, 2020; Tierney et al., 2013; Gerdsri et al., 2009; Phaal and Muller, 2009; Cosner et al., 2007; Albright and Kappel, 2003; Strauss et al., 1998
	16	Definition of the investigation width (scope) and investigation depth (granularity)	Meydanli and Polat, 2020; Buczacki and Laporte, 2016; Vatananan and Gerdsri, 2012; de Alcantara and Martens, 2019; Caetano and Amaral, 2011; Phaal and Muller, 2009; Cosner et al., 2007; Phaal and Farukh, 2000
	17	Definition of the architecture (layer – timeframe)	Meydanli and Polat, 2020; Cosner et al., 2007
	18	Shared format, criteria, and language	Ding and Hernández, 2023; Meydanli and Polat, 2020; Pataki et al., 2010; Alcantara and Martens, 2019; Bruce and Fine, 2004; Phaal et al., 2004a; Kostoff and Schaller, 2001
	19	Sharing and communication	Kerr and Phaal, 2021; Meydanli and Polat, 2020; Pataki et al., 2010; Lee et al., 2007; Bruce and Fine, 2004

4.1. TRM Organization (motivation and management)

The general organization of the initiative is a critical area, as many important elements must be established before starting the activities and a series of basic conditions must be achieved (Pataki et al., 2010). The inter-organizational nature of the activity increases the degree of complexity (More et al., 2015). The identified factors ensure robust motivation and effective organization and management of the process within the intra-organizational and potentially inter-organizational context. The motivational and organizational aspects we consider are:

(1) Presence of a business owner/stakeholder involvement

The literature agrees that for a roadmap to be successful, it should have a strong sense of ownership and should include individuals who hold responsibility for the map and ownership of the process (Meydanli and Polat, 2020; Arshed et al., 2012; Pataki et al., 2010; Phaal and Muller, 2009). Therefore, a 'champion' or a contact 'owner' of the roadmap must be identified both in the central working group and by the individual participating organizations. It has been found that product-technology roadmaps are better if created by users themselves and that industry maps are more successful if promoted by the industry itself (Pataki et al., 2010). As with any process, involving stakeholders and gathering feedback from all interested parties is important so that the TRM process and planning can be continuously improved (Buczacki and Laporte, 2016). Feedback must encompass all aspects of the TRM value proposition, including development costs and the value added during and after roadmap development (Pataki et al., 2010). Furthermore, in practice, it has been found that product-technology roadmaps are better if created by the users themselves. At the same time, sector maps are more successful if promoted by the sector itself and supported through the involvement of relevant stakeholders, collecting feedback from all interested parties.

In the applications of the TRM in AREA, the activity was promoted directly by the cluster to pursue its strategic objectives. As AREA's foresight manager reported "*[…] the cluster fully assumed the role of proprietary contact person for the roadmap as it did not possess the methodological competences and resources necessary to perform the task autonomously*". Consequently, it requires the assistance of the intermediary, who entirely undertakes the role of process manager. In addition to directly involving all the interested companies in the cluster, the relevant institutional stakeholders were involved in the project: the Province of Trieste, Confindustria Trieste, and the Department of Economic Development of the Municipality of Trieste.

The topic proved to be delicate, and its relevance was immediately perceived. The multi-organizational structure, the cluster's lack of experience in this context, and the launch of a collaborative TRM process for the first time have made the definition of this point quite articulated and complex. In particular, the proposed configuration, which provides for the separation between the owner of the roadmap and the person responsible for the TRM process, is an element of further criticality. It was decided that a small TCC team with the champion role should be defined to address the situation. This team actively participated in the project activities, not so much at an operational level in terms of data collection and analysis, but rather by going step-by-step through the phases of the process and defining the specifications of interest, assessing the information and data collected, guiding the decisions, and outlining the paths to take.

(2) Relevance for future actions

To be successful, a roadmap should have a clear purpose: each mapping and associated data should be presented in a study or briefing aimed at decision-making; the work should contribute to the answer to a question while also serving as the foundation for emerging recommendations for future actions (Kilkiş, 2014; Tugrul et al., 2011; Kostoff and Schaller, 2001). Maps that do not fulfil this purpose and have no relevance to future action become self-serving, offer no insights, and contribute little to decision-making. This principle, which must be defined preliminarily, constitutes both the compass and the motivational fuel that guides and supports the process (Tugrul et al., 2011).

In the TRM exercises in AREA, the cluster, as an association, expects some valuable outputs from the exercise to address specifications actions that the organization has planned for the short- and medium-term future. For this as the foresight manager recounted, during the TRM it was necessary "*to (1) create a permanent Cluster Innovation Council and (2) organize conferences and focus groups with national resonance*". The expected outputs from the mapping concerning the first point are the identification of any figures of national/international importance who could be involved in the board and a set of cognitive elements (data and information) - the result of intelligence activity - functional to support the decision-making process and the activity of the board itself. The outputs expected from the mapping concerning the second point are once again the prospective information on the sectoral scenario (markets, products, and technologies), which, presented in a dissemination form, can be used to achieve the objectives of dissemination and communication towards policymakers (at various levels). As added, "*the companies in the cluster, like individual organizations, are bearers of individual objectives (collection of information on the state and evolution of the sector, as well as the reference PEEST factors), which find a general convergence in the sector mapping or part of it*".

Although the approach, the topic did not appear particularly critical because, at the start, the cluster's objectives were clear, and the future actions to be implemented had already been defined. The following plans to leave the specific insights of interest for the individual company to a post-project phase; the contents to be covered in the common map have been defined in trying to obtain the major collective relevance possible.

(3) Senior management commitment

An important factor is the commitment of the management in the organization and development of the roadmap (Hou et al., 2010), which, through decision-making power, can influence the quality of the result (e.g., providing rewards and incentives to participants, guaranteeing the necessary resources; etc.) (Pataki et al., 2010). This requires an ongoing commitment to a strategic TRM process instead of being limited to a singular endeavor. High-quality mapping can only be achieved if the commitment of senior management is guaranteed (Meydanli and Polat, 2020; Hou et al., 2010; Lee et al., 2007). A very important factor is the management's commitment to organizing and developing the roadmap, which, through decision-making power, can influence the quality of the result (Pataki et al., 2010).

In the projects in AREA, the cluster, as an association, was represented by members of its highest bodies (Presidency, Board of Directors, Executive Committee) who promoted the initiative and actively participated personally in the activities. As the project owner, the cluster shared a common intent towards the activity, which was confirmed for the entire project duration. As operational contact for the project, the intermediary operated both as an external consultant and a provider of intelligence services.

Since the cluster is not responsible for the process, for the AREA foresight manager "*[…] commitment can mainly be made by verifying the investment of resources dedicated to the project and assigning them to the operational contact person (the intermediary) to carry out TRM activities*". The work carried out by the 'TCC core team' as champion and point of reference for activities constitutes a further strong signal of commitment. The commitment of the contact person operational towards the project was particularly strong as there was a specific internal objective of "creation, structuring and implementation of a specific TRM tool/service for support SMEs in Technology Intelligence processes", which has led to it being considered as one experimentation and an opportunity for co-development. The project manager declares that "this objective led the operational representative [AREA] to invest his resources in the project, including time of human resources, including senior ones, beyond what is covered by the order. This commitment has strengthened the cluster's commitment and guaranteed the work's success".

(4) Clear definition of the objectives of the initiative

The mapping activity requires much effort and consumes time and resources, even more so if carried out as a multi-organization activity. The exercise involves obtaining contributions from many people from different organizations (More et al., 2015; Lee et al., 2013). Before starting work, management and the TRM team must clearly define the objectives and results, communicate and confirm the status of activities, and specify procedures and timeframes for any changes to the process (Pataki et al., 2010; Lee et al., 2007). The participants involved in the activities must perceive the value of their contribution to the initiative (and to individual organizations). It must be clear and shared what the expected benefits are intended to be acquired and what objectives the organization hopes to achieve in a short and long time (including general ones such as improving communication or supporting strategy definition) (More et al., 2015). Individuals and groups will endorse a process that explicitly facilitates the expansion of their organization, identifies gaps, and directs the business toward critical needs. Both commitment and reference points may be lost if the initiative's goals and the benefits to

the organization to which it belongs are unclear (Arshed et al., 2012; Pataki et al., 2010; Gerdsri et al., 2009).

In the specific cases, through the TRM activity, the cluster has set itself the objective of supporting the decision-making process and the activity of its strategic committee and of using the information contributions for dissemination and communication actions towards policymakers (at various levels): "*evolution of the issues that the board will have to follow, the acceleration of innovation processes in the coffee sector at a global level, the overwhelming advent of new supply markets as well as new outlet segments (one of which is the growth of the instant coffee segment), the financial crisis and the tension on the price side of raw materials, are all factors that require broadening the scope of action of the first nucleus of the board and enrich its activity, also by the Technological TRM action planned with Area Science Park. TRM responds to the need to monitor changes. This allows companies in the sector to focus on missing key skills, market uncertainties, competitive threats, or critical success factors, always from a technological perspective (foresight manager)*".

The cluster engaged its members in establishing the objectives from the project's conception. The project manager recalls that "given the personal commitment of the President and the Board of Directors who presented the TRM activity in the TCC strategic plan which the cluster members approved, the definition of the initiative's strategic objectives was never in doubt." This certainty reduced the criticality of this project element and allowed the operational representative to quickly move forward with the next step of defining the precise focus of the activity.

(5) Defining a precise focus

The literature maintains that, before undertaking a TRM initiative, it is necessary to create a strategic framework (Gerdsri and Kocaoglu, 2007), defining the focus and scope of the analysis. The focus of the technology roadmap should be considered as the analysis objective, the actual orientation of the roadmap, because it highlights the central issue that requires the implementation of a TRM process (Daim et al., 2018; Lee et al., 2013; Phaal et al., 2004b). The focal issue that drives the need to use a roadmap changes significantly depending on the level at which the TRM is implemented (Pataki et al., 2010).

In the applications of the TRM in AREA, the mapping was started with precise objectives and within a closed inter-organizational context, such as the association of a specific sector. The starting point already defined a precise focus: *"the Trieste Coffee Cluster needs to acquire cognitive elements to carry out its activities and therefore intends to develop a Coffee Industry Strategic Technology Roadmap focused on the industrial coffee sector (at an international level) (Foresight manager)".*

Despite this limited starting point, the areas concerning the industrial sector remain particularly broad. For this reason, it was decided to make a further clarification by limiting the analysis to the portions of the supply chain managed directly by the cluster companies. In reality, this constituency was not pushed too far. It resulted from compromise, as some participants expressed the opposite individual need to "expand" the supply chain to evaluate verticalization opportunities. The involvement of the cluster was important in this phase, as the "small team" participated in every activity of defining and narrowing the field. In the end, the project was also affected by the economic need to narrow the field to allow for in-depth analysis of a limited number of the proposed elements.

(6) Integration with management tools and strategic/decision-making processes

Suppose the organization does not integrate the TRM with pre-existing managerial tools (planning, evaluation, for example). In that case, it can be rejected (Probert et al., 2003) or isolated from other management tools (Gershman et al.,2016). TRM must integrate with the company's overall business processes, and how this should be done should be established before the initiative launches (Gershman et al., 2016). Specifically, this issue emerges with small-scale initial operations, which should be considered an integral part of the business enterprise rather than incidental activities. Making a roadmap needs to work with current management tools and strategic planning cycles already in place for planning new technologies and products. In this manner, planning services do not see mapping as two separate tasks that need to be done at different times using completely different planning methods (Meydanli and Polat, 2020; Buczacki and Laporte, 2016; Gershman et al., 2016; Lee et al., 2007). This issue was not addressed in the TRM exercise in AREA, and the need for it did not emerge. As the foresight manager in AREA stated, the *"possible reasons are linked to the fact that by operating in a multi-organizational context, or any case in this specific case, there are no particular common management tools and previously structured strategic/decision-making processes"*. We consider that one of the objectives of the cluster is precisely the establishment of a 'permanent Board for cluster innovation', a strategic committee capable of orienting ASDI's future activities on "Research, Development, Innovation and Higher Education", but that this body is in the process of being established.

Furthermore, the approach followed involves leaving the specific insights of interest for the individual company to a post-project phase; we can assume that in this phase, this criticality, more inherent to an intra-organizational context, could emerge. However, in the project presentation phase at the cluster, a subsequent activity was envisaged to exploit the results of the TRM activity in which individual companies would be involved to define an individual path. This activity is yet to be defined and launched, but if carried forward, it will undoubtedly require integration with management tools and strategic/decision-making processes.

(7) Guarantee process continuity (startup - maintenance - rolling-out)

The literature identifies managerial and motivational critical issues relating to the organizational (and inter-organizational) context of reference. In particular, at an organizational level, the fundamental critical issues to overcome are (Pataki et al., 2010; Phaal et al., 2001): the start of the TRM process (about preliminary activities); keeping the TRM process "alive" (about the review and updating of the map periodically); and the rolling-out of the method (referring to the extension of the approach and the dissemination of the results). These critical issues do not concern the process but rather managerial and motivational aspects relating to the organizational (and possibly inter-organizational) context of reference (Arianto and Surendro, 2017; Vatananan and Gerdsri, 2012).

In the applications of the TRM in AREA, the startup phase of the project was critical, despite being born from excellent foundations (convergence of objectives, relevance for future actions, involvement of stakeholders) and in a good motivational context or, in any case, with a strong interest for the initiative since most of the companies in the cluster participated actively and continuously in the planned project activities. In particular, the definition of the financing sources for the activities by the cluster took a long time. Once these sources had been obtained, the definition of the contractual agreements between the cluster and the intermediary was also

particularly laborious, essentially due to the necessary administrative procedures. The project implementation phase (about the review and periodic updating of the map) and the rolling-out phase of the method (about the extension of the approach and the dissemination of the results) have not been addressed as they concern post-project dynamics.

According to the project manager, "*[…] the criticality during the startup phase did not cause particular problems, but it extended the project timescales, entailing the need for flexibility in planning activities and scheduling tasks*". However, this factor could have been much more critical in other circumstances, when, for example, the objectives to be achieved (and the future actions to be implemented) had been characterized by a more significant temporal contingency, in this case, less stringent.

4.2. TRM Intelligence capability (resources and skills)

A set of elements contribute to forming the intelligence ability of the organization or organizations involved. Since TRM is used to capture and structure knowledge about industry and market trends and social, environmental and technological drivers, it is characterized by a distinctly exploratory nature. To carry out a systematic activity of acquisition, analysis, evaluation and internal dissemination of relevant information on technological and business events and trends (opportunities and threats), and therefore guarantee a satisfactory quality of the output, it is necessary to make available the necessary resources and have or involve specific skills (Carvalho et al., 2013).

(8) Project costs

The literature identifies a further critical success factor in the cost of the project because building the TRM process is typically complex and requires a strong commitment in terms of costs and time (Ding and Hernández, 2023; Lee et al., 2007; Albright and Kappel, 2003). Although it is commonly underestimated, the overall cost of creating a high-quality roadmap can be high. In roadmaps with an experienced development team, the predominant factor contributing to total costs is the time invested by all individuals engaged in developing and reviewing the map. When qualified people work on the development and review process, daily costs are high, and the total development cost may not be very low. Furthermore, costs relating to external personnel (expertise, consultancy) and acquiring tools and information (database, reports) must be considered. The project's overall cost is roughly equivalent to what it would have supported a large company to carry out a similar project requesting the support of a company's external consultancy (even the intermediary itself). Also, we could estimate, in principle, through internal resources. We want to point out that these comparison considerations are complex due to strong contingency and a lack of reference points. The fact remains as a fixed point that the multi-organizational approach followed, within the limits that characterize it, still allows for the same output to divide the costs by the number of participants. The project manager also believes it is important to note that "*the cost of the project is closely linked to the objectives and focus and therefore is important to every step manage the end user's expectations (in this case the cluster) to maintain the right balance between activity and cost*". For this reason, the intermediary was attentive to every decision-making moment to present choices at the cluster, allowing you to define the next step without leaving room to overextend the scope.

(9) Project timing

Many organizations have determined that the optimal approach is to conduct the TRM process within a brief timeframe (Pataki et al., 2010). When a project continues over an extended duration, there is a significant risk that participants might neglect activities due to their engagement with more immediate tasks (Pataki et al., 2010; Cosner et al., 2007). The team responsible for the process must maintain high attention and commitment to the project from analysts and roadmap developers throughout the period.

In the applications of the TRM in AREA, following the suggestion of the literature, it was decided to define a reasonably tight project schedule (6 months expected) to avoid a lack of attention on the work or activities being postponed until the last moment. The team responsible for the process has paid attention to keeping it high.

The approach worked, and the impression was that there was a need for a similar attitude and that the activities would have advanced uncontrolled. Despite this, the project manager reported that "*some unexpected or not adequately considered critical issues emerged in the design phase, which also caused a delay in the timescale of approximately 3 months*". These critical issues concern the natural difficulty that exists in managing any inter-organizational project of a collaborative nature. For example, it proved challenging to organize short-term meetings due to the incompatibility of the different agendas, answering questionnaires, remote reviews and checks and in general, all 'remote' group activities took longer than expected; the multiplicity/redundancy of levels that characterize an inter-organizational activity (single company - cluster - intermediary - development team) has created a greater slowness of communication. On the other hand, it must be noted that the cluster has been a valuable point of reference for the intermediary and played an excellent role as a spokesperson towards the individual companies (thanks also to the pre-existing strong ties) and from another point of view it, therefore, made communication towards the individual companies by the intermediary much less demanding.

(10) Data/information

The literature argues that a roadmap should ideally take into account all relevant inputs (e.g., information and data on research, technology, and markets), all systems developed, and operations or events that are in some way inherent or connected to the overall objectives of the roadmap itself (Pataki et al., 2010; Kostoff and Schaller, 2001). This factor is fundamental for the investment strategy in innovation, as the selection of innovation programs, compared to others, and the subsequent planning and implementation are based on these inputs (Caetano and Amaral, 2011; Pataki et al., 2010). Therefore, the information sources must be as complete as possible and exploited to the maximum during the roadmap development process. The lack of quality input data is often a critical factor (Kerr and Phaal, 2021; Yoon et al., 2008).

This topic was the most critical and debated in the TRM exercises in AREA. The responsibility for this factor was mainly at the head of the intermediary, but the interest in the quality of the output was a shared element. The intermediary had privileged access to many high-quality data (patent databases, technological reports, market reports, scientific literature, etc.) but not specific to the sector of

interest. The companies in the cluster have demonstrated that they have a high knowledge of the sector, although, on average, poorly articulated.

The project manager reported that *"it was immediately highlighted that any information or documents already known to the cluster could be made available to the working group and possibly considered as acquired, allowing the research to focus on other topics of specific interest; the material made available was limited […]"*. On the other hand, it must be noted that the intermediary's knowledge, data and information were of a good level on most of the topics relevant to those typically characteristic of the sector, an area of investigation in which the basic knowledge of the cluster was on average less than ideal. The added value offered by the intermediary on the surrounding topics was significant, and the cluster's interest shifted more towards these topics during the project. On the characteristic topics, where the basic knowledge of the cluster was high, the added value of the intermediary seemed to be limited. The shared choice made during the work was to shift the interest to border issues, on which the intermediary's investigation was further focused; the choice could have been to increase the direct involvement of the cluster members by also extending it to data collection, analysis and processing activities limited to the typical themes of the sector, essentially asking for an effort to articulate the tacit knowledge already possessed. Agreeing with (Yoon et al., 2008) , it is necessary that "the information sources are as complete as possible and are exploited to the maximum during the roadmap development process, and the lack of quality input data is a critical factor".

(11) Support Tools

To best develop the various phases of the TRM process, the actors involved have various tools, methods and techniques available to support them in carrying out the activities. According to a functional criterion, we include tools and techniques for collecting, analyzing, evaluating/synthesizing, and representing information and data (Meydanli and Polat, 2020; Kerr and Phaal, 2021). The availability of effective and systematic support tools that organize information is a critical element (Kerr and Phaal, 2021; Yoon et al., 2008).

In the applications of the TRM in AREA, the tools and support techniques used were very useful: workshops, brainstorming, case studies, foresight and intelligence tools, literature review, patent analysis, Linked grid analysis, etc. Among these, particular importance was shown by those tools used to collect information and data input to the roadmap (such as patent databases, intelligence tools such as Explorer and Business Insights) and the techniques used to evaluate the different options and draw a summary from them. For example, two internal analysis tools were successfully used: the first is the Opportunity Profile Sheet, similar to technological profiles, which was very useful for guiding the analysis and synthesis of information on a particular path; the second is a markets-products-technologies grid, similar to Linked grids, which proved particularly effective and clarifying in the analysis and selection of the elements to include in the map.

The availability of various tools to support the various phases of the work was guaranteed, and there were no critical issues. However, it is noted that in addition to the availability of tools to carry out the work, adequate competence is also necessary to use them. The tools with which operators were more familiar were preferred, and their use was more efficient and effective. However, the newly introduced tools (precisely those mentioned in the examples) specific to TRM required preliminary training, a gradual introduction and an experience curve. Both the interviewees highlighted that "*after an initial period of acceptance and learning by doing on the use of the tool and once its usefulness had been demonstrated, its subsequent applications proved to be more efficient.*"

(12) Necessary interdisciplinary skills

The process attempts to create a framework for arranging and displaying important technology planning data. Consequently, participants or consultants must possess knowledge of the TRM methodological process, which encompasses the ability to identify technological needs and drivers and identify, analyze, select technological alternatives, and delineate pathways. Other participants must have specific knowledge and expertise on the content of the thematic area on which the TRM is carried out. Usually, the activity requires creating an inter-functional TRM team, given that multiple skills must be involved in the process (Battistella et al., 2015; Abe et al., 2009). The participants' skills and objectivity are crucial; seniority is not necessary. Each expert should be technically skilled in their field, and the team working on the map should have skills in all the different research areas. The team's goal should not be interpreted as being restricted to the disciplines that are directly related to the area of investigation; instead, it should include disciplines that are adjacent to it and other areas that may have an impact on the project's goals (for example, by offering novel ideas or non-obvious considerations for new paradigms) (Meydanli and Polat, 2020; Caetano and Amaral, 2011; Castellacci, 2008). In these specific cases, a multidisciplinary team was formed. In the work team, some participants possessed the methodological skills to develop the TRM process, which is necessary to support the identification of technology needs and drivers, as well as the analysis and selection of technological alternatives and the definition of the paths. Other participants possessed the knowledge and expertise on the contents of the thematic area on which the TRM was carried out, with greater specialization in the disciplines and neighbouring areas that could impact the project objectives.

Experience has demonstrated that these skills must be integrated or overlapped to a certain extent, in addition to being essential multidisciplinary abilities.

The 'methodologists' frequently dealt with the 'analysts' to explain how to effectively organize information to clarify the logic of certain conceptual steps (for example, the inter-level link). Numerous discussions have taken place to define a unique terminology or to find a common definition for the concepts underlying TRM. Conversely, discussions were held on specific scientific and technological issues that required a 'methodological' contribution to be resolved. Furthermore, remaining within the technical skills (technological and sectoral), it was found that even in a focused exercise, the different surrounding disciplines are truly numerous and often very different. These boundary disciplines may not be anticipated but arise during the investigation, especially when a remote technology, product, or market is discovered. This confirms that the team's expertise should include disciplines directly related to the research area and adjacent disciplines that may offer novel insights or non-obvious considerations for emerging paradigms. In this regard, the project manager claims that *"this obviously implies the need from time to time to involve additional experts to address a new, unforeseen topic. It would*

be appropriate in future projects to include a budget reserve to cover this potential additional cost."

(13) Facilitation/training

Technical and methodological skills are necessary but need to be improved. Interpersonal and teamwork skills matter, too (Meydanli and Polat, 2020). Thus, a well-integrated team with skills or a facilitator or consultant with interpersonal management and TRM skills is essential. (Albright and Kappel, 2003) note that training the working group on TRM methodologies is an important element, which usually precedes more active support and assistance from facilitators in carrying out the projects. According to Meydanli and Polat (2020), a facilitator can assist a team in overcoming challenges encountered in the work, comprehending the significance of the shared components of the overall framework developed, and offering a more detached external point of view to the development process. The working group can greatly benefit, particularly during the first experiences with TRM, from the support provided by an appropriate external consultant (Meydanli and Polat, 2020; Cosner et al., 2007).

According to Cosner et al. (2007), this factor is particularly important during a first experience with TRM. In the TRM exercises in AREA, the topic of facilitation was not particularly critical. However, a facilitation role was played towards the cluster by preparing presentations, explanations, and functional guidelines to clarify terminological and methodological issues. Furthermore, there was a need to manage interpersonal relationships in group meetings and encourage the achievement of compromises when necessary. The participants' climate seemed good from the start, and no particular moments of tension or criticality ever arose. However, active support and collaboration between the methodologists and the analysts were necessary within the operational working group. The interventions were designed to give technicians a more objective external point of view during the development process, help them understand the importance of the common elements of the general framework, and help them overcome obstacles in their work. The approach followed even more meets this need, as in addition to facilitation/training, it provides an active role of the intermediary in operational activities. It must be taken into consideration that most of the operational development activities were carried out by the intermediary and that the cluster contributed with an orientation and supervision role (following the process phases step by step, defining *"the specifications of interest, evaluating the data and information collected, guiding choices and defining the paths to follow) which required limited facilitation (Project manager)"*.

4.3. Process management (architecture and method)

Once the activity started, the main critical issues occurred in managing the TRM process. The difficulties encountered were of a planning, methodological, and relational nature.

If in the first category presented, 'Organization (motivation and management)', we included general context issues; instead, we collect more specific factors inherent to the architecture and method of TRM.

(14) Clear/effective/robust/efficient process

The application of TRM can present critical issues for organizations because, despite being relatively simple in structure and concept, it must provide valid information as a final result to support the decision-making processes underlying the strategy and planning process (Alcantara and Martens, 2019; Arianto and Surendro, 2017; Buczacki and Laporte, 2016; Vatananan and Gerdsri, 2012). A clear, strong, efficient, and effective process must be developed (Lee et al., 2013; Phaal et al., 2001; Alcantara and Martens, 2019). The risk is that the total development costs will exceed the organization's capacity if a better outcome can only be attained by devoting more time to the TRM process. Another important factor is the process's reliability (or repeatability) (Lee et al., 2013).

In the applications of the TRM in AREA, the planning was detailed in the preparatory phase, defining the main macro phases and all the necessary sub-activities. A Gantt chart was created at the highest level of detail, precisely defining roles, activities, times, and deliverables. A coordinator took care of the project management and supervised the activities. This was necessary for two reasons: (1) to support the contractual specifications of the parties and (2) to plan and coordinate common activities carried out collaboratively among the participants.

Experience has shown that defining a clear and robust process is the basis of the initiative's success. However, since the TRM process is characterized by being highly exploratory, it includes research and analysis activities that cannot by nature be rigidified beyond a certain extent. Within the structure of the process, it is necessary to provide a certain flexibility of operations. Since the budget is a defined parameter (Lee et al., 2007 argue that costs are the reference driver) and as there are no other comparison parameters available, it is not easy to think in terms of effectiveness and efficiency. However, experience has shown that a very significant bottleneck is linked to the data collection phase. Suppose the accessibility, completeness, and articulation of the data and information to be collected are high on a specific topic. In that case, the work proceeds more easily, and the objective is achieved more quickly. Various topics were covered to create the map, and the investigation followed the same method and process. Despite this, the results obtained regarding output quality and effort required differed in various cases. As project manager reported, "*the discussion on the topic made it possible to identify, in the first instance, the cause of a different criticality in data collection (data of greater or lesser quality, accessibility, articulation)*."

(15) Definition of roles

TRM, both at a corporate and sectoral level, requires a certain set of knowledge and skills, so the choice of who to involve in the process varies based on organizational structures and culture (Cosner et al., 2007; Strauss et al., 1998). In order for the TRM process to be carried out in the best possible way, the presence of some key figures must be guaranteed in the development, and to have the widest possible spectrum of knowledge available, a cross-functional team is normally set up (Gerdsri et al., 2009; Albright and Kappel, 2003; Strauss et al., 1998) in which it is possible to identify a leader. The team typically includes professionals from different organizational units who are interested in the development and results of TRM (analysts who are technology experts, experts in different business areas) and sometimes also external figures (generally consultants or sector experts, but the involvement of customers and suppliers is

also possible).

The definition of this parameter is critical because (1) it may require reaching a compromise between different interests, even more so in a multi-organizational context (Meydanli and Polat, 2020); (2) in agreement with Phaal and Muller (2009) and Tierney et al., (2013) this factor is also critical from an operational point of view as it determined the terms of the subsequent phases of collection, analysis and evaluation of data and information; (3) the two elements that compose it (breadth and depth of investigation) are in trade-off with each other (Meydanli and Polat, 2020). The definition of this parameter already in the preparatory phase was very important because it allowed us to define a shared level of granularity of the map architecture and delimit the study's boundaries.

To carry out TRM in the best possible way, the literature suggests the presence of some key figures within a multidisciplinary team (Meydanli and Polat, 2020; Albright and Kappel, 2003; Strauss et al., 1998) and the identification of a leader. The team typically includes professionals who know the mapping methodologies and processes, analysts who are experts in technology or experts in different business areas, and sometimes external figures (generally consultants or sector experts).

As previously mentioned, the projects carried out in AREA have already defined roles in the design phase. The definition aimed to guarantee the presence of all the figures considered key to have the widest possible spectrum of knowledge available. According to previous studies (Albright and Kappel, 2003; Strauss et al., 1998), a cross-functional team was set up with the definition of a Project manager (a leader who was an expert in the methodology and facilitator in group sessions), two TRM coordinators (methodologists, who are experts in the methodology, one of whom also took on the role of project coordinator), three technicians (analysts, who are experts in technology and various business areas). External experts were not involved, except occasionally.

(16) Definition of the investigation width (scope) and investigation depth (granularity)

The initial definition of the 'width' and 'depth' of the investigation is a critical success factor that determines the commitment and outlines the boundaries of the subsequent phases of collection, analysis and evaluation of data and information (Meydanli and Polat, 2020; de Alcantara and Martens, 2019). Meydanli and Polat (2020), Vatananan and Gerdsri (2012), and Phaal and Muller (2009) note that in the preparatory phase, it is very important to establish an appropriate level of granularity of the map architecture.

Caetano and Amaral (2011) and Cosner et al. (2007) state that the roadmap's reference time dimension is crucial, especially if multiple organizations are involved. Innovation rate and competitive environment may affect product life cycles for participating organizations. This parameter is required to specify the investigation's focus and ensure that the layers—technology, product, service, business, and market evolution—are precisely defined and coordinated (Buczacki and Laporte, 2016; Phaal and Farrukh, 2000).

Each roadmap must explicitly indicate the reference time dimension (Phaal and Farrukh, 2000), a parameter necessary to define the focus of the investigation and guarantee that technological, product, service, business and market evolution are synchronized in an effective way. This parameter is critical, especially if the initiative involves multiple organizations. Participating organizations may exhibit different product life cycles due to differences in innovation rates and competitive contexts (Buczacki and Laporte, 2016; Caetano and Amaral, 2011; Cosner et al., 2007). A further critical element is to direct participants (with an operational role) to invest time thinking about possible future opportunities and the conditions for success, with a strategic time horizon, as many participants in their ordinary activity will be mainly focused on achieving objectives fixed in the short term, and may find it difficult to shift focus to longer timescales (de Alcantara and Martens, 2019).

As project manager reported, *"during the kick-off phase of the project, after defining the focus of the study, a lot of time and effort was spent on defining the investigation's boundaries. The opinions and interests of the cluster members were quite diversified. To reach a consensus, a questionnaire was prepared to collect interests, identify common themes, and start a discussion to reach a compromise."*

(17) Definition of the architecture (layer – timeframe)

In the projects carried out in AREA, during the kick-off phase of the project, after the definition of the focus of the study, a comparison was started to reach a definition of the levels of analysis to include in the map, as well as the reference time horizon. Concerning the definition of the layers, following a brief comparison to discuss some possible configurations, an overall consensus emerged regarding the choice of a standard solution (technologies - products - markets). However, the opinions and interests of the cluster members were somewhat diversified over time. A questionnaire was prepared to collect the participants' preferences and quickly converge on a shared solution to reach an agreement.

This element was not particularly critical, even if the literature suggested it should have been particularly critical in a multi-organizational context (Meydanli and Polat, 2020; Cosner et al., 2007). Possible explanations are: (1) similar product life cycles, innovation rates, and competitive context characterize the organizations in the cluster. This is plausible considering that the variety of offerings in this area is limited and that companies differ mainly due to different positions in the supply chain. (2) The proactive management of this issue by the intermediary and the TCC leaders made the process much easier. The project manager claims that "*the involvement of the TCC members in a 'democratic' procedure made possible a rapid definition and complete sharing of the architecture. The fact that the individual company did not contribute visibly to the cost of labour may be an element that allowed us to reach a sharing without great difficulty. If instead, we had asked for a "spot" contribution to finance the activity, some companies may have insisted more on imposing their vision of priorities*".

(18) Shared format, criteria, and language

For the construction of any map, it is essential to define the criteria for selecting and quantifying the crucial elements and the connections between them. Furthermore, for roadmaps that will be used for comparison for research and development projects or programs, normalization and standardization between maps (by research area and development team) are important factors. Thus, relevant factors are the shared definition of the criteria for the selection, quantification, and interconnection of the elements of the map (Pataki et al., 2010; Kostoff and Schaller, 2001) and a functional and standardized format for the output (Meydanli and Polat, 2020; de Alcantara and Martens, 2019; Phaal et al., 2004a;). Additional challenges include defining a functional format for the output and visualization of an experimental mapping activity and developing a common "vocabulary" for people from different organizations to

develop a TRM project (Ding and Hernández, 2023; Bruce and Fine, 2004).

In the TRM exercises in AREA, within the working group, a great effort was made to share the language in the initial phase. As previously mentioned, numerous discussions took place to define a unique terminology and find a common definition for the concepts of 'market', 'product', 'technology' or other constructs, such as the 'elements' and 'links' in the map.

Initially, sufficient importance was not given to the problem, and once the tasks had been shared, the work was divided. Evidence of different interpretations of the same concepts emerged from the first subsequent comparisons. With the awareness of the importance of reaching a uniform output, steps were taken to share terminology and concepts. Similarly, in a more advanced phase of the project, it was necessary to pause to clearly define shared criteria for defining and selecting the elements and the connections between them.

(19) Sharing and communication

The literature considers TRM as a collective activity (Pataki et al., 2010) and notes that the social and interaction aspects must not be underestimated, even more so in the presence of different participant organizations (Kerr and Phaal, 2021; Bruce and Fine, 2004). Trust is a critical component of inter-organizational TRM (Meydanli and Polat, 2020). Maps are built thanks to a group of people working collaboratively. A critical component of inter-organizational TRM is trust. There must be a willingness and openness to share information. Communication and sharing are critical elements (Pataki et al., 2010). TRM should be more efficient if participants can easily update and share information (Pataki et al., 2010; Lee et al., 2007). Communication and sharing are crucial to involve all participants and ensure that the mapping is based on consistent assumptions and includes all necessary elements. According to (Kerr and Phaal, 2021; Bruce and Fine, 2004), the social and interaction aspects that characterize TRM must not be underestimated, even more so when different organizations are involved.

In the projects carried out in AREA, some unexpected, or not adequately considered, critical issues emerged concerning the greater communication difficulty that affects collaborative inter-organizational projects. As previously mentioned, one of these issues was the multiplicity/redundancy of the levels of the inter-organizational system (single company - cluster - intermediary - development team), which has led to a certain slowness of communication. On the other hand, the cluster was recognized as a precious point of reference for the intermediary and played an excellent role as a spokesperson towards the individual companies, making communication to/from the intermediary much less demanding. Concerning the theme of sharing, during the group meetings with the cluster members, interactions and discussions between the companies were quite open. However, these spaces were limited, and the activities' nature was simplified: companies' role was mainly oriented towards supervision, evaluation, and choice rather than the certainly more critical activity of sharing proprietary information.

"[…] The experience allowed us to highlight the importance of communication aspects; however, on issues relating to topics such as trust and willingness to exchange information, the strong intervention of the intermediary in operational development activities has made it possible to 'get around' the problem and, in our opinion, makes the test bed for substantial considerations insufficient (foresight manager)." A subsequent activity with individual companies, as envisaged by this project as a possible subsequent activity, could give more space to experiment with applying the sector map results to define the individual company's path. This activity requires more sensitive data sharing, which the company may be more willing to do if no other potentially competitive companies are involved.

5. Discussion

Our analysis identifies critical success factors for TRM analyses in SME clusters coordinated by an intermediary from a systemic point of view, i.e. by placing them for each step of the required process. Previous literature does not explicitly discuss critical success factors in SMEs and SME clusters coordinated by an intermediary. Only Park et al. (2013) consider TRM critical success factors in SMEs but only those that impact TRM performance. Our analysis expands the research conducted by Park et al. (2013), revealing 19 critical success factors previously unrecognized in the literature. These factors are categorized into three groups encompassing the entire TRM process: Organization (motivation and management), Intelligence Capability (resources and competencies), and Process Management (architecture and methods), rather than focusing on performance. Another contribution of our study is the formalization of a framework of critical success factors applicable to SMEs, which frequently encounter structural limitations in foresight due to limited resources (Carayannis et al., 2025; Dörr et al., 2024). We propose the implementation of TRM via clusters of SMEs, coordinated by an intermediary that facilitates the process and offers organizational and operational support. Current research on SME clusters has concentrated on formulating novel methodologies for implementing TRM (Lee et al., 2007; Gindy et al., 2009; Battistella et al., 2015), overlooking the examination of the factors that facilitate successful intervention. In contrast to the research conducted by Battistella et al. (2015) and Buczacki et al. (2016), which examine SME clusters within a singular sector (the coffee sector and the creative industry, respectively), our study adopts a cross-sectoral approach, encompassing clusters in the coffee sector, the cultural and creative industry, and the blue economy, thereby enhancing the generalizability of critical success factors. Our analysis showed that TRM is not a process without critical issues. With critical factors we referred to the set of elements that directly or indirectly impact on the TRM exercise, facilitating, favouring, and enabling (success factors) or not (barriers) the completion of the activity. Despite its potential benefits, this approach presents significant challenges to businesses. TRM is simple in structure and concepts, but results depend on a detailed strategy and planning process (Phaal et al., 2001; Lee et al., 2007). Consequently, enterprises, particularly small and medium-sized ones, continue to face challenges in implementing TRM (Kim and Seo, 2023; Carvalho et al. 2013; Arshed et al. 2012). The cases allowed us to observe and validate in the field the essential factors for TRM implementation in SMEs, which can be categorized into three distinct domains: Organization, Intelligence capabilities, and Process. In accordance with this premise, we note that recently the literature has begun to address the issue of critical success factors of TRM but does not present structured and quantitative contributions (Lee et al., 2013; Park et al. 2013; Pataki et al., 2010; Daim et al., 2018; Daim and Oliver, 2008) In fact, it provides the results of case studies, lessons learned, qualitative questionnaires drawn mainly from operational experience. Not surprisingly, this

research topic is guided by the practical experience of practitioners and to a lesser extent by theoretical studies (e.g, Lee et al., 2007; Oliveira and Rozenfeld, 2010; Battistella et al., 2015; Buczacki and Laporte, 2016; Vicente Oliva and Martinez-Sanchez, 2018)

Furthermore, since there are numerous methods and possible configurations to carry out a TRM process, the nature of the empirical findings is quite heterogeneous, not structured, and difficult to compare (e.g., Vicente Oliva and Martinez-Sanchez, 2018; Schimpf and Abele, 2019) Indeed, most TRM studies have focused on corporate processes in large companies, many on inter-organizational processes involving large trade or industry associations, and few on SMEs. While TRM has been used successfully in big businesses and by the government, not much research has been done on how it can be used in small and medium-sized businesses, either as promoters or as members of a group building the strategic context of reference (e.g., Carvalho et al. 2013; Battistella et al., 2015; Jun et al., 2013; Park et al., 2013; Arshed et al., 2012),

The limited focus on SMEs in the current literature is partially attributable to their frequent exclusion from the TRM process in practice. This because they still have difficulties in applying the TRM as the methodology was not designed for these firms and requires customization. Indeed, the technology roadmap is a valuable and flexible approach. However, its potential benefit may not be fully exploited if it is difficult to customize it to meet specific needs or adapt to participant organizations' specific features (Lee and Park, 2005) . The literature analysis helped us identify critical factors that affect TRM and initiative success. Nevertheless, previous studies mostly derive from the experiences gained in the applications in large companies or large trade associations. As discussed, the proposed contributions do not appear in literature in a structured form, and the synthesis work carried out has allowed us to frame them in a simple framework. The proposed framework encompasses three categories (TRM organization. TRM intelligence ability, TRM process management) that, in our assessment, represent the main domains of critical success factors for the TRM process.

From a more general perspective, research confirms the key role of intermediaries in foresight exercises. Indeed, it is crucial to have intermediaries who take on the task and responsibility of integrating and managing the participating firms in clusters (Gattringer and Wiener, 2020; Rinkinen and Mäkimattila, 2015). Intermediaries, as shown by our analysis, in addition to coordinating activities, transfer knowledge and promote the use of this transferred knowledge as a future kit for foresight activities (Rinkinen and Mäkimattila, 2015; Major and Cordey-Hayes, 2000).

6. Conclusions

The research aimed to structure, implement, and evaluate a TRM methodology tailored for SMEs. We examined the essential critical success factors in a scenario where an intermediary acts as an agent to assist in the process and enable the execution of the TRM process. Hence, this study aimed to proceed with three in-depth studies aimed at identifying and verifying the critical success factors of TRM in the Intermediary - SME case. The experience carried out involved AREA as an intermediary to support the foresight process of SMEs involved. In this context, AREA's mission is to offer concrete assistance to SME clusters to ensure the critical success factors identified during the process are present. The objective is to assist SMEs in establishing systematic strategic foresight mechanisms that enhance their capacity to anticipate technological and market shifts while safeguarding the critical success factors identified through analysis. Through this coordination as intermediary, AREA aims to enhance companies' capability for proactive future planning, minimizing improvisation and fostering a culture of innovation grounded in robust analytical foundations and strategic knowledge management.

This happened through:

- The support for the shared definition of objectives and the focus of foresight needs – the intermediary favored the definition of a precise focus of the investigation, linked to future actions of interest and relevance for the companies involved, thus allowing to reach a shared vision of the purposes and boundaries of the roadmap, and the definition of opportunity profiles – the intermediary supported the selection of possible strategic options and projects, as well as the subsequent implementation plans (*Critical success factors:* Relevance for future actions; Senior management commitment; Clear definition of the objectives of initiative; Defining a precise focus; Integration with management tools and strategic / decision – making processes; Guarantee process continuity (startup – maintenance – rolling out); Definition of the investigation width (scope) and investigation depth (granularity));
- The promotion of interest in the project – the intermediary facilitated preliminary activities by supporting the buy-in of the initiative to illustrate the potential and limits of a little-known foresight tool, support organizations to understand the application context better, and clarify the possible evolution paths –, the coordination of activities – the intermediary has carried out a facilitation action in group activities, managed interpersonal relationships, stimulating collaboration, and supporting the shared definition of choices, often resulting from compromises – and management of project activities – the intermediary assumes operational responsibility for activities, resources, timing, objectives; (*Critical success factors*: Project costs; Project timing; Clear/effective/robust/efficient roles; Definition of roles);
- The provision of foresight operational and methodological skills, especially in scanning the environment and processing, generating, and combining information, in gatekeeping and brokering, in the technology assessment and evaluation that are necessary to carry out intelligence activities – the intermediary has acquired the analyst functions, used for the collection, analysis and synthesis of data, thus lightening the commitment of resources and skills required to each company in operational activity, also providing methodological support by aligning the participants during the TRM process, also through informal training interventions (*Critical success factors:* Data/information; Facilitation/training; Definition of the architecture (layer – timeframe); Shared format, criteria and language; Sharing and communication);
- This facilitated access to knowledge networks, research, and many analysis and evaluation tools (*Critical success factors:* Presence of a business owner/stakeholder involvement; Relevance for future actions; Support tools; Necessary interdisciplinary skills);

From an academic point of view, these contributions can enrich the literature on TRM adoption and SMEs' approaches to innovation and new technologies. Furthermore, they can guide future research by exploring these factors in greater depth or examining their interrelationships. It also paves the way for new research that can adopt intermediaries' perspectives to study clusters of organizations that would otherwise be difficult to study independently.

From a practical perspective, the paper provides clear guidelines on the critical success factors that can guide TRM analyses in SME clusters. These guidelines are also particularly useful for service intermediaries who can more consciously coordinate TRM studies in SME clusters, checking whether critical success factors are present during the process.

Besides, the present study may also support SMEs in evaluating the possible roadmaps for their products/services.

The study has some limitations. The analysis is confined to clusters of SMEs situated in the Friuli-Venezia Giulia region in Italy. This territory's unique economic, infrastructural, and institutional conditions may not reflect other regional contexts at the national and European levels. Thus, context variables that are not generalizable may affect the identified critical success factors. Moreover, the presence of a well-organized and proficient intermediary like Area Science Park, which actively coordinates the clusters, is a unique characteristic that may be not replicable in regions with no intermediaries with comparable capabilities and resources. Subsequent research may broaden the focus to clusters of SMEs coordinated by intermediaries in various Italian and European regions to evaluate the applicability of the proposed framework and conduct a comparative analysis of the intermediary's role across diverse territorial and economic contexts.

CRediT authorship contribution statement

Giovanna Attanasio: Writing – review & editing, Writing – original draft, Visualization, Data curation, Methodology. **Cinzia Battistella:** Writing – original draft, Investigation, Funding acquisition, Conceptualization, Methodology, Supervision. **Roberto Pillon:** Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Acknowledgement

The authors acknowledge the contribution of the Italian project "MUR Progetto PRIN2022 – Financed by European Union – Next generation EU – PNRR M4.C2.1.1– Paths and bundles 4.0 - PATHS4.0 - Code 2022AAB4WL - CUP G53D23002000006".

Data availability

Data will be made available on request.

References

Abbasi, M., Vassilopoulou, P., Stergioulas, L., 2017. Technology roadmap for the creative industries. Creat. Ind. J. 10 (1), 40–58.
Abe, H., Ashiki, T., Suzuki, A., Jinno, F., Sakuma, H., 2009. Integrating business modeling and roadmapping methods–The Innovation Support Technology (IST) approach. Technol. Forecast. Soc. Change 76 (1), 80–90.
Agyapong, A., Zamore, S., Mensah, H.K., 2020. Strategy and performance: does environmental dynamism matter? J. Afr. Bus. 21 (3), 315–337.
Ahumada-Tello, E., Ovalle-Osuna, O.O., Evans, R.D., 2023. Strategic roadmapping for technological change. IEEE Technol. Eng. Manag. Soc. Body Knowl. (TEMSBOK) 53–67.
Akhavan, P., Jafari, M., Fathian, M., 2006. Critical success factors of knowledge management systems: a multi-case analysis. Eur. Bus. Rev. 18 (2), 97–113.
Albright, R.E., Kappel, T.A., 2003. Roadmapping in the corporation. Res. Technol. Manag. 46 (2), 31–40.
Alcantara D.P., Martens M.L. (2019). Technology Roadmapping (TRM): a systematic review of the literature focusing on models. Technological Forecasting and Social Change.
Allee, V. (2012). The knowledge evolution. Routledge.
Amati, G., Motta, V., Vecchiato, R., 2020. Roadmapping for innovation management: evidence from pirelli. RD Manag. 50 (4), 462–477.
Amer, M., Daim, T.U., 2010. Application of technology roadmaps for renewable energy sector. Technol. Forecast. Soc. Change 77 (8), 1355–1370.
Arianto, B.G., Surendro, K., 2017. October). Implementation of building process integration of business model. canvas and technology roadmap for strategic management: Case study: PT. XYZ. IEEE, pp. 61–66.
Arshed, N., Finch, J., Bunduchi, R. (2012). Technology roadmapping and SMEs: A literature review. DRUID Society Conference, Copenhagen.
Ateetanan, P., Shirahada, K., 2016. A seamless value co-creation service roadmap of assistive technologies for the elderly (September). In 2016 Portland International Conference on Management of Engineering and Technology (PICMET). IEEE, pp. 2751–2761 (September).
Attanasio, G., Battistella, C., Chizzolini, E., 2025. Efficient, secure and green future scenarios: An application of foresight methodologies on seaports digitalisation. Research in Transportation Business & Management 61, 101411.
Baabdullah, A.M., Alalwan, A.A., Slade, E.L., Raman, R., Khatatneh, K.F., 2021. SMEs and artificial intelligence (AI): antecedents and consequences of AI-based B2B practices. Ind. Mark. Manag. 98, 255–270.
Battistella, C., Colucci, K., De Toni, Nonino, F., 2013. Methodology of business ecosystems network analysis: A case study in Telecom Italia Future Centre. Technol. Forecast. Soc. Change 80 (6), 1194–1210.
Battistella, C., De Toni, A.F., Pillon, R., 2015. The extended map methodology: technology roadmapping for SMEs clusters. J. Eng. Technol. Manag. 38, 1–23.
Battistella, C., De Toni, A.F., 2011. A methodology of technological foresight: A proposal and field study. Technol. Forecast. Soc. Change 78 (6), 1029–1048.
Battistella, C., Ferraro, G., Pessot, E., 2023. Technology transfer services impacts on open innovation capabilities of SMEs. Technol. Forecast. Soc. Change 196 (2023), 122875.
Beerepoot, I., Di Ciccio, C., Reijers, H.A., Rinderle-Ma, S., Bandara, W., Burattin, A., Zerbato, F., 2023. The biggest business process management problems to solve before we die. Comput. Ind. 146, 103837.
Bergh, D.D., D'Oria, L., Crook, T.R., Roccapriore, A., 2024. Is knowledge really the most important strategic resource? A meta-analytic review. Strateg. Manag. J. 1, 16.
Bower, J.L., Christensen, C.M., 1995. Disruptive technologies: catching the wave. Harv. Bus. Rev. 73 (1), 43–53.
Bozeman, B., Rimes, H., Youtie, J., 2015. The evolving state-of-the-art in technology transfer research: revisiting the contingent effectiveness model. Res. Policy 44 (1), 34–49.

Bruce, E.J., Fine, C.H., 2004. Technology roadmapping: mapping a future for integrated photonics. Mass. Inst. Technol. 1–21.
Buczacki, A., Laporte, C.Y., 2016. Technology planning approach for very small entities. INCOSE Int. Symp. 26 (1), 1293–1306 (July).
Caetano, M., Amaral, D.C., 2011. Roadmapping for technology push and partnership: a contribution for open innovation environments. Technovation 31 (7), 320–335.
Caner, T., Sun, J., Prescott, J.E., 2014. When a firm's centrality in R&D alliance network is (not) the answer for invention: the interaction of centrality, inward and outward knowledge transfer. J. Eng. Technol. Manag. 33, 193–209.
Carayannis, E.G., Papamichail, G., Zotas, N., Askounis, D., 2025. Corporate foresight: navigating uncertainty in a VUCA world. J. Knowl. Econ. 1–22.
Carvalho, M.M., Fleury, A., Lopes, A.P., 2013. An overview of the literature on technology roadmapping (TRM): contributions and trends. Technol. Forecast. Soc. Change 80 (7), 1418–1437.
Castellacci, F., 2008. Technological paradigms, regimes and trajectories: manufacturing and service industries in a new taxonomy of sectoral patterns of innovation. Res. Policy 37 (6-7), 978–994.
Chakraborty, S., Nijssen, E.J., Valkenburg, R., 2022. A systematic review of industry-level applications of technology roadmapping: evaluation and design propositions for roadmapping practitioners. Technol. Forecast. Soc. Change 179, 121141.
Clarke, I., Ramirez, M., 2014. Intermediaries and capability building in 'emerging'clusters. Environ. Plan. C Gov. Policy 32 (4), 714–730.
Cosner, R.R., Hynds, E.J., Fusfeld, A.R., Loweth, C.V., Scouten, C., Albright, R., 2007. Integrating roadmapping into technical planning. Res. Technol. Manag. 50 (6), 31–48.
da Silveira Junior, L.A.B., Vasconcellos, E., Guedes, L.V., Guedes, L.F.A., Costa, R.M., 2018. Technology roadmapping: a methodological proposition to refine delphi results. Technol. Forecast. Soc. Change 126, 194–206.
Daim, T.U., Oliver, T., Phaal, R., 2018. Technology roadmapping improvement through an add-on process: presentation and initial application. Technol. Roadmap 2, 383–424.
de Alcantara, D.P., Martens, M.L., 2019. Technology roadmapping (TRM): a systematic review of the literature focusing on models. Technol. Forecast. Soc. Change 138, 127–138.
de Weck, O.L., 2022. Knowledge management and technology transfer. In Technology Roadmapping and Development: A Quantitative Approach to the Management of Technology. Springer International Publishing, Cham, pp. 425–446.
Ding, B., Hernández, X.F., 2023. Case study as a methodological foundation for technology roadmapping (TRM): literature review and future research agenda. J. Eng. Technol. Manag. 67, 101731.
Dörr, U.S., Schönhofer, G., Schwarz, J.O., 2024. The state of foresight in small and medium enterprises: literature review and research agenda. Eur. J. Futures Res. 12 (1), 16.
Ednie, G., Kapoor, T., Koppel, O., Piczak, M.L., Reid, J.L., Murdoch, A.D., Cooke, S.J., 2023. Foresight science in conservation: tools, barriers, and mainstreaming opportunities. Ambio 52 (2), 411–424.
Escoz Barragan, K., Hassan, S.S., Meisner, K., Bzhalava, L., 2025. Dynamics of digital change–measuring the digital transformation and its impacts on the innovation activities of SMEs. Eur. J. Innov. Manag. 28 (4), 1625–1648.
European Commission. (2002). Clusters in europe, observatory of european SMEs, no. 3.
Faisol, F., Aliami, S., Anas, M., 2022. Pathway of building SMEs performance in cluster through innovation capability. Econ. Dev. Anal. J. 11 (2), 140–152.
Farrukh, C., Phaal, R., Probert, D., 2003. Technology roadmapping: linking technology resources into business planning. Int. J. Technol. Manag. 26 (1), 2–19.
Faruque, M.O., Chowdhury, S., Rabbani, G., Nure, A., 2024. Technology adoption and digital transformation in small businesses: trends, challenges, and opportunities. Int. J. Multidiscip. Res. 6 (10.), 36948.
Fergnani, A., 2022. Corporate foresight: a new frontier for strategy and management. Acad. Manag. Perspect. 36 (2), 820–844.
Fitzgerald, M., Kruschwitz, N., Bonnet, D., Welch, M., 2014. Embracing digital technology: a new strategic imperative. MIT sloan Manag. Rev. 55 (2), 1.
Gancarczyk, M., 2015. Enterprise-and industry-level drivers of cluster evolution and their outcomes for clusters from developed and less-developed countries. Eur. Plan. Stud. 23 (10), 1932–1952.
Gancarczyk, M., Gancarczyk, J., 2018. Proactive international strategies of cluster SMEs. Eur. Manag. J. 36 (1), 59–70.
Garcia, M.L., Bray, O.H., 1997. Sandia national laboratories. Fundam. Technol. Roadmap. SAND-97-0665.
Gattringer, R., Wiener, M., 2020. Key factors in the start-up phase of collaborative foresight. Technol. Forecast. Soc. Change 153, 119931.
Gerdsri, N., 2013. Implementing technology roadmapping in an organization. In Technology Roadmapping for Strategy and Innovation: Charting the Route to Success. Heidelberg: Springer Berlin Heidelberg, Berlin, pp. 191–210.
Gerdsri, N., Assakul, P., Vatananan, R.S., 2010. An activity guideline for technology roadmapping implementation. Technol. Anal. Strateg. Manag. 22 (2), 229–242.
Gerdsri, N., Kocaoglu, D.F., 2007. Applying the analytic hierarchy process (AHP) to build a strategic framework for technology roadmapping. Math. Comput. Model. 46 (7-8), 1071–1080.
Gerdsri, N., Kongthon, A., Vatananan, R.S., 2013. Mapping the knowledge evolution and professional network in the field of technology roadmapping: a bibliometric analysis. Technol. Anal. Strateg. Manag. 25 (4), 403–422.
Gerdsri, N., Puengrusme, S., Vatananan, R., Tansurat, P., 2019. Conceptual framework to assess the impacts of changes on the status of a roadmap. J. Eng. Technol. Manag. 52, 16–31.
Gerdsri, N., Vatananan, R.S., Dansamasatid, S., 2009. Dealing with the dynamics of technology roadmapping implementation: a case study. Technol. Forecast. Soc. Change 76 (1), 50–60.
Gershman, M., Bredikhin, S., Vishnevskiy, K., 2016. The role of corporate foresight and technology roadmapping in companies' innovation development: the case of Russian state-owned enterprises. Technol. Forecast. Soc. Change 110, 187–195.
Gershman, M., Bredikhin, S., Vishnevskiy, K., 2016. The role of corporate foresight and technology roadmapping in companies' innovation development: the case of Russian state-owned enterprises. Technol. Forecast. Soc. Change 110, 187–195.
Geum, Y., Farrukh, C., Lee, S., 2023. An integrated framework for assessing the technology roadmapping process from multiple perspectives: the case at the sector level. J. Eng. Technol. Manag. 67, 101732.
Geum, Y., Kim, J., Son, C., Park, Y., 2013. Development of dual technology roadmap (TRM) for open innovation: structure and typology. J. Eng. Technol. Manag. 30 (3), 309–325.
Geum, Y., Lee, S., Kang, D., Park, Y., 2011. The customisation framework for roadmapping product-service integration. Serv. Bus. 5, 213–236.
Gholipoor, P., Mozaffari, M.M., 2020. Designing a strategic foresight model in small and medium-sized enterprises. Int. J. Foresight Innov. Policy 14 (2-4), 292–313.
Gindy, N.N.Z., Arman, H., Cavin, S., 2009. Linking RandD investment strategies to business needs: strategic technology alignment roadmapping (STAR). PICMET Portland Int. Conf. Manag. Eng. Technol. 2455–2465 (August).
Gindy, N.N.Z., Cerit, B., Hodgson, A., 2006. Technology roadmapping for the next generation manufacturing enterprise. J. Manuf. Technol. Manag. 14 (4), 404–416.
Grodal, S., Krabbe, A.D., Chang-Zunino, M., 2023. The evolution of technology. Acad. Manag. Ann. 17 (1), 141–180.
Groenveld, P., 2007. Roadmapping integrates business and technology. Res. Technol. Manag. 50 (6), 49–58.
Hansen, C., Daim, T., Ernst, H., Herstatt, C., 2016. The future of rail automation: a scenario-based technology roadmap for the rail automation market. Technol. Forecast. Soc. Change 110, 196–212.
Heger, T., Boman, M., 2015. Networked foresight—The case of EIT ICT labs. Technol. Forecast. Soc. Change 101, 147–164.
Hermann, A., Gollhardt, T., Cordes, A.K., von, Lojewski, L., Hartmann, M.P., Becker, J., 2024. Digital transformation in SMEs: a taxonomy of externally supported digital innovation projects. Int. J. Inf. Manag. 74, 102713.
Hirose, Y., Phaal, R., Farrukh, C., Gerdsri, N., Lee, S., 2020. Characterizing Maturity Levels for Organization-Wide Roadmapping Implementation. IEEE Eng. Manag. Rev.
Holmes, C., Ferrill, M., 2005. The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies. Technol. Forecast. Soc. Change 72 (3), 349–357.

Hou, J., Lu, Q., Shi, Y., Rong, K., Lei, Q., 2010. Critical factors for technology roadmapping: case studies (December). In 2010 IEEE International Conference on Industrial Engineering and Engineering Management. IEEE, pp. 2168–2172 (December).
Jacob, J., Mei, M.Q., Gunawan, T., Duysters, G., 2022. Ambidexterity and innovation in cluster SMEs: evidence from Indonesian manufacturing. Ind. Innov. 29 (8), 948–968.
Jannek, K., Burmeister, K., 2007. Corporate foresight in small and medium-sized enterprises. Foresight Brief. Eur. Foresight Monit. Netw. 101, 1–4.
Jun, S.P., Seo, J.H., Son, J.K., 2013. A study of the SME technology roadmapping program to strengthen the R&D planning capability of Korean SMEs. Technol. Forecast. Soc. Change 80 (5), 1002–1014.
Kajikawa, Y., Kikuchi, Y., Fukushima, Y., Koyama, M., 2013. Utilizing risk analysis and scenario planning for technology roadmapping. Strateg. Plan. Decis. High. Tech. Ind. 231–244.
Karaev, A., Lenny Koh, S.C., Szamosi, L.T., 2007. The cluster approach and SME competitiveness: a review. J. Manuf. Technol. Manag. 18 (7), 818–835.
Kerr, C., Phaal, R., 2020. Technology roadmapping: industrial roots, forgotten history and unknown origins. Technol. Forecast. Soc. Change 155, 119967.
Kerr, C., Phaal, R., 2021. Roadmapping and roadmaps: definition and underpinning concepts. IEEE Trans. Eng. Manag. 69 (1), 6–16.
Kilkiş, Ş., 2014. Transition management: case study of an energy efficiency technology roadmap in Turkey. J. Sustain. Dev. Energy Water Environ. Syst. 2 (4), 331–349.
Kim, S., Jang, H., Yoon, B., 2023. Developing a data-driven technology roadmapping method using generative adversarial network (GAN). Computers in Industry 145, 103835.
Kim, J.S., Seo, D., 2023. Foresight and strategic decision-making framework from artificial intelligence technology development to utilization activities in small-and-medium-sized enterprises. Foresight 25 (6), 769–787.
Kim, E., Simonse, L.W., Beckman, S.L., Appleyard, M.M., Velazquez, H., Madrigal, A.S., Agogino, A.M., 2020. User-centered design roadmapping: anchoring roadmapping in customer value before technology selection. IEEE Trans. Eng. Manag. 69 (1), 109–126.
Kogut, B., Zander, U., 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. J. Int. Bus. Stud. 24, 625–645.
Kogut, B., Zander, U., 1995. Knowledge, market failure and the multinational enterprise: a reply. J. Int. Bus. Stud. 417–426.
Kostoff, R.N., Schaller, R.R., 2001. Science and technology roadmaps. IEEE Trans. Eng. Manag. 48 (2), 132–143.
Kwon, K., Jun, S., Lee, Y.J., Choi, S., Lee, C., 2022. Logistics technology forecasting framework using patent analysis for technology roadmap. Sustainability 14 (9), 5430.
Lamprinopoulou, C., Tregear, A., 2011. Inter-firm relations in SME clusters and the link to marketing performance. J. Bus. Ind. Mark. 26 (6), 421–429.
Lee, S., Kang, S., Park, Y., Park, Y., 2007. Technology roadmapping for R&D planning: the case of the Korean parts and materials industry. Technovation 27 (8), 433–445.
Lee, S., Park, Y., 2005. Customization of technology roadmaps according to roadmapping purposes: Overall process and detailed modules. Technol. Forecast. Soc. Change 72 (5), 567–583.
Lee, J.H., Phaal, R., Lee, C., 2011. An empirical analysis of the determinants of technology roadmap utilization. RD Manag.
Lee, J.H., Phaal, R., Lee, S.H., 2013. An integrated service-device-technology roadmap for smart city development. Technol. Forecast. Soc. Change 80 (2), 286–306.
Li, X., Wang, Y., Huang, L., Gao, N., Huang, X., 2024. A novel integrated approach for roadmapping disruptive technologies from a technology convergence perspective. IEEE Trans. Eng. Manag.
Lichtenthaler, U., Ernst, H., 2008. Innovation intermediaries: why Internet marketplaces for technology have not yet met the expectations. Creat. Innov. Manag. 17 (1), 14–25.
Linares-Barbero, C., & De La Vega, I. (2024). The impact of strategic foresight on innovation: A systematic literature review. IEEE Engineering Management Review.
Linnenluecke, M.K., Marrone, M., Singh, A.K., 2020. Conducting systematic literature reviews and bibliometric analyses. Australian journal of management 45 (2), 175–194.
Lorentz, H., Hilmola, O.P., Malmsten, J., Srai, J.S., 2016. Cluster analysis application for understanding SME manufacturing strategies. Expert Syst. Appl. 66, 176–188.
Major, E., Cordey-Hayes, M., 2000. Knowledge translation: a new perspective on knowledge transfer and foresight. Foresight 2 (4), 411–423.
Marinković, M., Al-Tabbaa, O., Khan, Z., Wu, J., 2022. Corporate foresight: a systematic literature review and future research trajectories. J. Bus. Res. 144, 289–311.
Matthews, W.H., 1992. Conceptual framework for integrating technology into business strategy. Int. J. Veh. Des. 13 (5-6), 524–532.
McCarthy, R.C., 2003. Linking technological change to business needs. Res. Technol. Manag. 42 (2), 47–52.
McMillan, A., 2003. Roadmapping—agent of change. Res. Technol. Manag. 46 (2), 40–47.
Metz, P.D., 1996. Integrating technology planning with business planning. Res. Technol. Manag. 39 (3), 19–22.
Meydanli, I.I., Polat, M., 2020. Roadmapping process implementation: challenges for a large-scale company. IEEE Trans. Eng. Manag. 69 (1), 34–43.
Milshina, Y., Vishnevskiy, K., 2018. Potentials of collaborative foresight for SMEs. Technol. Anal. Strateg. Manag. 30 (6), 701–717.
More, E., Gungor, Z.E., Phaal, R., Probert, D., 2015. Addressing resource over-exploitation via cooperative institutions: examining how technology roadmapping could contribute. Procedia CIRP 26, 173–178.
Mubarak, M.F., Jucevicius, G., Shabbir, M., Petraite, M., Ghobakhloo, M., Evans, R., 2025. Strategic foresight, knowledge management, and open innovation: drivers of new product development success. J. Innov. Knowl. 10 (2), 100654.
Nazarenko, A., Vishnevskiy, K., Meissner, D., Daim, T., 2022. Applying digital technologies in technology roadmapping to overcome individual biased assessments. Technovation 110, 102364.
Nimmo, G., 2013. Technology roadmapping on the industry level: experiences from Canada. In: Moehrle, In.M.G., Isenmann, R., Phaal, R. (Eds.), Technology Roadmapping for Strategy and Innovation: Charting the Route to Success. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 47–65.
Oliveira, M.G., Rozenfeld, H., 2010. Integrating technology roadmapping and portfolio management at the front-end of new product development. Technol. Forecast. Soc. Change 77 (8), 1339–1354.
Ozcan, S., Homayounfard, A., Simms, C., Wasim, J., 2021. Technology roadmapping using text mining: a foresight study for the retail industry. IEEE Trans. Eng. Manag. 69 (1), 228–244.
Park, H., Phaal, R., Ho, J.Y., O'Sullivan, E., 2020. Twenty years of technology and strategic roadmapping research: A school of thought perspective. Technol. Forecast. Soc. Change 154, 119965.
Park, S., Son, J., Seo, J., Seo, J., 2013. Performance evaluation index of TRM: a Korean case for SMEs. Asian J. Innov. Policy 2 (1), 63–96.
Parker, R., Hine, D., 2014. The role of knowledge intermediaries in developing firm learning capabilities. Eur. Plan. Stud. 22 (5), 1048–1061.
Pataki, B., Szalkai, Z., Biro-Szigeti, S., 2010. Technology roadmapping in Hungary: some practical observations. *perspectives of innovations, economics, and business*, 5 (2), 20–23.
Phaal, R., Farrukh, C.J., Probert, D.R., 2001. Characterisation of technology roadmaps: purpose and format (, July). In PICMET'01. Portland International Conference on Management of Engineering and Technology. Proceedings Vol. 1: Book of Summaries (IEEE Cat. No. 01CH37199). IEEE, pp. 367–374 (, July).
Phaal, R., Farrukh, C., Probert, D., 2001a. Technology roadmapping: linking technology resources to business objectives. Cent. Technol. Manag. Univ. Camb. 1–18.
Phaal, R., Farrukh, C.J., Probert, D.R., 2004. Technology roadmapping—A planning framework for evolution and revolution (ba)). Technol. Forecast. Soc. Change 71 (1-2), 5–26.
Phaal, R., Farrukh, C.J., Probert, D.R., 2004a. Technology roadmapping—A planning framework for evolution and revolution. Technol. Forecast. Soc. Change 71 (1-2), 5–26.
Phaal, R., Farrukh, C.J., Probert, D., 2004b. Customizing roadmapping. Res. Technol. Manag. 47 (2), 26–37.
Phaal, R., Farrukh, C.J., Probert, D.R., 2005. Developing a technology roadmapping system (, July). In A Unifying Discipline for Melting the Boundaries Technology Management. IEEE, pp. 99–111 (, July).
Phaal, R., Muller, G., 2009. An architectural framework for roadmapping: towards visual strategy. Technol. Forecast. Soc. Change 76 (1), 39–49.
Phaal, R., Farrukh, C. J. P. (2000). Technology planning survey–results. *Institute for Manufacturing, University of Cambridge, project report, 14th March*.
Porter, M.E. (1998). Clusters and the new economics of competition (Vol. 76, No. 6, pp. 77-90). Boston: Harvard Business Review.

Preissl, B. and Solimene, L. (2003), "Innovation clusters: virtual links and globalization", Proceedings of the Conference on Clusters, Industrial Districts and Firms: The Challenge of Globalization held at University of Modena and Reggio Emilia.
Probert, D.R., Farrukh, C.J., Phaal, R., 2003. Technology roadmapping—Developing a practical approach for linking resources to strategic goals. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. 217 (9), 1183–1195.
Rinkinen, S., Mäkimattila, M., 2015. The use of foresight information in small and medium-sized enterprises-the role of intermediary organisations. Int. J. Foresight Innov. Policy 10 (1), 1–16.
Robson, I., Ojiako, U., Maguire, S., 2022. A complexity perspective of dynamic capabilities in enterprise project organizations. Prod. Plan. Control 1–25.
Rosenfeld, S.A., 1997. Bringing business clusters into the mainstream of economic development. Eur. Plan. Stud. 5 (1), 3–23.
Schimpf, S., Abele, T., 2019. How German companies apply roadmapping: evidence from an empirical study. J. Eng. Technol. Manag. 52, 74–88.
Shon, M., Lee, D., Lee, C., 2022. Inward or outward? Direction of knowledge flow and firm efficiency. Int. J. Technol. Manag. 90 (1-2), 102–121.
Smedlund, A., 2006. The roles of intermediaries in a regional knowledge system. J. Intellect. Cap. 7 (2), 204–220.
Stig, D.C., 2013. A proposed technology platform framework to support technology reuse. Procedia Comput. Sci. 16, 918–926.
Stonehouse, G., Pemberton, J., 2002. Strategic planning in SMEs–Some empirical findings. Manag. Decis. 40 (9), 853–861.
Strauss, J., Radnor, M., 2004. Roadmapping for dynamic and uncertain environments. Res. Technol. Manag. 42 (2), 51–58.
Strauss, J.D., Radnor, M., Peterson, J.W., 1998. Plotting and navigating a non-linear roadmap: knowledge-based roadmapping for emerging and dynamic environments. Asian-Pac. J. Manag.
T.U. Daim, T. Oliver In: Implementing technology roadmap process in the energy services sector: A case study of a government agency, 75 (5). Technological Forecasting and Social Change, pp. 687–720.
Tierney, R., Hermina, W., Walsh, S., 2013. The pharmaceutical technology landscape: a new form of technology roadmapping. Technol. Forecast. Soc. Change 80 (2), 194–211.
Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British journal of management 14 (3), 207–222.
Tsou, H.T., Chen, J.S., 2023. How does digital technology usage benefit firm performance? Digital transformation strategy and organisational innovation as mediators. Technol. Anal. Strateg. Manag. 35 (9), 1114–1127.
Tsoukas, H., Vladimirou, E., 2001. What is organizational knowledge? J. Manag. Stud. 38 (7), 973–993.
Tugrul, D.A.I.M., Gerdsri, N., Kockan, I., Kocaoglu, D., 2011. Technology development envelope approach for the adoption of future powertrain technologies: a case study on ford otosan roadmapping model. J. Transp. Syst. Eng. Inf. Technol. 11 (2), 58–69.
UNIDO, 2000. Economy Environment Employment. United Nations Industrial Development Organization.
Vanhaverbeke, W., 2001. Realizing new regional core competencies: establishing a customer-oriented SME network. Entrep. Reg. Dev. 13 (2), 97–116.
Vatananan, R.S., Gerdsri, N., 2012. The current state of technology roadmapping (TRM) research and practice. PICMET 2010 Technol. Manag. Glob. Econ. Growth 1–10.
Vecchiato, R., Do, H., Pierrakis, Y., Blackburn, R., 2024. Innovation and foresight in SMEs: lessons from the case of UK digital health companies. IEEE Trans. Eng. Manag. 71, 1655–1668.
Verbano, C., Crema, M., 2016. Linking technology innovation strategy, intellectual capital and technology innovation performance in manufacturing SMEs. Technol. Anal. Strateg. Manag. 28 (5), 524–540.
Vicente Oliva, S., Martinez-Sanchez, A., 2018. Technology roadmapping in security and defence foresight. Foresight 20 (6), 635–647.
Vinayavekhin, S., Phaal, R., Thanamaitreejit, T., Asatani, K., 2023. Emerging trends in roadmapping research: a bibliometric literature review. Technol. Anal. Strateg. Manag. 35 (5), 558–572.
Vishnevskiy, K., Karasev, O., Meissner, D., 2016. Integrated roadmaps for strategic management and planning. Technol. Forecast. Soc. Change 110, 153–166.
von Weltzien Høivik, H., Shankar, D., 2011. How can SMEs in a cluster respond to global demands for corporate responsibility? J. Bus. Ethics 101, 175–195.
Yin, R.K., 2003. Designing case studies. Qual. Res. Methods 5 (14), 359–386.
Yoon, J., Kim, Y.J., Vonortas, N.S., Han, S.W., 2019. A moderated mediation model of technology roadmapping and innovation: the roles of corporate foresight and organizational support. J. Eng. Technol. Manag. 52, 61–73.
Yoon, B., Phaal, R., Probert, D.R., 2008. Morphology analysis for technology roadmapping: application of text mining. R&D Manag. 38 (1), 51–68.
Yusuf, A., Saffu, K., 2005. Planning and performance of small and medium enterprise operators in a country in transition. J. Small Bus. Manag. 43 (4), 480–497.