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Technology Roadmapping and SMEs: A Literature Review

Norin Arshed
University of Strathclyde
Business School
norin.arshed@strath.ac.uk

John Finch
University of Strathclyde
Business School
john.finch@strath.ac.uk

Raluca Bunduchi
University of Aberdeen
Business School
r.bunduchi@abdn.ac.uk

Abstract

This paper critically reviews extant literature on Technology Roadmapping (TRM) and identifies a gap in which SMEs are rarely studied within the TRM process, whether as stakeholders for other companies or as focal companies in their own right. TRM literature typically discusses the processes and opportunities for exploring and communicating the dynamic connections between technological resources, the organisational objectives and the changing environments surrounding the market and product. However, within the academic literature channels of communication are non-existent to SMEs who may not only find such a process valuable to support their own product and capabilities, but may also bring a significant contribution to the TRM process benefitting the TRM initiators themselves (generally large firms or intermediary organisations). This literature review serves as a stimulating discussion around the fundamental gap in the process, which often excludes SMEs, and highlights the importance of providing a framework for understanding how to engage SMEs in the TRM process. It also proposes implications for involving government as a mechanism for engagement.

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This paper critically reviews extant literature on Technology Roadmapping (TRM) and identifies a gap in which SMEs are rarely studied within the TRM process, whether as stakeholders for other companies or as focal companies in their own right. TRM literature typically discusses the processes and opportunities for exploring and communicating the dynamic connections between technological resources, the organisational objectives and the changing environments surrounding the market and product. However, within the academic literature channels of communication are non-existent to SMEs who may not only find such a process valuable to support their own product and capabilities, but may also bring a significant contribution to the TRM process benefitting the TRM initiators themselves (generally large firms or intermediary organisations). This literature review serves as a stimulating discussion around the fundamental gap in the process, which often excludes SMEs, and highlights the importance of providing a framework for understanding how to engage SMEs in the TRM process. It also proposes implications for involving government as a mechanism for engagement.

Key words: Technology roadmapping, SMEs, open innovation, business process, collaboration, partnerships, government intervention

1. Introduction

Motorola, Lucent Technologies, Philips, BP, Samsung, LG, Rockwell, Roche and Domino Printing, are only but a few of the leading companies that have been employing Technology Roadmapping (TRM) as a key part of their innovation toolkit. They highlight TRM as fundamental to their R&D management and planning (Lee, Kim and Phaal 2012).

Since the late 1990s, researchers have situated their work on TRM by citing Motorola as the champion of the approach (Goenaga and Phaal 2009; Richey and Grinnell 2004; Major, Pellegrin and Pittler 1998; Willyard and McClees 1987). The most cited definition of TRM comes from Robert Galvin, the former chairman of Motorola. He defines technology roadmaps as:

> "an extended look at the future of a chosen field of enquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field. Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They become the inventory of possibilities for a particular field" (Galvin 1998, p. 803).

The term 'TRM' is widely and loosely used with significant variation in definition and meaning (Loureiro, Borschiver and Coutinho 2010; Lee and Park 2005). For example, Kappel (2001) argues that roadmapping is a challenging task, involving a variety of different documents. He differentiates between 'roadmapping', which is a process that can be done with different objectives, and 'roadmaps', which are the documents generated from the 'roadmapping' process. For Garcia and Bray (1997) TRM is an activity which provides a way to develop, organise and present information about critical requirements and the required performance of objectives that must be achieved at the planned time. Petrick and Echols (2004) refer to TRM as a tool that enables organisations to make decisions more consciously, thus preventing the waste of time and resources, and helping to reduce risk involved in decision making. For Phaal, Farrukh and Probert (2004) TRM represents a powerful technique to support technological management and planning, especially to explore and communicate dynamic interactions between resources, organisational goals and environment changes. TRM is also frequently referred to and studied in the literature as a 'management tool' in R&D and product development, which involves various communication processes amongst a variety of stakeholders (Yasunaga, Watanabe and Korenaga 2009).

Within the literature, the meaning of TRM varies from a process to a tool. Phaal, Farrukh and Probert (2001b, pp. 3-4) distinguish between these two concepts arguing that "a process is an approach for achieving a managerial objective, through the transformation of inputs into outputs". In contrast, "a tool facilitates the practical application of a technique", where a technique is defined as "a structured way of completing part of a procedure", and procedure is defined "as a series of steps for operationalizing a process" (ibid). A number of authors argue that TRM is a process. Kappel (2001) for example classifies roadmapping generally as process which includes: the forecasting process, the planning process, the decisions-making process, and the design process. Similarly, Garcia and Bray (1997) describe TRM as a process that assists its practitioners in identifying, selecting and developing technology alternatives to satisfy a set of product needs. In contrast, the technology roadmap itself is the document generated by the technology roadmapping process. It identifies the critical system requirements, the product and process performance targets, and the technology alternatives along with the milestones for meeting those targets (ibid). A more recent argument places the importance namely on the *process* of roadmapping (which involves undertaking a workshop with key stakeholders and domain experts to capture, share and structure information in a way that highlights strategic issues concerning the organisation) and then on the *product* of roadmapping i.e. a roadmap (this involves the tangible outcome, usually a visual representation) (Kerr, Phaal and Probert 2012). Generally,

> "a 'roadmap' can be considered as an umbrella term for a group of techniques that support the structurization of complex interdependent processes and are intended to serve as decision aids for strategy building and planning in organisations that depend on and participate in the development and/or technology" (Fleischer, Decker and Fiedeler 2005, p. 1117).

TRM process facilitates agents, be them an industry or an organisation, in describing an environment in a future state in terms of the agent's objectives and plans as to how the objectives can be achieved over a period of time (Albright 2003). This allows for ways to identify, evaluate and select among alternatives that can be used to achieve the agent's set of strategic objectives (Kostoff and Schaller 2001). At the organisation level, TRM provides a graphical means for exploring and communicating the relationships between markets, products and technologies over time (Phaal, Farrukh, Mitchell and Probert 2003). At an industry level, TRM involves multiple agents as a consortium of organisations therefore requiring a focus on common needs.

In understanding TRM as a process the academic terminology within this literature review comes from Loureiro *et al.'s* (2010, p. 183) definition, "technology roadmapping is of a flexible method in which the main goal is to assist strategic planning in market development, product and technology in an integrated way over time" (Albright and Kappel 2003; Kappel 2001; Phaal, Farrukh and Probert 2001a; Phaal *et al.* 2004). It enables R&D activities to be carried out in a more systematic manner, by laying out explicit plans about what technologies to develop, when and how by forecasting future trends and identifying gaps between the firm's current technology levels and advanced levels it desires to achieve (Lee, Kang, Park and Park 2007).

TRM aids agents in effectively addressing critical research and collaboratively developing the common technologies (Garcia and Bray 1997). Whilst TRM has been used successfully at the corporate, sector, and government levels, there has been little if any research reported into its application to identify SMEs that either support or collaborate in the TRM process to build a shared visual representation of an organisation's strategic context. Many researchers have focused on describing the functional aspects with little respect to the process with which SMEs can become involved (Lee *et al.* 2012).

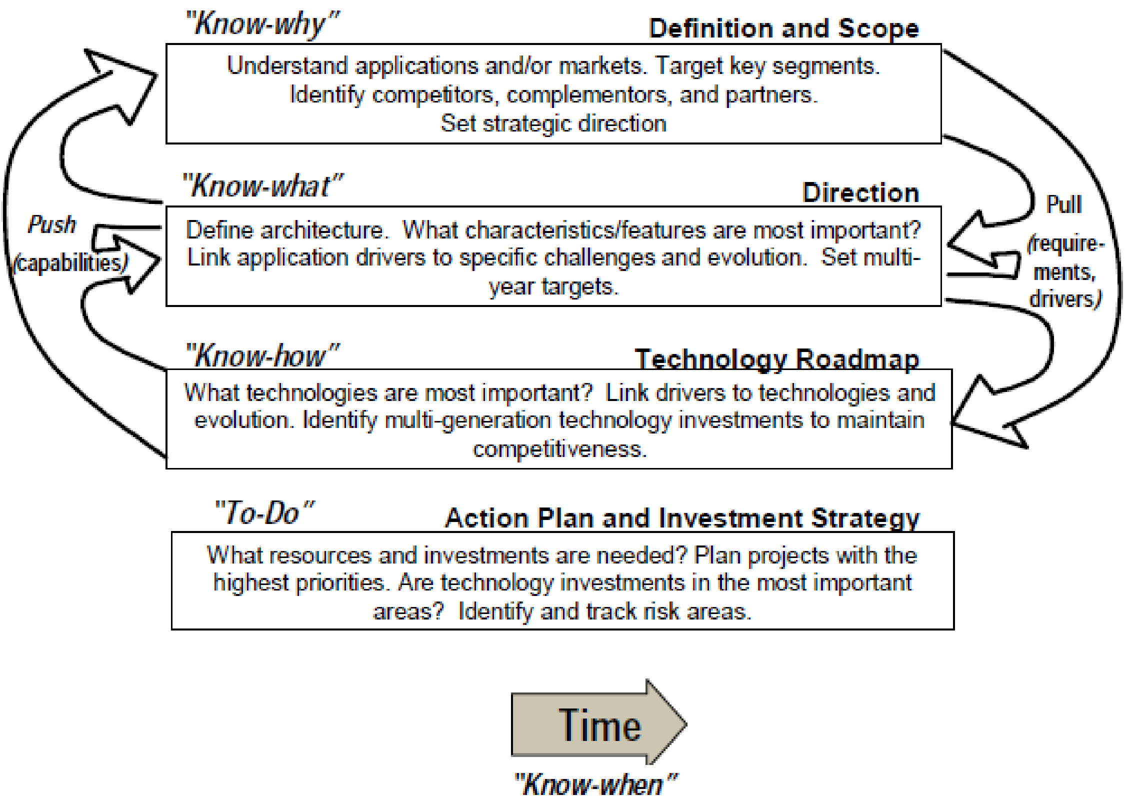
Having introduced TRM the following section sets the scene as to the context in which the process is applicable. Section three presents the process of TRM within the academic literature. Section four highlights the limitations of TRM collected from various studies. Section five draws attention to the missing link between the TRM process and application of its use and the involvement of SMEs within the process. Section seven highlights scope for government intervention with respect to TRM and SMEs. Finally, section eight concludes the literature review and highlights the key gaps in the existing research on TRM.

2. Setting the Scene: TRM

With respect to a broad range of industrial sectors and problem areas, the USA government and organisations have undertaken TRM since the 1990s, with Japan and Canada recently following suit. In recent years Europe has also shown interest in roadmapping activity (Laat and McKibbin 2003). The popularity of TRM has increased over the years, particularly given the use of TRM by Motorola since the 1970s. Motorola applied the TRM process to anticipate developments in markets and technologies, as a means to address customer problems and to improve productivity. The ability of TRM to anticipate market and technological changes has meant that the process begun to be applied more commonly to support corporate strategy development in organisations (Vatananan and Gerdsri 2010). By providing a framework for linking business directly to technology, TRM has become a useful part of strategy development in a wide range of industries by individual firms, government organisations and consortia (Lee *et al.* 2007).

Albright (2003) introduced a common framework for roadmaps. Figure 1 describes the four levels of the roadmap. The aspects of know-why, know-what, know-how and know-when facilitate the identification of critical decision points in the technological routes drawn within the technological roadmap.

Figure 1: A unifying four-part roadmap framework

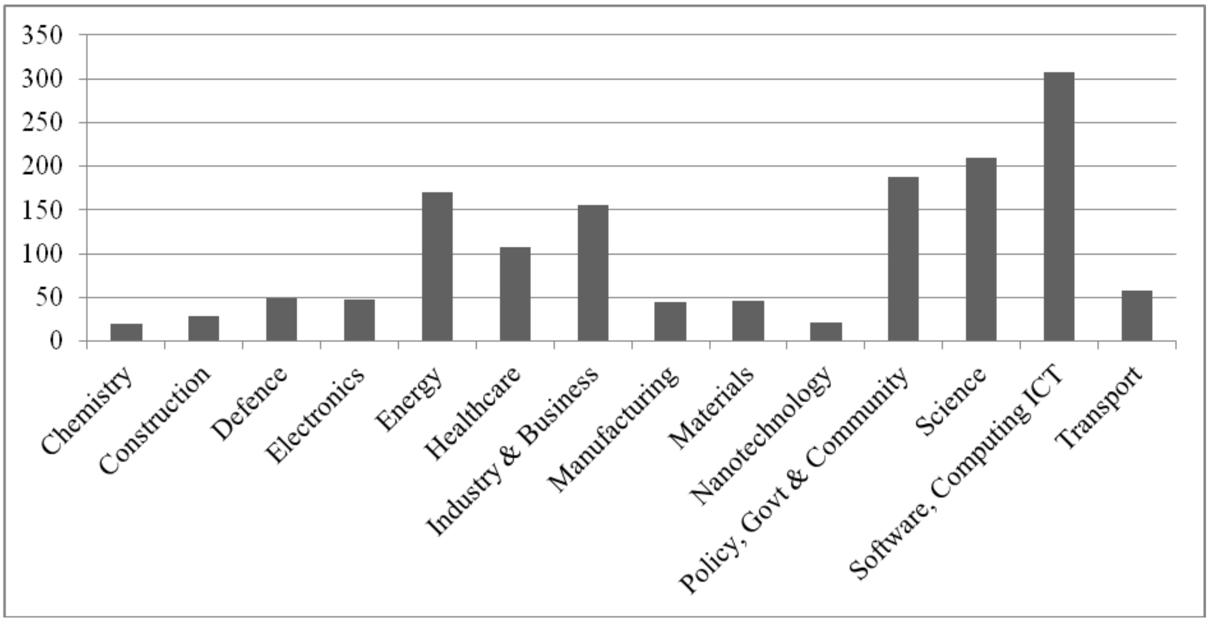


Source: Albright (2003, p. 1).

Firstly, the 'why' of the roadmap defines the domain of the roadmap, the team's objectives and their strategy in achieving those objectives. Secondly, the 'what' defines the direction, the challenges, the architecture and evolution of the team's solution and the measureable targets. Thirdly, the 'how' defines the technologies that will be used to implement each part of the architecture. Fourthly, the 'to-do's' defines the action plan and the risks. Lastly, the 'when' part of the roadmap discusses the time period of the process (ibid).

Robert Phaal, one of the leading TRM academics, has compiled an extensive list of public domain roadmaps, which include over 2,000 roadmaps from a variety of different industries (see Figure 2). Such broad interest in using TRM in the corporate world has led academics, researchers and policy-makers to see TRM as a device for technology management and industrial policy planning, potentially becoming a reliable procedure for future technological planning, and which may be utilised to lead the development of strategy at corporate and operation levels (Choomon and Leeprechanon 2011). Figure 2 identifies the wide range of industries that use TRM and the numbers of technology roadmaps undertaken within each industry.

Figure 2: Public domain roadmaps from various sectors



Source: Amer and Daim (2010, p. 1358).

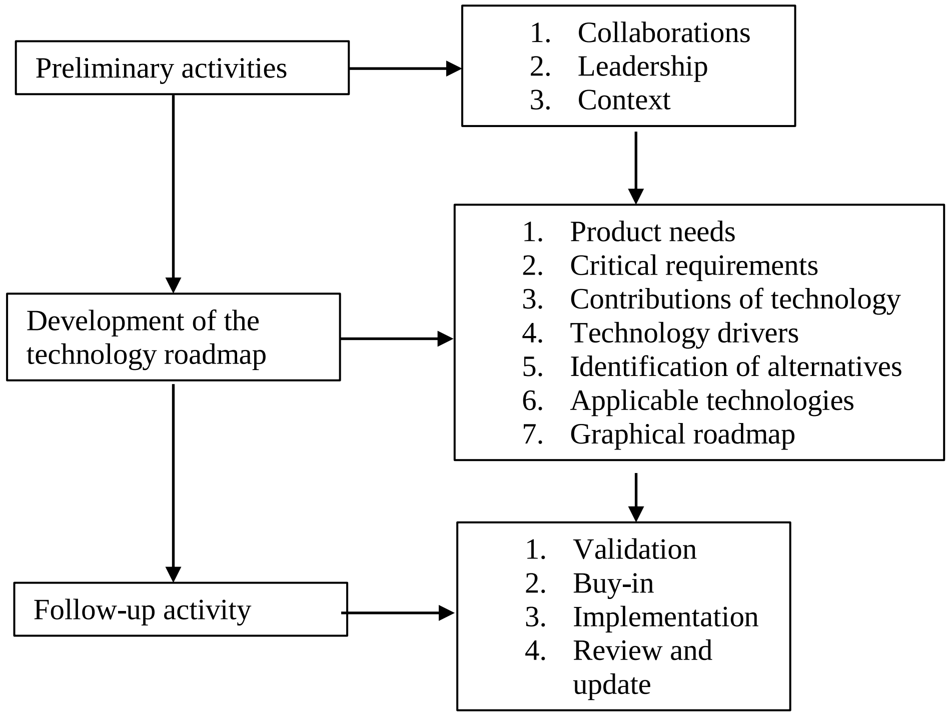
Figure 2 shows that the use of TRM has become pervasive across a range of industries, and identifies the Software, Computing ICT industry as the industry with the largest number of public domain roadmaps, followed by the Science industry and the Policy, Government and Community sector. A survey undertaken by Phaal, Farrukh and Probert (2000) estimates 10% of manufacturing firms (mostly large) have applied technology roadmaps to some extent, with 80% of those companies using TRM more than once, or on an on-going basis. Their study however does argue that organisations struggle with the application of roadmapping as there are many specific forms of roadmaps, which often have been tailored to the specific needs of the firm and its business context. Nokia, for example, uses roadmaps extensively for planning the development of its product portfolio and defining its competitive position in emerging markets with their roadmaps only applicable to their own unique business context (Vecchiato 2012).

The literature to some extent provides the processes and methods undertaken within TRM as seen with case studies such as Royal Mail (Wells, Phaal, Farrukh and Probert 2004), Philips Electronics (Groenveld 2007) and Lucent Technologies (Albright and Kappel 2003). These cases, whilst being important in highlighting the benefits of such a process, offer little practical help to those adopting TRM for the first time (Lee *et al.* 2007). Although there has been much work done on science and technology roadmaps, little work has been undertaken on elucidating the structure of existing roadmaps, with the exception of Phaal and Muller (2009) (Kajikawa, Usui, Hakata, Yasunaga and Matsushim 2008). Thus there are two areas of contention within the TRM literature. Firstly, the literature does not actively seek to involve SMEs within the TRM process as the case studies are developed around larger organisations or government bodies. Secondly, the TRM process does not explicitly explain or elucidate how to communicate with SMEs to involve them as partners or collaborators when initially undertaking TRM. SMEs are often unaware of the practicalities involved in becoming stakeholders in the process and are unable to achieve the means to come forth to participate.

3. The TRM Process

Developing a technology roadmap requires answers to fundamental questions that apply in any strategic context. Firstly, where do we want to go? Where are we now? How can we get there? Secondly, why do we need to act? What should we do? How should we do it? By when? (Galvin 1998; Phaal and Muller 2009). These questions then focus on three key areas needing to be considered when planning a roadmapping activity: the context (nature of the issue), the architecture (layout of the roadmap) and the process (staged activities) (Garcia and Bray 1997). Garcia and Bray (1997) provide a description of what is involved in the TRM process, dividing it into three steps (see Figure 3).

Figure 3: TRM Process

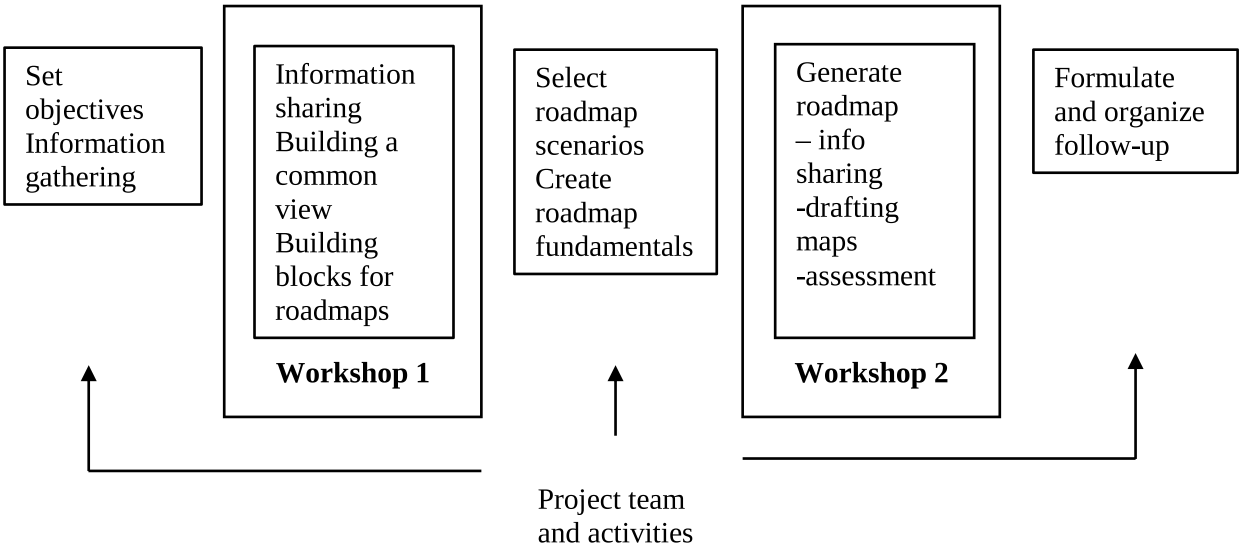


Source: Adapted from Garcia and Bray (1997).

Firstly, the *preliminary activities* include three levels: the process begins with collaboration to achieve common ground and understanding, followed by a committed leadership or sponsorship and then establishing the context of the roadmap which integrates the aims, the time frames, the scope and the boundaries. Secondly, the *development of the technology roadmap* involves seven steps: first, the agreement of the product needs and focus to achieve and sustain buy-in; second, the definition of critical system requirements with time-based targets; third, the specification of the major technological areas that can contribute to the critical system; fourth, the product or system needs to be translated into technology drivers; fifth, the identification of technology alternatives (potential to respond to technology drivers and meet targets); sixth, the selection of the most applicable technologies and; lastly, all the steps are integrated into a report which include a graphical roadmap, current status, critical risks, barriers, gaps and recommendations. The third and final step of the TRM process is known as the *follow-up activity* and includes the validation and buy-in from a much larger group, the development of implementation to make better technology selection and investment decisions, and the frequent review and update of the technology roadmap.

Groenveld (1997) also presented an outline representing how the roadmapping process can be structured (Figure 4).

Figure 4: Roadmapping process

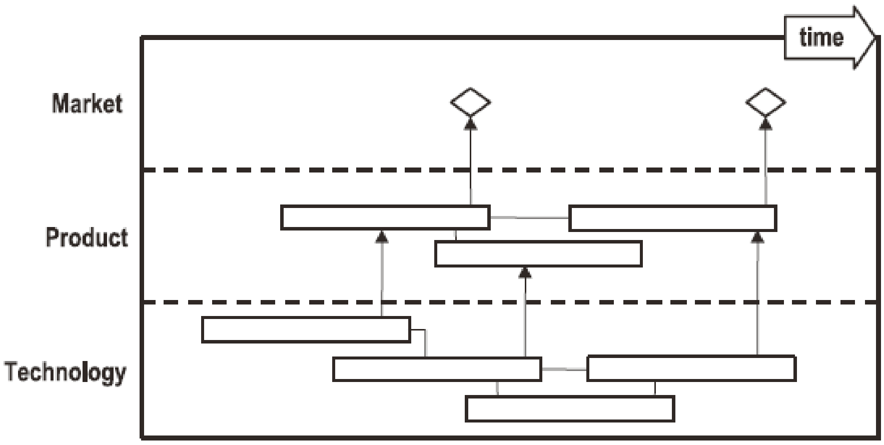


Souce: Groenveld (1997, p. 52).

Figure 4 highlights the importance of beginning the process with a clear set of objectives. However, the structured process fails to elaborate on the information sharing aspect as to whom would the information be shared with and how. Nevertheless, for a concise and coherent TRM process several success should be considered: firstly, it is essential to establish a clear business need; secondly, one must ensure commitment from senior management; thirdly, plan and customise your approach; fourthly, phase the process to ensure early delivery of benefits; fifthly, ensure the right people and functions are involved; also, keep it simple and finally, iterate and learn from experience.

With respect to the TRM process, a schematic diagram of a generic technology roadmap is depicted below (Phaal *et al.* 2004) (see Figure 5).

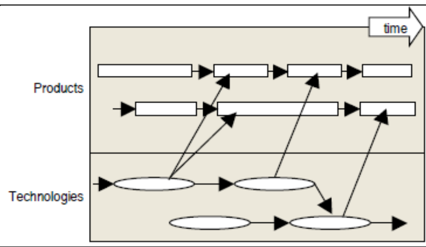
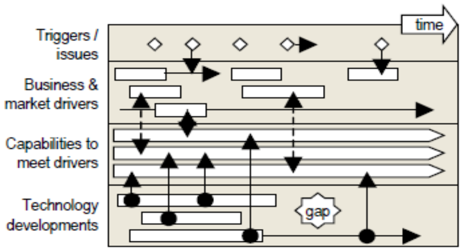
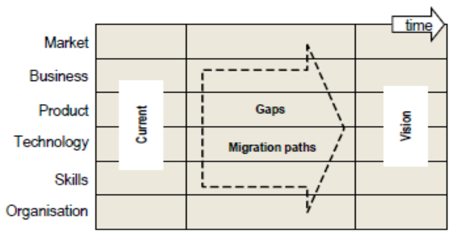
Figure 5: Generic technology roadmap

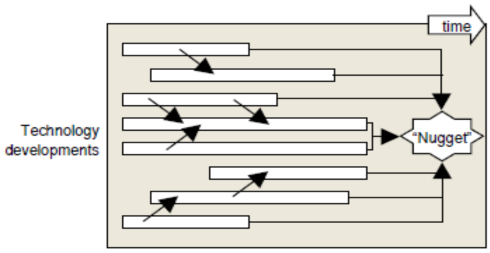
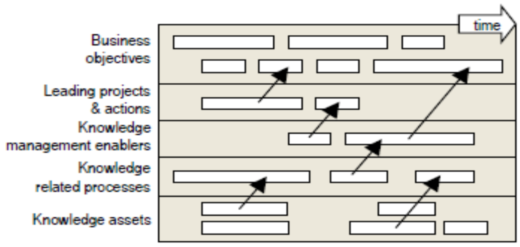
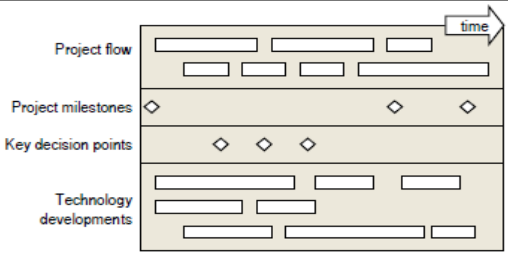
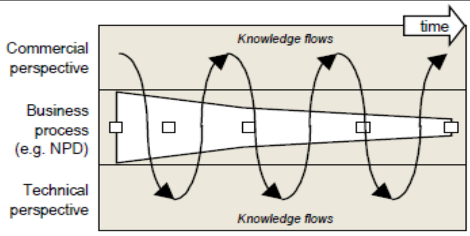
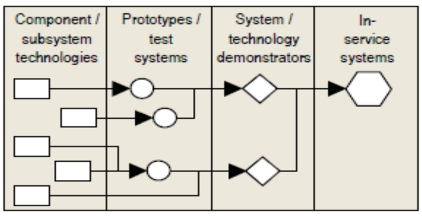


Source: Phaal *et al.* (2004, p. 10).

Moreover, Probert and Radnor (2003) and Phaal *et al.* (2004) identify eight different types of roadmaps. Table 1 illustrates the roadmaps and explains their uses.

Table 1: Types of roadmaps

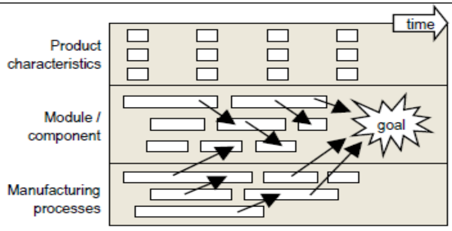
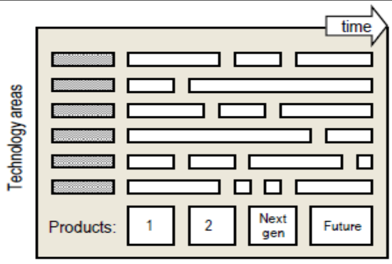
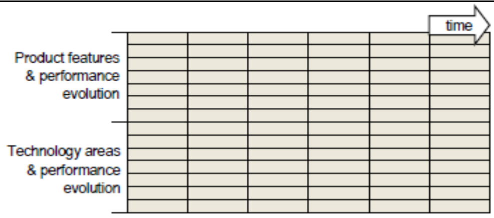
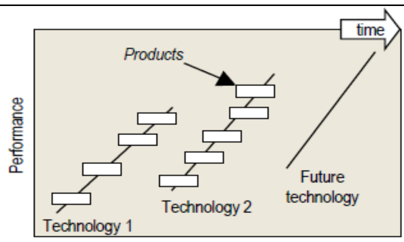
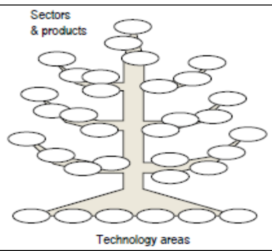
Type of roadmap	**Definition**	**Visual representation**
Product planning	The most common roadmap. It relates to the insertion of technology into manufactured products.	
Service/capability planning	Service based enterprises – how technology supports organisational capabilities.	
Strategic planning	Generic strategic appraisal – focuses on the development of a vision of the future business in terms of markets, business, products, technologies,	

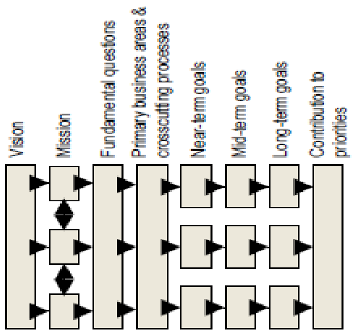
	skills, cultures etc. Gaps are identified.	
Long-range planning	Performed at sector or national level (foresight) and acts as a radar for the organisation to identify potentially disruptive technologies and markets.	
Knowledge asset planning	Allows to visualise organisations' critical knowledge assets and the linkages to the skills, technologies and competences to meet future market demands.	
Program planning	Focusses on implementation of strategy and more directly related to project planning.	
Process planning	This type supports the management of knowledge, focussing on a particular process area, e.g. new product development.	
Integration planning	Integration and/or evolution of technologies within products and systems.	

Source: Adapated from Phaal, *et al.* (2004).

Regardless of the type of roadmaps, the main aims of TRM are to assist in the identification of gaps, prioritisations of issues, target setting, creating action plans and encouraging communications across the organisation (Gindy, Cerit and Hodgson 2006). The unique feature highlighted with roadmaps is that it is a technology management process directly linked to business needs by using simple charts or graphs (McCarthy 2003). Eight different types of formats have been identified which TRM can adapt (Table 2).

Table 2: Roadmap formats

Format of roadmap	**Definition**	**Visual representation**
Multiple layers	The most common format, often comprises of layers which include technology, product and market. Each layer is dependent on each other.	
Bars	Represented with bars, simplifying and unifying the required outputs.	
Tables	Roadmaps are quantifiable and expressed as tables.	
Graphs	A graph for each sub-layer, product or technology performance can be quantified.	
Pictorial representations	Pictorial representations to communicate technology integration and plans.	

Flow charts	A flow chart which is typically used to relate objectives, actions and outcomes.	
Single layer	Single layer of the multiple layer roadmap – a simple and less complex roadmap.	
Text	Written reports describing the process and issues.	

Source: Adapted from (Phaal *et al.* 2004).

Undertaking the process of TRM can provide numerous benefits of roadmapping which have been highlighted by Garcia and Bray (1997). Firstly, roadmaps help develop consensus among decision makers about a set of science and technology needs; secondly, roadmapping provides a mechanism to help experts forecast science and technology developments in targeted areas and; lastly, roadmaps present a framework to help plan and coordinate science and technology developments at any level; within an organisation or company, throughout an entire discipline and at national or international levels. Kostoff and Schaller (2001) describe roadmapping as fundamentally linking social mechanisms and accordingly promoting a broader understanding across a company of science and technology development programmes, highlighting communication as key to the process (Lee *et al.* 2012). Albright and Kappel (2003) note, communication ideally creates a dialogue of alignment with customers as well as suppliers. An important issue here is that although TRM also refers to the idea that companies need to communicate and manage information effectively, there is concern as to how this communication both within organisations (e.g. cross-functional, geographical) and also across supply chains (e.g. buyer-supplier relationships, industrial consortia) can come together to shape the same TRM process.

Two approaches to TRM can be undertaken, firstly, the 'backward' approach (retrospective analyses) which involves finding out how to reach a given target (which could be a business goal, a product or a process, or the fulfilment of a legislative requirement or a technology). Secondly, the 'forward' approach (prospective analyses) involves paying close attention on the future technology and market (Kostoff and Schaller 2001). This means requirements-pull starts with a desired technology or system or other end product and works backward to identify the critical research and development required to arrive at the end product. Whereas technology-push starts with science and technology projects or programmes either funded presently or proposed to be funded, and traces evolution forward to identify potential impacts (ibid). To achieve its full potential by adapting either of the approaches, existing research suggests that the TRM process should include six steps: identifying the needs and drivers; identifying products or services that meet these needs and drivers; identifying the required technologies to support these products or services; establishing the linkages among the first three steps; developing plans to acquire or develop the required technologies and; assigning resources to accomplish the plans for the acquisition and development of these technologies (Daim and Oliver 2008). The case of Rockwell Automation highlights the benefits of following these steps where TRM "became knowledge-capture and communication tools for the company" (McMillan 2003, p. 46). The roadmaps were seen as change agents, with TRM becoming an important driver of cultural change in management thought which following a problematic management buyout, allowed for gaps in the company core competencies to be filled. Other similar successful applications are highlighted in the pharmaceuticalbiotechnology industry, which concur that successful TRM enables strong linkages between technology implementation and business needs (McCarthy 2003).

It has been emphasised that for the most effective roadmapping and other management, decision aids need to be fully integrated into the strategic planning and business operations of the organisations (Kostoff and Schaller 2001; Phaal, Farrukh and Probert 2006). It is understood that roadmapping borrows heavily from the established disciplines of technology forecasting, strategic planning, and other long-standing future activities (Kappel 2001). There is the possibility that roadmaps can be integrated with other management techniques such as the Delphi method, portfolio methods, balanced scorecards, SWOT analysis, PEST analysis, QFS, innovation matrix, technology intelligence techniques, bibliometrics analysis, citation network analysis, patent analysis, and product development (Amer and Daim 2010). Some of these approaches are closely related to TRM. For example, it has been argued that "scenario planning could enhance the flexibility and vision of roadmapping, capture and convey the full context of decisions, and enable anticipation of a broader range of possible changes" (Strauss and Radnor 2004, p. 53). TRM is also closely related to other graphical planning approaches such as PERT (program evaluation and review technique) and GANTT charts, highlighting that TRM works in harmony with other strategic approaches to an organisation's capabilities and future planning. As Talonen and Hakkarainen (2008) argue stand-alone strategies are insufficient, business and technology roadmaps link company-wide strategic plans by integrating, synchronising and exploring them to allow operationalisation of the visual strategy.

To date, the published literature on roadmapping is still sparse, despite an increase in the use of TRM by both academics and various industries (Amer and Daim 2010; Kostoff and

Schaller 2001;). Consequently, there is a lack of standardised approach to TRM, with its practices varying widely because of the context of individual businesses and industry. There is also a lack of emphasis on the inclusion of key stakeholders in the TRM process to articulate and identify these key relationships and points of alignment (Cetindamar, Phaal and Probert 2010).

4. Limitations of TRM

TRM is not without its problems. The problems associated with TRM primarily are around starting the initial TRM process and developing a robust process (Phaal, Farrukh and Probert 2001d). It has been argued that there is little practical support available and companies typically re-invent the process. There have been some efforts to share experiences because of various forms roadmaps take and the specific business context in which they are applied (ibid). Efforts to overcome these problems have been sought. One solution including the T-Plan, developed by Phaal, Farrukh and Probert (2001c) where the unique characteristics of technology roadmap is composed of 'architecture of knowledge' (Yasunaga *et al.* 2009). The T-plan approach is based on a technological management framework that aims to create a balance between the technology push and the market pull (Phaal *et al.* 2004).

A further problem in assessing the published roadmaps is the inability of the reader who is often the one determining their quality (Kostoff and Schaller 2001). The quality of the technology roadmap results depends on the number of participants, the multidisciplinary backgrounds, competences of experts involved in the definition of the forecast and the level of legitimacy in adopting a vision and using solutions depicted within the technology roadmap (Cuel 2005). The potential value of TRM is often high and its simple structure and concept make it an attractive technique in supporting technology management and planning, its outputs depending on a strategy and planning process that involves considerable detail (Phaal, *et al.* 2004).

Strauss and Radnor (2004) highlight several limitations of TRM from their own experiences of the process of empirical-based observations derived from a large-scale study. Firstly, roadmapping is often depicted as a one-off activity which is undertaken in response to a crisis or a company need and not part of the on-going daily workings of management. To be useful, roadmaps have to be integrated within the overall company ethos and within the organisational structures and long term goals of the organisation. Secondly, internal changes cannot be catered for when sudden policy changes occur, specifically when planning technological capabilities or when faced with unanticipated challenges. As often, technology roadmaps are linear and focussed on specifics. Thirdly, the lack of explicit assumptions concerning future needs may shift focus from the needs of the customers to the fluency of the technology. Fourthly, critical gaps surface in knowledge and foresight concerning future conditions and events. Finally, communication channels need to be open where discussion and developments of roadmaps can take place, otherwise the process is left with gaps between the market, the product and the technology within a set time frame.

It has been argued that the real business benefits of roadmapping are often undertaken without thoroughly considering that "principles and practices are often loosely defined or missing in the literature. What is the input information? What are the processes? What are the outputs? And, most important, how does roadmapping link to the rest of R&D and strategic technology management?" (Talonen and Hakkarainen 2008, p. 56). The authors further stress that some of the literature is at times misleading, often indicating that roadmapping is a way for managers to tell people where their company is going but in reality, roadmapping is about "how the company will get there" (ibid). In addition, one of the questions the literature does not articulate is how to involve SMEs in getting the company *there*, wherever *there* might be. The potential of them becoming stakeholders within the process to enhance their product and technological capabilities is dismissed due to the literature concentrating solely on larger, well-established firms.

5. The Missing Link: TRM and SMEs

The TRM process can follow different approaches, ranging between two extremes: technology push where the process is divergent and the focus is on looking for opportunities, and market pull where the focus is on reaching for customer defined products. Existing TRM literature focuses on the latter, at the expense of the former approach. According to Caetano and Amaral (2011) the research on roadmapping methods has been developed to suit the context of large corporations, which combine R&D and product development structures i.e. organisations that mainly adopt the market pull strategy and closed innovation technologies to be developed based on specific market needs. In contrast, there has been little effort to develop a TRM method for the technology push integration strategy, where the focus is on exploiting an idea or a technology opportunity, on developing a TRM method specific to a particular situation, and on considering partnerships relationships among the TRM agents (ibid). In particular, the literature on TRM treats partnerships only superficially by acknowledging that partnership exists (Gerdsri, Vatananan and Dansamasatid 2009; Phaal *et al.* 2001c; Wells *et al.* 2004) and proposing the identification of TRM partners (Lichtenthaler 2010; Lee, Yoon, Lee and Park 2009; Daim and Oliver 2008), but without any effort to develop a clear " system of identification, selection, prioritisation and incorporation of partners into roadmapping or take into account the different types of partners to be identified" (Caetano and Amaral 2011, p. 12).

Too often, it is larger firms that have been targeted for TRM as they tend to have longer-term contracts and are driven by very long-term planning, and therefore they are more suited to the technology pull TRM approach, unlike most SMEs whose needs would require a TRM process that is market rather than business driven (Gindy *et al.* 2006). The partners in this context are SMEs who can engage with larger firms who initiate the TRM process to collaborate in developing the roadmaps either as partners or suppliers. What is unclear in the literature is how these relationships can be sought out, built and utilised. While these relationships are often established easily in the new product development process (Handfield and Lawson 2007), their nature can change during the TRM process. Therefore, it is important to understand the nature of relationships between the customers, manufacturers and suppliers involved in the TRM process. Dixon (2001) highlights roadmapping as an integrated process to promoting the participation of the problem owner, solution provider, customer and other stakeholders (Lee *et al.* 2012). However, no study explicitly indicates or enables SMEs to join this process to become part of the visual representation which is the final outcome of the process.

In a rare case that looks at SMEs involvement in TRM, Holmes and Ferrill (2005) applied TRM to aid Singaporean SMEs in identifying and selecting emerging technologies. The introduction in the SME manufacturing sector in Singapore aimed to improve the future outlook of these companies from the traditional 4-6 months to an average of 3-5 years, allowing them to think and plan future developments. From the viewpoint of SMEs it highlighted that TRM was successful and SMEs were satisfied in undertaking the process, particularly when it involved the initial stages of developing new products or services given the timescales. However, the research found that in SMEs the strategic technology planning processes and the traditional business strategy overlap, resulting in an integrated approach to roadmapping known as an operation and technology roadmap.

Authors acknowledge that research on TRM primarily targets large companies, while neglecting SMEs within the joined-up process and are implicitly calling for more research to focus on TRM in SMEs (Gindy *et al.* 2006). The lack of focus on SMEs in the extant literature on TRM, either as partners of large organisations in adopting TRM processes or as adopters themselves, is partly due to fact that in practice, SMEs are often excluded from the TRM process. This exclusion is due to a number of reasons.

First, many of the large organisations that tend to be the typical adopters of TRM methods do not want to involve SMEs or any other external stakeholders for that matter in the process. Such large organisations have in-house teams, departments and managers to undertake the TRM processes and to foresee what their product will look like and what markets will benefit from it. Therefore they see little value in seeking out SMEs (who may not be able to incorporate or guarantee that they will be able to remain in the market themselves given the longer-term scales) in the process. An example of this is Cisco’s technological roadmap. Cisco employed a mergers and acquisition strategy to concentrate on internal partners to provide the necessary capabilities in complementary areas to support them, which were far too complex to be completely developed by a single company (Li 2009).

Second, in Lichtenhaler’s (2010) case study of a large machinery company, many of the firm’s employees were relatively reluctant to licence technology. This reluctance was not expressed with respect to the roadmap tool, but rather with regard to the transfer of proprietary technology in general. There was "fear to commercialize the crown jewels, many employees first wanted to pursue a relatively closed innovation approach" (Lichtenthaler 2010, p. 433). Therefore an open innovation approach may not at first seem ideal and needs to be considered carefully with respect to the company itself and its 'crown jewels'. Sharing knowledge may encourage opportunistic behaviour when knowledge asymmetries occur, as well as behaviourally conditioning firms to trust less if they experience negative effects from sharing too early on, or incur more negative than positive experiences (Petrick and Echols 2004). Thus external technology exploitation involves considerable risk, in particular it may result in strengthening competitors by diffusing competitive know-how (Lichtenthaler 2008). Furthermore, leakages may accidentally or strategically occur causing some firms who are highly skilled at something to lose out to less competent partners. However, at the same time technology roadmapping is simply a process that can enable firms to make more sustainable new product decisions. Bearing this in mind, it can prevent the waste of time and resources, reduce risks and uncertainty and as a result increase the accuracy of making profitable decisions (ibid). This so far the benefits outweigh the costs of roadmapping.

Last, many technology roadmaps are designed in practice to contain information for strategic use, rather than operational use (Savioz and Blum 2002). Such strategic approaches are often not useful for smaller companies due to the short term, operational focus of most SMEs (Probert and Shehabuddeen 1999).

To address the problem of SMEs involvement with the TRM process, the literature identifies a number of solutions. First, some authors argue that alternative tools could be used by SMEs instead of the TRM, such as Opportunity Landscape, which brings together technological intelligence and strategic planning specifically by relying on the SME specific strengths (Savioz and Blum 2002). In practice the use of Opportunity Landscape builds and is strongly dependent on an open-minded company culture and a serious commitment of top management (ibid).

Another suggestion has been to rely on open innovation which would allow SMEs to have access to market information and necessary technologies to combine with their own competent technology, in order to create value for customers. The practical application of the open innovation approach to SMEs starts with technology push environments. Using the concept of open innovation it is possible to think about a method such as TRM, specifically designed for SMEs and technology push environments. Open innovation helps to expand the absorptive capacity of SMEs by bringing benefit from open innovation paradigms and relating positively with their environment in order to capture, transform and exploit the knowledge needed for innovation (Igartua, Garrigós and Hervas-Oliver 2010). The challenge is to establish a link between open innovation framework and TRM methods, and to adapt TRM to SMEs in open innovation environment (Caetano and Amaral 2011).

However, the implementation of open innovation in practice is difficult. A study undertaken by Minshall, Mortara, Valli and Probert (2010) highlight the ‘asymmetric’ partnerships between technology-based start-ups and large firms which can be part of an open innovation approach, but also indicates many of the challenges faced by the SMEs, the larger organisations and by the potential investors involved in these relationships. Such challenges for SMEs include contacting the right person, the unrealistic demands made on the SME by the larger firms, and the slow speed at which large firms operate, where many layers of management and bureaucracy may delay the process for SMEs. Large firms also face challenges of partnering up with SMEs, they are reluctant to reveal details of their technology without legal formalities i.e. non-disclosure agreement, the time and the cost involved in illustrating the product to the SME or even the start-ups being run by individuals who do not want to lose the governance and autonomy of their company. The authors suggest that to address these challenges, the partnerships could be aligned with TRM to highlight the missing links or bridge the gap in some way between the larger organisations and SMEs.

A final solution to involve SMEs with TRM was proposed by Yasunaga *et al.* (2009) who developed what they call the IS-Plan (Innovation Strategy) to involve SMEs which have specific and unique competencies and technologies in the markets they operate. They argue that such enterprises often seek new applications for their technologies. They conducted an experiment which included how to assign a 'coordinator' who has experience and know-how to work with some SMEs who are interested in collaboration and alliances. They exchanged information about their companies before their workshops and sessions, began their sessions with the future of their business and their contributions, defined their business model and business structure, intensively continued technological discussions and exploited this with 'post-it' note method on a white board, drew up a technology roadmap and business plan on the discussions and finally concluded the session. However, the results from the study indicated that there were no tangible results of whether this really works for creating business and they argued they needed more time to see if this succeeds or not.

7. Government Intervention

The Bolton Report (1971) increased the recognition that small firms were important and that they had to cope with an "uneven playing field" (Greene, Mole and Storey 2008, p. 57). This led to governments introducing numerous policies, including the provision of advice, to facilitate the formation of new firms and to offer support to SMEs to aid their survival and foster improved rates of growth (Robson and Bennett 2000). Within the TRM literature, Laat and McKibbin (2003) highlight that in Japan TRM exercises are typically aimed (either primarily or as a secondary target) at government especially to increase public sector R&D funding for a given field. Highlighting that contributions of the government can be beneficial if involved early in TRM in that it provides data and analysis, garners support and participation from other departments, agencies, quangos etc., present to industry the concerns and benefits of TRM and help industry bring in the requisite skills, act as a meeting facilitator or roadmap manager, liaise with other government departments or agencies that influence and monitor progress and disseminate the results knowledge (Kaplan 2001).

TRM has already gathered interest from government, who have been interested in promoting roadmaps to facilitate the development of competitive industries and to push science and technology forward, with a growing interest in the development of new and emerging technologies (McDowall 2012). TRM tools have been widely used to study and plan the development of industries in which the government has been involved, e.g. foresight vehicle technology roadmapping in the UK, Industry Canada (Saritas and Oner 2004; Centre for Public Management 2003). There has been an evident shift from industry to public policy; the nature of TRM activities has been on-going partly as a process of setting directions for the social goals. The government has been increasingly using roadmapping approaches in technology, particularly in the context of energy policy and sustainable energy (McDowall 2012; Amer and Daim, 2010; Foresight 2008). An example of governmental TRM activities and its use are relatively small but The Ministry of Economy, Trade and Industry in Japan has actively involved itself in TRM since 2003 (Yasunaga *et al.* 2009).

8. Research Gaps and Conclusion

This review has identified literature on TRM and has shown TRM to be an effective process for enabling companies, especially large companies, to enhance their investment decisions and their technological capabilities. Our review has identified a number of gaps in existing research on TRM. First, there is still confusion in what concerns the content of TRM: is it a process, a tool, or a method for technology planning? Although a lot has been written about TRM as a process to support the integration of both technology and business strategy planning, in practice there is still a lack of cohesion of what TRM represents. To be able to build upon existing research, we need to clarify the many sides of the TRM concept.

Second, while a lot of research has been done on what TRM is (or should involve) there is little research on the content of existing roadmaps and the way companies are implementing and using them in practice. To assess the full benefits of adopting TRM in organisations, we need to move beyond the process itself to assess how partnerships, networks and collaborations are built with emphasis on the communication aspect of the process.

Third, existing TRM studies tend to cater primarily to the needs of large organisations, detailing the application of TRM that are technology push rather than focusing on market pull approaches to TRM which are more suited to the needs of SMEs. Consequently, there is a scarcity of studies that address the involvement of SMEs in the TRM process either in the form of developing partnerships with larger organisations that initiate the TRM process, or as standalone organisations that initiate the TRM process themselves. While few studies have begun to explore alternative approaches to involve SMEs in the TRM process (e.g. by proposing alternative tools and invoking the open innovation paradigm), more effort needs to be made to identify if and when it is appropriate to involve SMEs in TRM because it has been argued that technology roadmaps have the potential to become the infrastructure for innovation (Rinne, 2004).

References

Albright, R. E. (2003). *Roadmapping Convergence*: Albright Strategy Group.

Albright, R. E., and Kappel, T. A. (2003). Technology roadmapping: Roadmapping the corporation. *Research Technology Management,* **46**(2), 31-40.

Amer, M., and Daim, T. U. (2010). Application of technology roadmaps for renewable energy sector. *Technological Forecasting and Social Change,* **77**(8), 1355-1370.

Caetano, M., and Amaral, D. C. (2011). Roadmapping for technology push and partnership: A contribution for open innovation environments. *Technovation,* **31**, 320-335.

Centre for Public Management. (2003). *Industry Canada Technology Roadmaps Progress Report and Contribution to Canada's Innovation Strategy*.

Cetindamar, D., Phaal, R., and Probert, D. (2010). *Technology management - activities and tools*. Basingstoke: Palgrave Macmillan.

Choomon, K., and Leeprechanon, N. (2011). A literature review on technology road-mapping: A case of power-line communication. *African Journal of Business Management,* **5**(14), 5477-5488.

Cuel, R. (2005). *D1.4.1v1 Technology Roadmap*: IST Program pf the European Community.

Daim, T. U., and Oliver, T. (2008). Implementing technology roadmap process in the energy services sector: A case study of a government agency. *Technological Forecasting and Social Change,* **75**(5), 687-720.

Dixon, B. (2001). *Guidance for environmental management science and technology roadmapping*. Paper presented at the Waste Management Conference.

Fleischer, T., Decker, M., and Fiedeler, U. (2005). Assessing emerging technologies—Methodological challenges and the case of nanotechnologies. *Technological Forecasting and Social Change*, **72**(9), 1112-1121.

Foresight. (2008). *Powering Our Lives: Sustainable Energy Management and the Built Environment*.

Galvin, R. (1998). Science roadmaps. *Science*, **280**(5365), 803.

Garcia, M. L., and Bray, O. H. (1997). *Fundamentals of Technology Roadmapping*.

Gerdsri, N., Vatananan, R. S., and Dansamasatid, S. (2009). Dealing with the dynamics of technology roadmapping implementation: A case study. *Technological Forecasting and Social Change*, **76**(1), 50-60.

Gindy, N. N. Z., Cerit, B., and Hodgson, A. (2006). Technology roadmapping for the next generation manufacturing enterprise. *Journal of Manufacturing Technology Management*, **14**(4), 404-416.

Goenaga, J. M., and Phaal, R. (2009). Roadmapping lessons from the basque country. *Research Technology Management*, **52**(4), 9-12.

Groenveld, P. (2007). Roadmapping integrates business and technology. *Research Technology Management*, **50**(6), 49-58.

Greene, F. J., Mole, K. F., & Storey, D. J. (2008). *Three Decades of Enterprise Culture*. Great Britain: Palgrave MacMillan.

Handfield, R. B., and Lawson, B. (2007). Integrating suppliers into new product development. *Research Technology Management*, **50**(2), 44-51.

Holmes, C., and Ferrill, M. (2005). The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies *Technological Forecasting and Social Change,* **72**(3), 349-357.

Igartua, J. I., Garrigós, J. A., and Hervas-Oliver, J. (2010). How innovation management techniques support an open innovation strategy. *Research Technology Management,* **53**(3), 41-52.

Kajikawa, Y., Usui, O., Hakata, K., Yasunaga, Y., and Matsushima, K. (2008). Structure of knowledge in the science and technology roadmaps. *Technological Forecasting and Social Change,* **75**(1), 1-11.

Kaplan, G. (2001). New roadmap flags electronics industry roadblocks. *Research Technology Management,* **44**(3), 4-5.

Kappel, T. A. (2001). Perspectives on roadmaps: how organizations talk about the future. *Journal of Product Innovation Management,* **18**(1), 39-50.

Kerr, C., Phaal, R., and Probert, D. (2012). Cogitate, articulate, communicate: the psychosocial reality of technology roadmapping and roadmaps. *R&D Management,* **42**(1), 1-13.

Kostoff, R. N., and Schaller, R. R. (2001). Science and Technology Roadmaps. *IEEE Transactions of Engineering Management,* **48**(2), 132-143.

Laat, B. D., & McKibbin, S. (2003). *The Effectiveness of Technology Roadmapping - Building a Strategic Vision*. Holland: Dutch Ministry of Economic Affairs.

Lee, S., and Park, Y. (2005). Customization of technology roadmaps according to roadmapping purposes: Overall process and detailed modules. *Technological Forecasting and Social Change*, **72**(5), 567-583.

Lee, S., Kang, S., Park, Y., and Park, Y. (2007). Technology roadmapping for Randamp;D planning: The case of the Korean parts and materials industry. *Technovation, 27*(8), 433-445.

Lee, S., Yoon, B., Lee, C., and Park, J. (2009). Business planning based on technological capabilities: Patent analysis for technology-driven roadmapping. *Technological Forecasting and Social Change*, **76**(6), 769-786.

Lee, J. H., Kim, H., and Phaal, R. (2012). An analysis of factors improving technology roadmap credibility: A communications theory assessment of roadmapping processes. *Technological Forecasting and Social Change*, **79**(2), 263–280.

Li, Y. (2009). The technological roadmap of Cisco's business ecosystem. *Technovation*, **29**(5), 379-386.

Lichtenthaler, U. (2008). Integrated roadmaps for open innovation. *Research Technology Management*, **51**(3), 45-49.

Lichtenthaler, U. (2010). Technology exploitation in the context of open innovation: Finding the right 'job' for your technology. *Technovation*, **30**(7-8), 429-435.

Loureiro, A. M. V., Borschiver, S., and Coutinho, P. L. A. (2010). The Technology Roadmapping Method and its Usage in Chemistry. *Journal of Technology Management and Innovation*, **5**(3), 181-191.

Major, J., Pellegrin, J. F., and Pittler, A. W. (1998). Meeting the software challenge: Strategy for competitive success. *Research Technology Management*, **41**(1), 48-56.

McCarthy, R. C. (2003). Technology roadmapping: Linking technological change to business needs. *Research Technology Management*, **46**(2), 47-52.

McDowall, W. (2012). Technology roadmaps for transition management: The case of hydrogen energy. *Technological Forecasting and Social Change, Online*.

McMillan, A. (2003). Technology roadmapping: Roadmapping--agent of change. *Research Technology Management*, **46**(2), 40-47.

Minshall, T., Mortara, L., Valli, R., and Probert, D. (2010). Making "asymmetric" partnerships work. *Research Technology Management*, **53**(3), 53-63.

Petrick, I. J., and Echols, A. E. (2004). Technology roadmapping in review: A tool for making sustainable new product development decisions. *Technological Forecasting and Social Change*, **71**(1-2), 81-100.

Phaal, R., Farrukh, C., and Probert, D. (2000). *Technology planning survey – results*: Institute for Manufacturing, University of Cambridge.

Phaal, R., Farrukh, C., and Probert, D. (2001a). *Fast-start Technology Roadmapping*. Paper presented at the Management of Technology: the Key to Prosperity in the Third Millennium: Proceedings of the 9th International Conference on Management of Technology (IAMOT).

Phaal, R., Farrukh, C., and Probert, D. (2001b). *A framework for supporting the management of technological innovation*. Paper presented at the Eindhoven Centre for Innovation Studies (ECIS) conference The Future of Innovation Studies.

Phaal, R., Farrukh, C., and Probert, D. (2001c). *T-plan: Fast start to technology roadmapping. Institute of Manufacturing*. Cambridge: Cambridge Unviersity.

Phaal, R., Farrukh, C., and Probert, D. (2001d). *Technology Roadmapping: linking technology resources to business objectives*: This paper has been produced as part of a three-year applied research project, supported by the UK Engineering and Physical Sciences Research Council (EPSRC).

Phaal, R., Farrukh, C., Mitchell, R., and Probert, D. (2003). Technology roadmapping: Starting-up roadmapping fast. *Research Technology Management, **46***(2), 52-58.

Phaal, R., Farrukh, C., and Probert, D. (2004). Technology roadmapping - A planning framework for evolution and revolution. *Technological Forecasting and Social Change*, **71**, 5-26.

Phaal, R., Farrukh, C., and Probert, D. (2006). Technology management tools: concept, development and application. *Technovation*, **26**(3), 336-344.

Phaal, R., and Muller, G. (2009). An architectural framework for roadmapping: Towards visual strategy. *Technological Forecasting and Social Change*, **76**(1), 39-49.

Probert, D., and Radnor, M. (2003). Technology roadmapping: Frontier experiences from industry-academia consortia. *Research Technology Management*, **46**(2), 27-59.

Probert, D., and Shehabuddeen, N. (1999). Technology road mapping: The issues of managing technology change. *International Journal of Technology Management,* **17**(6), 646-661.

Richey, J. M., and Grinnell, M. (2004). Evolution of roadmapping at Motorola. *Research Technology Management*, **47**(2), 37-41.

Rinne, M. (2004). Technology roadmaps: Infrastructure for innovation. *Technological Forecasting and Social Change*, **71**(1-2), 67-80.

Robson, P. J. A., & Bennett, R. J. (2000). The use of and impact of business advice in Britian: An empirical assessment using logit and ordered logit models. *Applied Economics*, **32**(13), 1675-1688.

Saritas, O., & Oner, M. A. (2004). Systemic analysis of UK foresight results: Joint application of integrated management model and roadmapping. *Technological Forecasting and Social Change*, **71**(1-2), 27-65.

Savioz, P., and Blum, M. (2002). Strategic forecast tool for SMEs: how the opportunity landscape interacts with business strategy to anticipate technological trends. *Technovation*, **22**(2), 91-100.

Strauss, J., and Radnor, M. (2004). Roadmapping for Dynamic and Uncertain Environments. *Research Technology Management*, **42**(2), 51-58.

Talonen, T., and Hakkarainen, K. (2008). Strategies for driving R & D and technology development. *Research Technology Management*, **51**(5), 54-60.

Vatananan, R. S., and Gerdsri, N. (2010). The current state of technology roadmapping (TRM) research and practice. *Technology Management for Global Economic Growth (PICMET), 18-22 July 2010*(2010 Proceedings of PICMET '10), 1-10.

Wells, R., Phaal, R., Farrukh, C., and Probert, D. (2004). Technology Roadmapping for a Service Organization. *Research Technology Management*, **47**(2), 46-51.

Willyard, C. H., and McClees, C. W. (1987). Motorolas technology roadmap process. *Research Technology Management*, **30**(65), 13-13.

Vecchiato, R. (2012). Environmental uncertainty, foresight and strategic decision making: An integrated study. *Technological Forecasting and Social Change*, **79**(3), 436-447.

Yasunaga, Y., Watanabe, M., and Korenaga, M. (2009). Application of technology roadmaps to governmental innovation policy for promoting technology convergence. *Technological Forecasting and Social Change*, **76**(1), 61-79.