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A framework for supporting the management of technological innovation

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Abstract

Technology is a key driver for innovation and sustainable business growth. However, the management of technology presents ongoing challenges to firms, owing to the increasing cost and complexity of technology, against a background of global competition, accelerating industrial change, competing technical standards, and reducing product development cycle times. Whilst industrial interest in the area is growing, from an academic perspective the conceptual basis of the subject of technology management is fragmented and poorly defined.

A framework has been developed to support practical and theoretical understanding of the management of technological innovation. At the heart of the framework are two sets of business processes that are important for effective technology management, including the three 'core' processes of strategy, innovation and operations, together with a set of five supporting technology management processes: identification, selection, acquisition, exploitation and protection. The framework supports the integration of these processes by focusing on the 'pull' and 'push' knowledge flows that need to occur between the commercial and technological functions within the firm.

This paper describes the framework and its application, outlining the general requirements and characteristics of such a framework. The development of the framework is discussed, based on concepts from systems, resource-based and other theoretical perspectives. The relationships between the core business and technology management processes are explored, and the utility of the framework as an integrating mechanism is discussed, in terms of the 'technology roadmapping' approach, which has been the focus of recent research.

1. Introduction

Technology has been a fundamental driver for innovation throughout the development of human society. With advances in fields such as information and communication technology, biotechnology and nanotechnology, the pace of innovation and change is set to increase further in the 21st century. This poses multiple challenges, for individuals, society and organisations, where managers are faced with hard decisions concerning how best to allocate limited resources, in terms of the increasing cost, complexity and risk of technology investments, against a background of increasing global competition.

Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies needed to maintain a stream of products and services to the market (Gregory, 1995). It deals with all aspects of integrating technological issues into business decision making, and is directly relevant to a number of core business processes, including strategy development, innovation and new product development, and operations management. Healthy technology management requires establishing appropriate knowledge flows between commercial and technological perspectives in the firm, to achieve a balance between market 'pull' and technology 'push'. The

nature of these knowledge flows depends on both the internal and external context, including factors such as business aims, market dynamics, organisational culture, etc.

While the emerging field of technology management holds out the promise of supporting managers in dealing with the challenges associated with technology, there are a number practical and theoretical hurdles to overcome. Technology management is a multifunctional and multidisciplinary field, requiring inputs from both commercial and technical functions in the firm, and a synthesis of academic perspectives, such as engineering, economics, business studies, social science and psychology. As yet there are very few widely adopted methods for the practical application of technology management principles, and few universally accepted conceptual models or frameworks to underpin them. Research within the Centre for Technology Management at the University of Cambridge aims to contribute towards addressing these difficulties, focusing on the development of tools and frameworks for supporting managers in industry, that are both practical and theoretically robust (e.g. Probert, 1997, Farrukh *et al.*, 2000b, Phaal *et al.*, 2000a).

This paper firstly considers the meaning of the term 'framework' (Section 2), reviews a number of key technology management themes (Section 3), and describes the development of a high-level framework for supporting technological innovation (Section 4). It is proposed that this framework provides a bridge between theory and practice (Phaal *et al.*, 2000b, Probert *et al.*, 2001). This is illustrated by examination a process for initiating technology roadmapping in the firm (Section 5), a technique that is of growing importance in industry, and which has been developed in parallel to the framework.

2. What is a management framework?

Conceptual frameworks in management theory and practice support understanding of an issue or area of study, provide structure, and support decision making and action. Before considering the technology management framework that is the focus of this paper, it is worth reviewing what is meant by the term 'framework'. There is little rigour or consistency in the literature in terms of definition, development and application of frameworks, and other related terms such as models, maps, methods, etc. In order to clarify this situation, the 'meta-framework' in Fig. 1 has been proposed by Shehabuddeen *et al.* (2000). This meta-framework structures a number of related terms for management representations and approaches according to two key dimensions: applied-conceptual and static-dynamic, defined as follows:

- *Conceptual:* concerned with the abstraction or understanding of a situation.
- *Applied:* concerned with concrete action in a practical environment.
- *Static:* concerned with the structure and position of elements within a system.
- *Dynamic:* concerned with causality and interaction between the elements of a system.

The relationships between the various terms that refer to management representations are implied by the structure shown in the Fig. 1, adopting the following definitions:

- A *paradigm* describes the established assumptions and conventions that underpin a particular perspective on a management issue.
- A *system* defines a set of bounded interrelated elements and represents it within the context of a paradigm.
- A *framework* supports understanding and communication of structure and relationship within a system for a defined purpose.
- A *map* supports understanding of the static relationship between elements of a system.
- A *model* supports the understanding of the dynamic interaction between the elements of a system.
- A *process* is an approach for achieving a managerial objective, through the transformation of inputs into outputs.

- A *procedure* is a series of steps for operationalising a process.
- A *technique* is a structured way of completing part of a procedure.
- A *tool* facilitates the practical application of a technique.

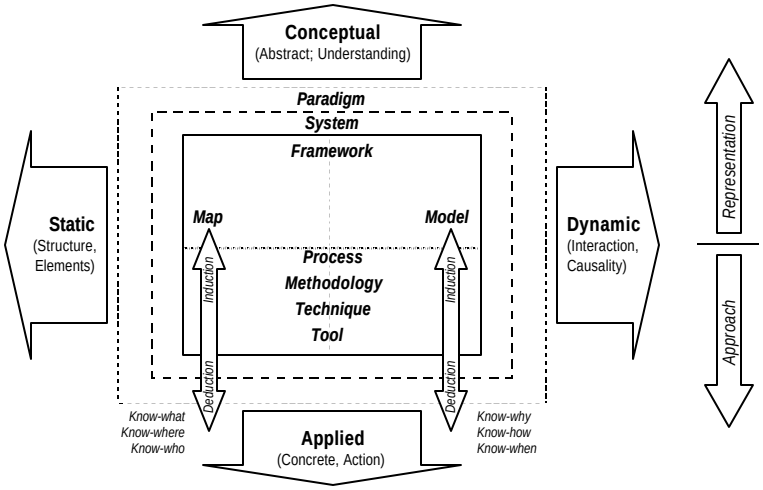

Fig. 1 - Meta-framework: management representations and approaches (Shehabuddeen et al.*, 2000); note, the boundaries between the various forms of representations and approaches are not distinct, and hybrid forms exist*

The relationship between 'representations', which tend to be conceptual in nature, and 'approaches', which tend to focus on action, is important. The key point is that conceptual frameworks exist largely in the mind, and require practical devices (i.e. methods, processes, techniques and tools) to 'interface' with the real world, in terms of both the development (induction) and application (deduction) of frameworks. In this regard the meta-framework shown in Fig. 1 is closely related to organisational and personal learning cycles (e.g. the Kolb learning cycle, Reeves, 1997). The application of the technology roadmapping approach, which is closely related to the technology management framework, supported the development of the framework, and provides a means for the concepts contained within the framework to be applied in practice (see Section 5).

3. Technology and the management of technology

There are many published definitions of 'technology' (e.g. Floyd 1997, Whipp 1991, Steele 1989). Examination of these definitions highlights a number of factors that characterise technology, which can be considered as a specific type of knowledge (although this knowledge may be embodied within a physical artefact - i.e. a machine, component, system or product). The key characteristic of technology that distinguishes it from more general knowledge types is that it is *applied*, focusing on the 'know-*how*' of the organisation. While technology is often associated with science and engineering ('hard' technology), the processes which enable its effective application are also important - for example new product and innovation processes, together with organisational structures and supporting communication / knowledge networks ('soft' aspects of technology).

Treating technology as a type of knowledge is helpful, as knowledge management concepts can be brought to bear (e.g. Stata, 1989, Nonaka, 1991, Leonard-Barton, 1995, Fleck, 1997, Pelc, 1997, Madhaven and Grover, 1998, Bowonder and Miyake, 2000). For instance, technological knowledge generally comprises both explicit and tacit knowledge. Explicit technological knowledge is that which has been (or can be) articulated (e.g. a report,

procedure or user guide), together with the physical manifestations of technology (e.g. equipment). Tacit technological knowledge is that which cannot be easily articulated, and which relies on training and experience (e.g. welding, or design skills).

Technology, in the business context, can best be considered as an important type of resource, and hence there are considerable linkages with other resource-based views of the firm (e.g. Wernerfelt , 1984, Dierickx and Cool ,1989, Penrose, 1995, Grant, 1996), such as competence (Hamel & Prahalad, 1994) and capability approaches (Teece *et al.*, 1997), and the general knowledge management literature. A key objective of technology management is to ensure that technological resources are effectively linked to business requirements, which is the focus of the technology management framework proposed in this paper, and a key benefit of the technology roadmapping approach.

Similarly to 'technology', there are many definitions of 'technology management' in the literature (e.g. Roussel *et al.*, 1991, Gaynor, 1996). For the purposes of this paper the following definition is adopted, proposed by the European Institute of Technology Management (EITM)[1]:

"Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process and infrastructural) needed to maintain a market position and business performance in accordance with the company's objectives".

This definition highlights two important technology management themes:

- Establishing and maintaining the linkages between technological resources and company objectives is of vital importance, and represents a continuing challenge for many firms. This requires effective communication and knowledge management, supported by appropriate tools and processes. Of particular importance is the dialogue and understanding that needs to be established between the commercial and technological functions in the business.
- Effective technology management requires a number of management processes, and the EITM definition includes the five processes proposed by Gregory (1995): identification, selection, acquisition, exploitation and protection of technology. These processes are not always very visible in firms, and are typically distributed within other business processes, such as strategy, innovation and operations.

The framework described in this paper is primarily intended to support technology management in the manufacturing sector, at the firm level (although, owing to the generic nature of the high-level framework, it is considered likely to have broader application). To improve understanding of the framework it is important to define the *system* within which it applies, in the context of technology management.

The manufacturing business systems model that has been adopted is that used by the University of Cambridge Manufacturing Leaders Programme (MLP), which forms the basis for a company audit (Hillier, 2001) - see Fig. 2. The MLP model is built up in three stages (or levels):

- *Level 1:* a simple resource-based process view, where resources are identified as comprising people and facilities, which are combined with operational processes to transform inputs into required outputs. Based on the discussions above, the technology base of the firm can be considered to be a sub-set of these resources and processes.
- *Level 2:* expansion of the model to the firm level, defining the manufacturing business, in the context of the value chain that links suppliers to customers, highlighting a number of important business processes. These processes are strategy development, supply chain

[1] *EITM is a collaboration between a number of European universities: see http://www-mmd.eng.cam.ac.uk/ctm/eitm/index.html*

management and new product introduction, supplemented by supplier and customer development processes.

- *Level 3:* expansion of the model to include the business environment in which the firm operates: industry sectors, competitors and suppliers, current available technology, customers and consumers, and liability, environment and economy. The broader trends that govern the evolution of this business environment are included in the model (i.e. industry trends, technology trends, general societal trends, and political and economic trends).

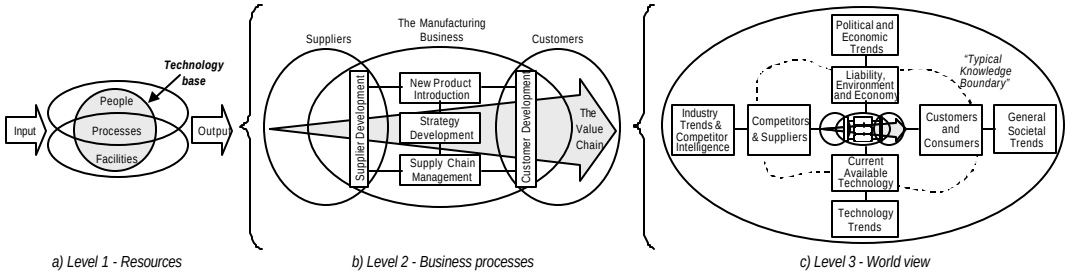

Fig. 2 - Cambridge Manufacturing Leaders' Programme Audit model (Hillier, 2001)

This type of model defines the system within which technology management considerations can be explored (see for example, the technological innovation system of Betz, 1998, the technology system interfaces defined by Geistauts and Eschenbach, 1997, and the product development systems model of Simons and de Klerk, 1997). The importance of defining the system, including its boundaries, interfaces and elements, and the relationships between them, is supported by general systems theory (e.g. Arbnor and Bjerke, 1997, Ackoff, 1999, Jackson, 2000). The 'soft' systems perspective (Checkland, 1981), where the importance of how people perceive and interact with the system, is of particular relevance to technology management, which requires co-operation between technological and commercial functions (Linstone, 1999).

The concepts discussed in this section (technology as an important resource in the firm, and the technology management processes that operate on the technology base, in the context of the manufacturing business system) provide the components on which the technology management framework is based.

4. The technology management framework

The technology management framework is shown in Fig. 3, and described below.

4.1 Purpose of technology management framework

The overall aim of the framework is to support understanding of how technological and commercial knowledge combine to support strategy, innovation and operational processes in the firm, in the context of both the internal and external environment.

Note, this is a high-level framework that supports broad understanding of key aspects of technology management. The many particular activities and aims that are associated with technology management practice in firms (e.g. technology strategy, foresight, transfer, selection, R&D management, make vs. buy, etc.) depend on the particular context and objectives. Detailed frameworks have been developed to support decision making and action in some of these more specific areas (for example, Canez *et al.*, 2001, Shehabuddeen, 2001).

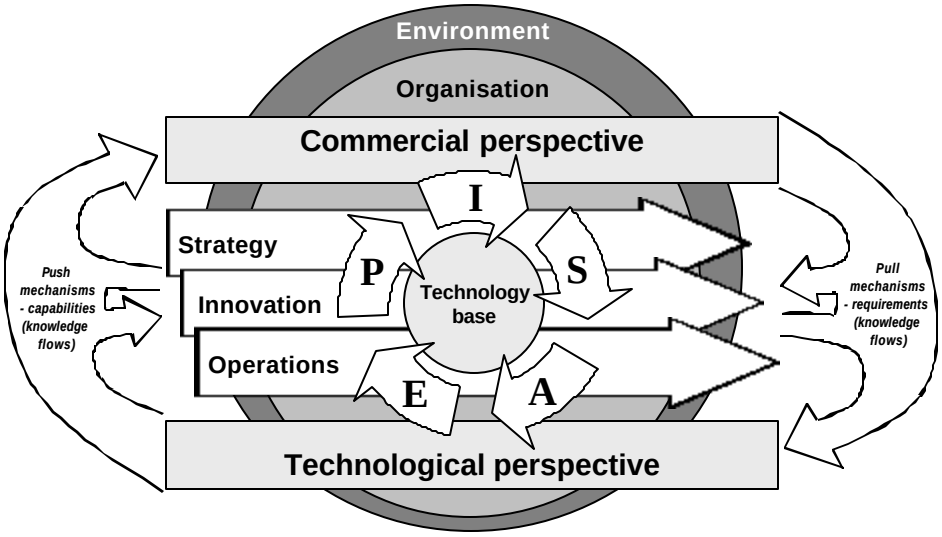

Fig. 3 - Technology management framework

4.2 Key features of the technology management framework

Technology management processes

At the heart of the framework is the technology base of the firm, which represents the technological knowledge, competences and capabilities that support the development and delivery of competitive products and services, and other organisational goals. Five technology management processes (ISAEP) operate on the technology base (Gregory, 1995), which combine to support the generation and exploitation of the firm's technology base, discussed further in Section 4.4:

- *Identification* of technologies that are not currently part of the firm's technology base, but may be important in the future (e.g. by attending conferences, reading journals, visiting trade fairs, questioning suppliers, conducting pure research, etc.)
- *Selection* of those technologies that the firm needs for its future products and technologies (e.g. by using portfolio-type methods, expert judgement, pilot studies, financial methods, etc).
- *Acquisition* of the technologies that have been selected (e.g. by R&D, licensing, purchase of equipment, hiring of staff, acquisition of firms, etc.).
- *Exploitation* of the technologies that have been acquired (e.g. by incorporating into products and services, licensing, etc.).
- *Protection* of the technological assets of the firm (e.g. by legal means such as patenting, contracts, trademarks, copyright, together with security measures, retention of key staff, etc.).

Business processes

The ISAEP technology management processes do not operate in isolation, and are generally not managed as separate 'core' business processes. The various activities that constitute these management processes tend to be distributed within other business processes (for instance, technology selection decisions are made during business strategy and new product development). Three 'core' business processes are of particular importance: *strategy, innovation and operations* (SIO), operating at different business system 'levels' in the firm,

considered in more detail in Section 4.4. The link to core business processes is important, as these are the focus of management and action in the business, and the means for ensuring sustainable productive output of the firm. The aim of effective technology management is to ensure that technological issues are incorporated appropriately into these processes, to form a technology management system that is coherent and integrated across and beyond specific business processes and activities.

Mechanisms for linking technological and commercial perspectives

The framework emphasises the dynamic nature of the knowledge flows that must occur between the commercial and technological functions in the firm, linking to the strategy, innovation and operational processes, if technology management is to be effective. An appropriate balance must be struck between market 'pull' (i.e. requirements), and technology 'push' (i.e. capabilities). Various 'mechanisms' can support the linkage of the commercial and technical perspectives, including traditional communication channels (e.g. discussions, email, etc.), cross-functional teams / meetings, management tools, business processes, staff transfers, training, etc.

Context

The specific technology management issues faced by firms depend on the context (both internal & external), in terms of organisational structure, systems, infrastructure, culture and structure, and the particular business environment and challenges confronting the firm, which change over time. In this regard, contingency theory (Jackson, 2000) is very relevant.

Time

Time is a key dimension in technology management, in terms of synchronising technological developments and capabilities with business requirements, in the context of evolving markets, products and technology. Although time is not explicitly depicted in the framework, it is implicit in SIO business and ISAEP technology management processes.

4.3 Application of technology management framework (illustration)

The concept of 'pull' and 'push' mechanisms, which is a central feature of the technology management framework, is illustrated in Fig. 4 (Muller, 1999), which shows how people, information, documents, resources, processes, etc. connect key business processes (including commercial and technological perspectives).

4.4 Integration of business and technology management processes

As noted above, technology management processes (ISAEP) do not exist in isolation, and tend not to be managed as explicit 'core' business processes, but rather are distributed as activities within other business processes, the most important of which being strategy, innovation and operations. Effective technology management requires that these relationships be understood, and supported by effective knowledge management systems (i.e. 'pull' and 'push' mechanisms). The following points illustrate the complex relationships between these business and technology management processes:

- The ISAEP technology management processes are not entirely linear in nature. While there is a logical flow from identification through selection, acquisition, exploitation and protection, some iteration and feedback is required. Broadly, the relationships between the processes can be described in terms of 'upstream' and 'downstream' flows. In the ISAEP sequence, information and knowledge generated during each activity can be useful for downstream processes. For example

- Information gathered during identification of technology can be a useful input to the selection process. On the other hand, the identification of technology requires some form of 'filter' to direct efforts, and to enable promising technologies to be recognised. This requires 'pre-selection', or a 'light' form of selection process to be embedded within the identification process. Similar observations can be made for the other processes.
- In terms of feedback, each process can benefit from the learning that is generated by the application of the set of processes, which requires a systems-level perspective, with associated responsibilities for high-level technology management in the firm. The role of the technology management function includes the overall co-ordination of the activities that constitute the ISAEP processes, and provision of the infrastructure for supporting their application (i.e. information and knowledge management, provision of management tools, training, etc.).

- While the main focus of each SIO business process is at the corresponding SIO 'business system level', these processes also operate at the other levels. For instance:
  - Strategy is primarily concerned with overall corporate or business objectives and direction, but also with innovation (e.g. development of product and technology platforms), and operations (e.g. how to best configure manufacturing and logistics).
  - Innovation is primarily concerned with the development of new products and services, but also has a role to play in improving strategic and operations processes.
  - Operations is primarily concerned with the flow of resources within the business system, but also with project management of the activities associated with strategy and innovation processes.

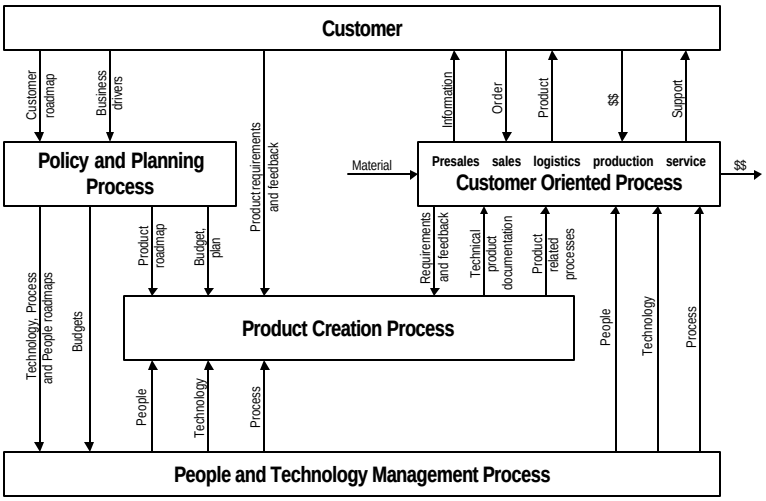

Fig. 4 - Simplified decomposition of the business in four main processes (Muller, 1999)

Thus, a complex picture emerges when assessing the relationship between the various ISAEP technology management and SIO business processes. Technological considerations impact on all of the business processes, at all levels of the business system. The processes for understanding and managing technology and the wider business are not simple or independent, but complex and intertwined. An holistic and predictive view of how all of these elements behave as an integrated system is perhaps too ambitious, owing to the context-dependent nature of many specific technology management tasks. Some useful attempts have been made to define this system, although the models have been complex. For instance the MOAD construct described by Levin (2000) attempts to map relationships between a comprehensive set of 27 technology management 'routines'. In contrast, the relative simplicity

and generality of the technology management framework described in this paper encapsulates the *principles* that underpin effective technology management, across the breadth of the organisation and its activities.

5. Practical implications

There is a close relationship between conceptual frameworks and the practical tools and techniques that are needed to both develop and apply the principles associated with them (see Section 2). The themes that have been included in the technology management framework described in Section 4 have evolved in parallel with ongoing applied research programmes to develop practical tools and processes for supporting technology management in business, including:

- Process for supporting strategic make-or-buy decisions in manufacturing (Probert, 1997).
- Portfolio-based method for R&D project evaluation (Farrukh *et al.*, 2000a).
- Procedure for assessing technology management processes in business (Farrukh *et al.*, 2000b).
- Process for initiating technology roadmapping in firms (Phaal *et al.*, 2000a).
- Tool catalogue for supporting technology managers in business (Phaal *et al.*, 2000c).

The principles encapsulated within the framework are apparent in the development and application of all the methods that have been generated during the research described above. One tool / process that is worth particular attention is 'technology roadmapping', which has significant potential for integrating processes and information across the span of the whole framework, and for supporting communication and co-operative working across the organisation. Technology roadmaps have been used in industry for several decades as a means for supporting strategic product and technology planning (see, for example, Willyard and McClees, 1987, Groenveld, 1997, EIRMA, 1997), and more recently for supporting sectoral foresight initiatives (for example, the Semiconductor Industry Association roadmap[2]).

The development and application of the roadmapping technique has been a focus of the practical work that underpins the technology management framework (e.g. Phaal *et al.*, 2000b). There are many types of roadmap, in terms of purpose and format (Phaal *et al.*, 2001); the most common (generic) type is shown in Fig. 5. The roadmap comprises a number of layers (and sub-layers), within which the evolution or migration of the business is charted (including market, product and technology perspectives) on a time basis, together with key linkages between the layers.

Comparing the generic technology roadmap with that of the technology management framework (Section 4), it can be seen that there are some key structural relationships between the two, which highlight the importance of roadmapping for embedding the principles contained in the framework in industrial practice:

1. The commercial and technological layers of the roadmap directly relate to the commercial and technological perspectives in the framework, and the linkages between these can be readily shown on the roadmap.
2. The linking (middle) layer of the roadmap (typically products or services, but more generally including other aspects such as capabilities and systems) is closely related to the 'push - pull' linkage mechanisms in the framework. Generally, the middle layer of the roadmap can also be considered as a linkage mechanism, providing common ground for both the commercial and technological functions in the firm. For example, while technologists and marketeers may approach the business from different perspectives, both groups have a sound understanding of products. The process whereby a roadmap is

[2] *http://public.itrs.net/files/1999_SIA_Roadmap/Home.htm*

developed brings together representatives from all relevant functions, directly enhancing communication and co-operation.

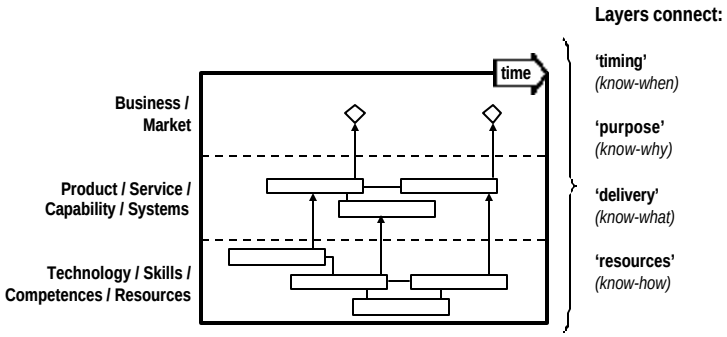

Fig. 5 - Generic technology roadmap (schematic)

The business processes (SIO) relate to the roadmap in a number of ways:

- The operations, innovation and strategy processes are associated with different time horizons (short, medium and long, respectively), which are also closely related to the structure of the roadmap. The roadmap includes the temporal dimension explicitly, and tends to include short-, medium- and long-term perspectives, typically up to at least two innovation cycles into the future.
- The strategy and innovation processes are often expressed at the 'Business' and 'Product' layers of the roadmap, respectively, in terms of strategic milestones, elements of strategy, new product introductions, service improvements, etc. For roadmaps that are driven by 'technology push', elements of technology strategy may be incorporated into the 'Technology' layer.
- The similarity of the roadmap structure to Gantt planning charts enables specific programmes and projects to be related directly to the roadmap, which are often used to monitor progress at a high level.

In summary, the technology roadmap is a key *integrating* method for supporting the management of technology in business, owing to:

- The flexibility for the roadmap in terms of its application and structure (the approach can be used for supporting many planning-oriented activities, at any level in the firm).
- The close relationship between the structure and use of roadmaps, and both the business (SIO) and technology management (ISAEP) processes.
- The strength of technology roadmaps for supporting the linkage of commercial and technological perspectives in the firm.
- Many tools and techniques may be used for supporting strategy and planning (e.g. competitor assessment, market research, technology audit, forecasting, etc.). The information that is generated using these approaches is a valuable input to the roadmapping process, which has the potential to act as a focal point for these activities.

6. Summary and conclusions

This paper has presented an overview of the development and application of a high-level framework for technology management. The framework is intended to be broad in scope, incorporating a number of key principles that underpin technology management. Although the framework is intended primarily for manufacturing businesses, it is thought to be more widely applicable. The framework evolved in parallel with ongoing applied research programmes, aimed at developing practical tools and techniques for supporting technology management in

business, with particular reference to the technology roadmapping approach. The framework, which is consistent with concepts from resource-based and systems thinking, provides a bridge between theory and practice.

The technology management framework incorporates the following key elements, which are all important for the understanding and application of technology management in business:

- The technology base of the firm, a key resource for many innovative companies.
- The technology management processes (identification, selection, acquisition, exploitation and protection) that operate on the technology base to support innovation in the firm.
- The core business processes of strategy, innovation (including new product development) and operations, which provide the means by which the potential value of technology can be realised.
- The mechanisms by which the technological and commercial perspectives of the firm are brought together, to ensure an appropriate balance between market 'pull' (requirements) and technology 'push' (capabilities).
- The internal and external factors that provide context to technology management in the firm, such as business purpose, organisational structure, culture and infrastructure, market environments, drivers, etc.
- Time is a key dimension in technology management; although not explicitly depicted in the framework, it is implicit in SIO business and ISAEP technology management processes.

Consideration of all of these factors is important for effective technology management, with a key overriding theme being the *integration* of knowledge, processes, activities, methods, etc. Technology roadmapping is a particular technique that provides a means of addressing all of these challenges, with its use expanding both at the firm and sector levels (i.e. Foresight) as a core tool for supporting technology management. Owing to the context-dependent nature of particular technology management challenges, business processes and management tools need to be somewhat flexible, and be able to be adapted or customised to fit the aims, needs, resources and culture of the particular firm. The technology management framework and roadmapping approach both incorporate this requirement for flexibility.

The technology management framework provides a high-level conceptualisation of the principles that underpin the management of technological innovation in the firm, linking technology management and business processes. The framework represents a contribution towards defining the emerging field of technology management, from the viewpoint of both academics and industrial managers. It has robust theoretical foundations (grounded in systems thinking and the resource-based perspective, including perspectives from topics such as technology and knowledge management, strategy, decision support, etc.), and has been shown to have practical utility.

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