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TECHNOLOGY MANAGEMENT TOOLS: GENERALIZATION, INTEGRATION AND CONFIGURATION

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Managers in technology-intensive businesses need to make decisions in complex and dynamic environments. Many tools, frameworks and processes have been developed to support managers in these situations, leading to a proliferation of such approaches, with little consistency in terminology or theoretical foundation, and a lack of understanding of how such tools can be linked together to tackle management challenges in an integrated way. As a step towards addressing these issues, this paper proposes the concept of an integrated 'toolkit', incorporating generalized forms of three core technology management tools that support strategic planning (roadmapping, portfolio analysis and linked analysis grids).

Keywords: Tools; Frameworks; Roadmapping; Portfolio

1. Introduction

Managers and consultants use a wide range of tools and techniques to support strategic decision-making and action in increasingly complex, competitive and dynamic business environments. The impact of new technologies and shortening innovation cycles places a greater demand on managers to make effective and timely decisions, supported by good quality market, competitive and technology intelligence. Such decisions typically require input from multiple functions and disciplines, and benefit from processes that support consensus. Management tools and approaches are needed to support such decisions.

The choice of what management tool to use, and how to deploy it most appropriately, can be very confusing, due to the proliferation of approaches developed by academics, consultants and firms. For example, Phaal *et al.* [2005a] have identified more than 850 tools of the simple '2x2 matrix' kind, covering all branches of management, of which approximately 40 are used to support R&D project and option portfolio management. Examination of these portfolio tools indicates that many, while expressed in a range of different ways, are similar in type. Also, Phaal *et al.* [2001c] have explored the many formats that the technology roadmapping approach can take, and the various purposes to which it has been applied. The importance of focusing on management tool development is highlighted by the following statement by Rigby [2001]: "The implementation of new management tools is often an expensive proposition costing companies millions of dollars in training and development, consulting fees, and other related costs".

This paper seeks to address the issue of how technology management tools can be designed, developed and deployed in a more rigorous fashion, to avoid unnecessary proliferation and to ensure that tools can integrate with each other and with business processes and systems. For example, it has been demonstrated that the roadmapping approach can be generalized to a form that can be customized to suit a wide range of applications [Phaal *et al.* (2004c); Lee and Park (2005)]. The principles that enable roadmapping to be used in this way are considered in Section 3, based on experience gained over a period of eight years developing a practical approach for initiating technology roadmapping in firms and networks, involving more than 75 collaborative engagements with companies and other organizations [e.g. Phaal *et al.* (2001a; 2004b; 2005b)].

In addition, the way in which roadmaps can be deployed in conjunction with other technology management tools is considered, with particular reference to portfolio management methods [e.g. Cooper *et al.* (1998)] and 'linked analysis grids' [e.g. Lindsay (2000)]. These concepts are extended further in Section 4 to propose a set of principles that could form the basis of a 'theory' of technology management tool design and application, leading to the vision of a 'universal toolkit' that can be configured to support a wide range of technology management decisions and processes. But firstly, the nature of management representations and approaches is considered in Section 2, to define terms and to understand the process through which management frameworks and tools can be developed in a robust manner.

2. Management Representations and Approaches

Brady *et al.* [1997] define a management tool as "a document, framework, procedure, system or method that enables a company to achieve or clarify an objective". Rigby [2001] states that "The term 'management tool' can mean many things, but often involves a set of concepts, processes, exercises, and analytic frameworks." In his survey of management tools and techniques, Rigby focuses on broad areas such as strategic planning, benchmarking, pay-for-performance, outsourcing, customer segmentation, reengineering, balanced scorecard and total quality management. This paper adopts a more specific and focused definition of management tool, described below.

2.1. *Meta-framework*

The broad definitions provided by Brady *et al.* and Rigby do not distinguish between a number of related terms that are used in various ways by different management authors and practitioners, with little rigor or consistency. 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 (which collectively might be termed 'methods') according to two key dimensions: applied-conceptual and static-dynamic, defined as follows:

- *Conceptual:* concerned with the abstraction or understanding of a situation (cognitive models).
- *Applied:* concerned with concrete action in a practical environment (real world).
- *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 and approaches are implied by the structure shown in the Fig. 1, adopting the following definitions (although it is recognized that many management representations and approaches combine elements of more than one of these):

- A *paradigm* describes the established assumptions and conventions that underpin a particular perspective on a management issue (e.g. the authors of this paper adopt an engineering problem-oriented paradigm).
- 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 (see example in Fig. 2).
- A *map* supports understanding of the static relationship between elements of a system.
- A *model* supports understanding of the dynamic interaction between the elements of a system (cause and effect; information flows).
- 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 operationalizing a process.
- A *technique* is a structured way of completing part of a procedure.
- A *tool* facilitates the practical application of a technique.

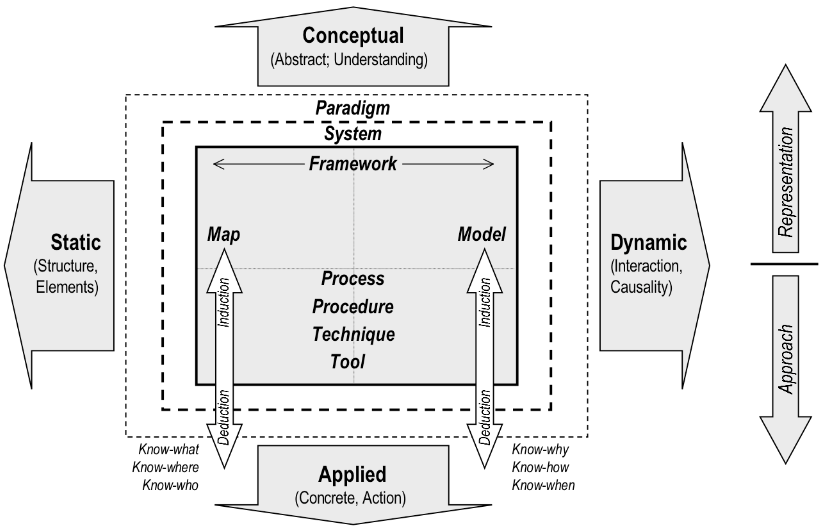

Fig. 1. Meta-framework: management representations and approaches [Shehabuddeen *et al.* (2000); Phaal *et al.* (2004a)]; note, the boundaries between the various forms of representations and approaches are not distinct, and hybrid forms are indeed common.

2.2. *Management tools and frameworks*

The definition of management tool in the meta-framework is more specific than that provided by Brady *et al.* and Rigby*,* although the ‘nested’ and interrelated nature of the concepts defined here implies that tools need to be considered in the context of the technique, procedure and process within which they are applied, together with the conceptual basis on which they are founded (models, maps and frameworks, together with the system and paradigm).

Brown [1997] and Farrukh *et al.* [1999] list some principles of good practice for tool design. Tools should be: founding on an objective best-practice model; simple in concept and use; flexible, allowing ‘best-fit’ to the current situation and needs of the company; not mechanistic or prescriptive; capable of integrating with other tools, processes and systems; result in quantifiable improvement; and support communication and buy-in. A manager faces a number of challenges when making use of such tools: How to find appropriate tools? How to assess the quality and utility of available tools? How to apply the tools in a practical setting or process? How to integrate tools with other tools, and with business processes and systems? [Phaal *et al.* (2005a)].

This paper focuses mainly on the issue of how technology management tools can be designed in such a way that they can be *flexible* (i.e. adapted to suit particular business situations) and *integrated* (with other tools, in the context of business processes). But firstly, the process of tool development will be addressed briefly, with reference to the meta-framework shown in Fig. 1, emphasizing the need to develop robust management tools that are based on well-founded conceptual frameworks linked to management theory.

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 (although they may be articulated in the form of text and drawings), and require practical devices (i.e. processes, procedures, techniques and tools) to 'interface' with the real world, in terms of both the development (induction) and application (deduction) of frameworks.

Through a process of induction, research tools are used as instruments to monitor and measure specific instances of behavior in the real world, from which general principles and frameworks can be inferred. Through a process of deduction, the development of robust conceptual frameworks allows well-founded management tools to be developed that can then be used to support change management processes within the organization, configuring the general principles in the framework and tools to the particular situation. In this regard the meta-framework shown in Fig. 1 is closely related to organizational and personal learning cycles (e.g. the Kolb learning cycle, Reeves [1997]).

The effective management of technology requires practical management tools to support decision-making and action, underpinned by well-founded conceptual frameworks. An example technology management framework is shown in Fig. 2 [Phaal *et al.* (2004a)], developed to support understanding of how technological and commercial knowledge combine to enable strategy, innovation and operational processes in the firm, in the context of both the internal and external environment.

This framework was developed in parallel with a technique for the rapid initiation of technology roadmapping [Phaal *et al.* (2001a)], one of the methods that will be described in more detail in the next Section. The process adopted for developing the framework and roadmapping tool was iterative in nature [Probert *et al.* (2003)], deploying a range of tools, techniques and procedures within the induction / deduction cycle shown in Fig. 1, including surveys / questionnaires, interviews and workshops, adopting an action-based research methodology to develop and test the emerging roadmapping tool and framework, based on extensive collaboration with industry. The methodology, termed the ‘Cambridge process approach’ is described elsewhere [Maslen and Lewis (1994); Platts

(1995); Phaal *et al.* (2001b); Probert *et al.* (2003)], and will not be explored in detail in this paper.

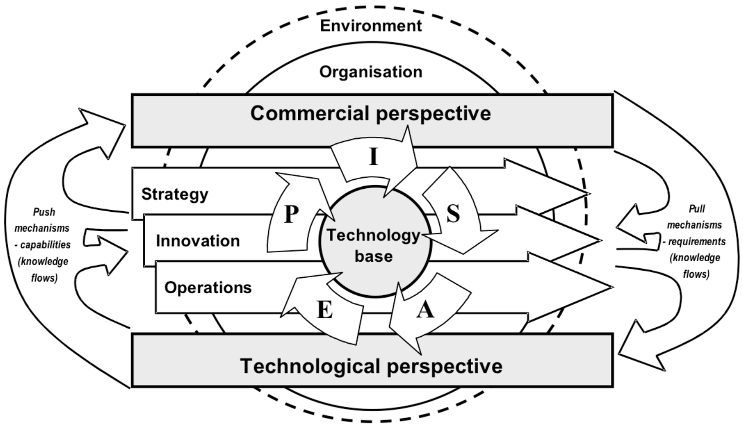

Fig. 2. Technology management framework [Phaal *et al.* (2004a)], highlighting how five technology management processes (Identification, Selection, Acquisition, Exploitation and Protection) operate on the technology base of the firm [Gregory (1995)], typically embedded within the core business processes of the firm (strategy, innovation and operations).

3. Example Technology Management Tools and their Integration

Many technology management tools and frameworks have been developed by companies, consultants and academics to support the understanding of complex management issues, to support decision making, and to enable the implementation of strategy and change plans [e.g. Phaal *et al.* (2001c; 2005)]. This section focuses on three of these: technology roadmapping, portfolio matrices and linked analysis grids, with particular reference to the roadmapping approach, considering how such tools can be generalized, combined and configured. These three tool types are described below with examples illustrated in Fig. 3. These principles are extended in Section 4 to consider the case of a generic management toolkit, illustrated again by means of the three management tools discussed here.

3.1. *Roadmapping, portfolio matrices and linked analysis grids*

a) Technology roadmapping

Roadmapping, in the context of strategic planning, has its early roots in product-technology planning, developed initially by Motorola and Corning in the 1970s [Willyard and McClees (1987); Probert and Radnor (2003)]. Since then the technique has been widely adopted, and adapted, by many organizations, at the firm, sector and national levels [e.g. Kappel (2001); Kostoff and Schaller (2001); de Laat and McKibbin (2003); Lee and Park (2005); Phaal *et al.* (2004c; 2005b)]. While the dominant term is 'technology roadmapping', this can be misleading as the approach strongly supports integrated strategic planning and innovation, linking resources (including technology) to organizational objectives [Phaal *et al.* (2004c); Lee and Park (2005)]. Thus, terms such as ‘strategic roadmapping’, ‘business roadmapping’ and ‘innovation roadmapping’ may be more appropriate, and are being increasingly used [Phaal *et al.* (2005b)].

While roadmaps can take various forms [Phaal *et al.* (2001c); Lee and Park (2005)], the most general and flexible architecture is illustrated in Fig. 3a, comprising a multi-layered time-based chart, within which the development and evolution of core themes can be explored and mapped. A typical firm-based roadmap would include themes such as markets, business, products, services, technology and resources. The example shown in Fig. 3a applies to the sector level (road transport), where the middle layer focuses on the performance measures and targets for the transport system. Very few examples of company-level roadmaps have been published, for reasons of confidentiality; however, many examples of sector- and national-level roadmaps (i.e. ‘supra-company’ roadmaps, De Laat and McKibbin [2003] are freely available on the internet, as the intention of this type of roadmap is typically to influence the research, standards and policy agenda. A recent internet search has identified more than 500 such roadmaps[1], coving a wide range of sectors and technologies.

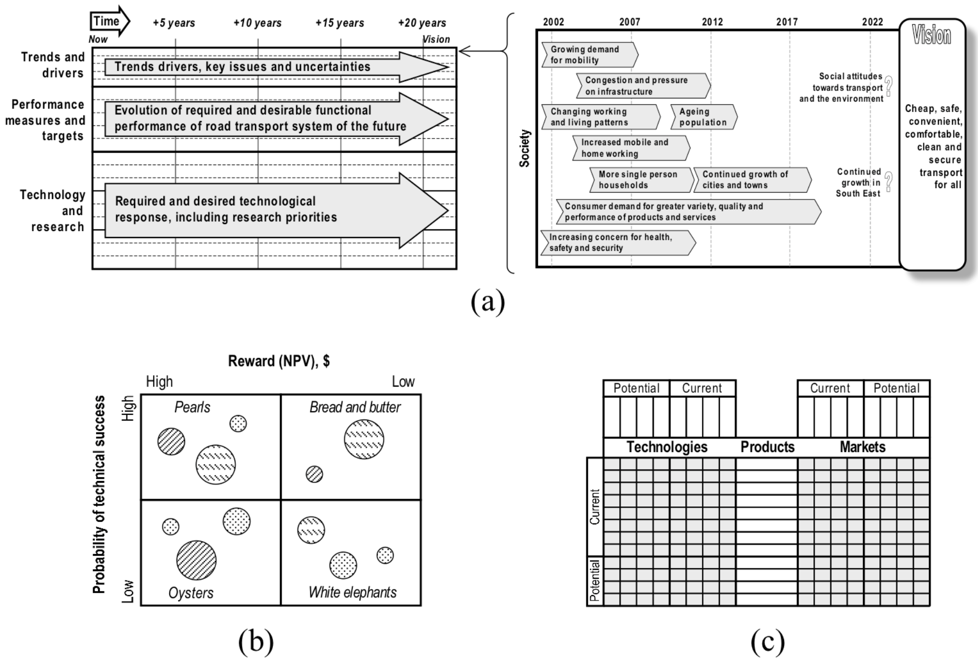

Fig. 3. Three technology management tools in common use: a) Technology roadmap [Phaal *et al.* (2004b)]; b) Portfolio matrix [Cooper *et al.* (1998)]; c) Linked analysis grid [Lindsay (2000)].

b) Portfolio matrix

Portfolio methods are widely used to support the management, prioritization and selection of research projects, and more generally strategic options. This type of tool comprises a “relatively simple two (or sometimes more) dimensional orthogonal structure, relating two key dimensions of the particular management issue being

[1] www.ifm.eng.cam.ac.uk/ctm/trm/resources.html

addressed", such as investment, risk, competence and business benefit [Phaal *et al.* (2005a)]. There are many such tools [e.g. Bitondo and Frohman (1981); Dussauge *et al.* (1992); Lowe (1995); Leuhrman (1998); Sharpe and Keelin (1998); Vernet and Arasti (1999); Lindsay (2000); Mikkola (2001)], with one of the more widely used, the risk-reward matrix, illustrated in Fig. 3b [Cooper *et al.* (1998)].

c) Linked analysis grids

Analysis grids are simple orthogonal structures that can be used to link one set of themes to another. There are many examples of such tools [e.g. Chester (1994); Klein and Hiscocks (1994); de Wet (1996); Miller (1997); Zadoks (1997); Lientz & Rea (1999)], with one illustrated in Fig. 3c (Lindsay, 2000), which relates markets to products and technologies (current and potential). One key advantage of such tools is that then can be linked together – the example in Fig. 3 actually comprises two separate grids (market-product and product-technology), linked together through a common view of the product categories used. Perhaps the most widely used example of this class of tool is the quality function deployment (QFD) grid, sometimes referred to as the 'house of quality', commonly used at a more detailed level to support engineering design, linking user requirements to technology solutions [e.g. Cohen (1995)].

3.2. *Integration of roadmaps, portfolio matrices and linkage grids*

The three tool types described above are widely used – each has a particular role to play in the strategic management of technology, providing a particular perspective, and having particular strengths and weaknesses. However, they are not always used in a coherent way, and there appears to be little published guidance on how they relate to each other, generally and in the context of specific management situations in which they can be applied. Figure 4 illustrates how these three management tools relate to each other:

(a) The roadmap provides a key role in terms of integration (of tools and process). In their general form, roadmaps can be considered as business or system frameworks [Phaal *et al.* (2005b)], and each of the other two tools (and many others) can be related to the structure and content of the roadmap. The key benefit provided by a roadmap is to enable visibility and communication, within a logical structure. Roadmaps are 'scaleable', in the sense that they can be developed at various levels, forming an hierarchy of roadmaps. For example, roadmaps can be developed at a high level for a business unit, mapping the evolution of a number of products and associated technology developments, and also in more detail for a specific product, mapping the evolving functionality and performance and the technology development necessary to support it. Clearly the discussion that surrounds this process does support decision-making and consensus, but more formal techniques are typically required to understand and justify key business decisions.

(b) Portfolio methods enable decision-making (project and options selection, and the ongoing management of the investment portfolio). The relationship between portfolio methods and roadmaps depends on the level at which the roadmap is being developed. For the business unit level example described above a portfolio matrix can be useful for deciding which elements (products or technology programs) to incorporate into the roadmap, including future potential options to explore and projects to fund in the shorter term. On the other hand, product-level roadmaps provide a much more detailed picture for each 'bubble' on the portfolio matrix, helping managers to understand the specific context of each option or project being discussed and compared.

(c) Linked analysis grids can be designed in a way such that their structure relates directly to the architecture of the roadmap (i.e. the rows and columns of the grids can be the same as the rows of the roadmap). Linked grids enable the relationships between the themes associated with the roadmap layers to be explored and understood, in terms of both market pull (requirements) and technology push (capabilities), helping managers to understand the causal relationships between layers of the roadmap. In addition, simple weighted scoring methods can be used to prioritize which themes are most important, based on an understanding of the relative benefit and priority of market sectors, customer requirements and product features / performance. The T-Plan roadmapping approach [Phaal *et al.* (2001a)] incorporates linked analysis grids as a key element of the 'fast-start' process.

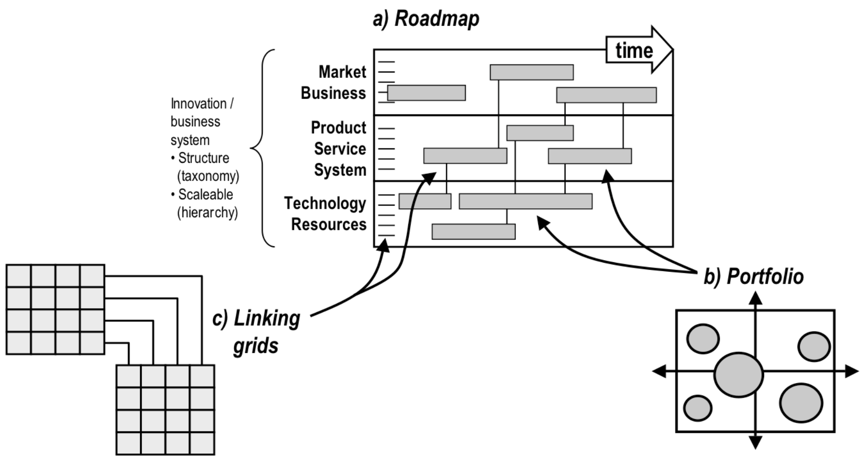

Fig. 4. Roadmapping as a core integrating mechanism, showing the relationship to portfolio matrices and linkage grids

It should be noted that all three of the management tools described above tend to incorporate both commercial and technical perspectives as a core element of their structure and application (i.e. market pull and technology push). This dynamic is a key element of the technology management framework illustrated in Fig. 2, and is considered to be vital for any effective technology management system or process.

The generalization and customization of the roadmapping approach is considered below in more detail, to illustrate key principles of management tool design and application. The focus on roadmapping here is due to its important integrating role in strategic planning, and the understanding developed through its application in diverse contexts [e.g. Phaal *et al.* (2004c)].

3.3. *Generalization and configuration of the roadmapping approach*

Roadmapping is clearly a flexible technique (the range of ways in which the approach has been applied can be easily demonstrated by a search of the internet). The factors that should be considered when designing a roadmapping initiative are considered below, adapting the roadmap architecture and roadmapping process to suit the particular problem and organizational context.

The design of a roadmapping initiative usually requires collaboration between the 'business owner' (the person who has responsibility for dealing with the strategic issue that is driving the need to develop a roadmap) and the 'process owner' (ideally a person with experience in the application of the roadmapping method in a variety of situations). The following issues need to be considered during the design process [Phaal *et al.* (2004c)]:

- *Context* – the nature of the issue that triggered interest in roadmapping needs to be explored and articulated, together with any constraints that will affect the approach adopted, including the following considerations:
    - *Focus:* the focal issue that is driving the need to roadmap.
    - *Scope:* defining the boundaries of the domain of interest (i.e. what is being considered, and what is not).
    - *Aims:* the set of goals and objectives that it is hoped to achieve with roadmapping, in the long- and short-term. As well as the overt business aims, organizational goals are also typically included, such as the desire to improve communication and to understand how the roadmapping approach can be used to support ongoing strategic planning in the firm.
    - *Resources:* the level of resource that the organization is willing to invest in the roadmapping process, in terms of people, effort and money.
    - *Participants:* typically a multi-functional team is required, representing both commercial and technical perspectives and with the knowledge and expertise necessary to develop a well-founded and credible roadmap.
    - *Information sources* – it is important that the roadmapping activity takes account of available information, although there is a practical limit as to the quantity of data that can be accommodated in a workshop, which often forms a key element of a roadmapping process.
- *Architecture* – the structure of the roadmap, in terms of:
    - *Timeframe:* the chronological aspects of the roadmap (horizontal axis), in terms of the planning horizon and key milestones, and also whether past events and activities should be included.
    - *Layers:* the structure of the vertical axis of the roadmap, in terms of broad layers and sub-layers, which is closely related to how the business is structured and viewed (physically and conceptually).
    - A generalized roadmap form is shown in Fig. 5, which illustrates the flexibility of the approach in terms of architecture (time-frames and layers). The structure of the roadmap can be readily adapted to suit the particular organizational and strategic context. Examples of different layers that have been observed are shown on the left in Fig. 5, with a more generalized perspective shown on the right (see Section 4 for further discussion).
- *Process* – the staged set of activities needed to build roadmap content, make decisions, identify and agree actions and maintain the roadmap in the future. The process includes a 'macro' level, in terms of the broad steps needed in the short-, medium- and long-term, as well as a 'micro' level, associated with the short-term and in particular the agenda that will guide the workshop/s.

Lee and Park [2005] have researched the issue of roadmap customization, and have proposed a system based on three key considerations:

- Classification: roadmapping purpose and type.

- Standardization: roadmap forms for product and technology:
  - *Product:* family map, planning roadmap, drive map and evolution roadmap.
  - *Technology:* portfolio map, prospect roadmap, position map and trend roadmap.
- Modularization: planning, forecasting and administration modules.

Lee and Park identify a number of standard graphical 'map' types that include roadmaps and other forms of graphical representations. The maps and roadmaps together combine to provide the range of perspectives necessary to support strategic decision-making and planning, and demonstrate how management tools can be integrated.

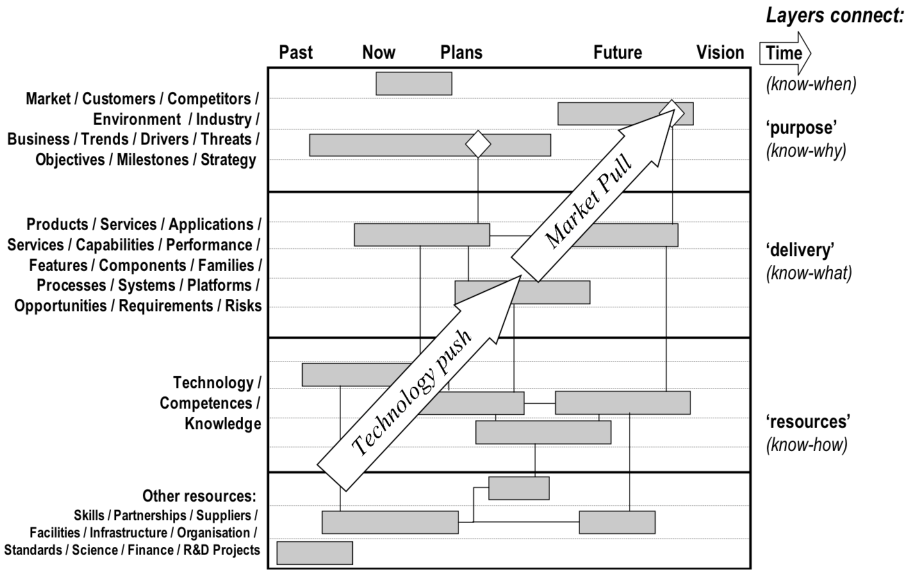

Fig. 5. Generic roadmap [Phaal et al. (2004c)], showing the range of ways in which a roadmap can be structured (examples of layers on the left) and the generalized form on the right; the content of the middle layer ('know-what') is typically a balance between market pull (requirements) and technology push (capabilities)

Figure 6 shows how the roadmapping approach can be adapted to different organizational situations, provided that the generalized form of the method is understood, together with the 'rules' for customization.

The flexibility of the roadmapping approach (in terms of both architecture and process), combined with the broad systems-based orientation that the method encourages, means that roadmaps provide a useful focal point in a strategic planning process, together with an integrating mechanism to enable 'joined up' thinking within the organization, linking together the range of tools, processes and systems that are required to develop and implement strategy. The relationship between roadmaps (which provide a structure within which information can be stored and communicated) and business processes (which generate and use information to support decision making) is illustrated in Fig. 7. Typically the roadmapping process needs to be aligned with key milestones and stage gates within the strategic planning and innovation / new product development processes. The roadmap structure, illustrated in Fig. 6, constitutes a flexible, broad, systems-based business framework that can be adapted as required to provide a core, integrating device within these business processes.

These concepts are explored further in Section 4, where the principles that can underpin the development and application of a strategic management toolkit are considered. These principles are illustrated with reference to the three tools discussed in this section.

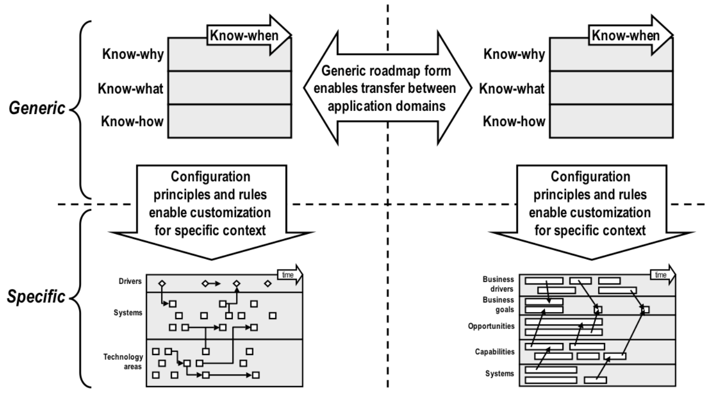

Fig. 6. Illustration of how generic form of roadmap can enable the technique to be transferred between different application domains (for example, company type, sector, strategic context); both the architecture and process need to be customized

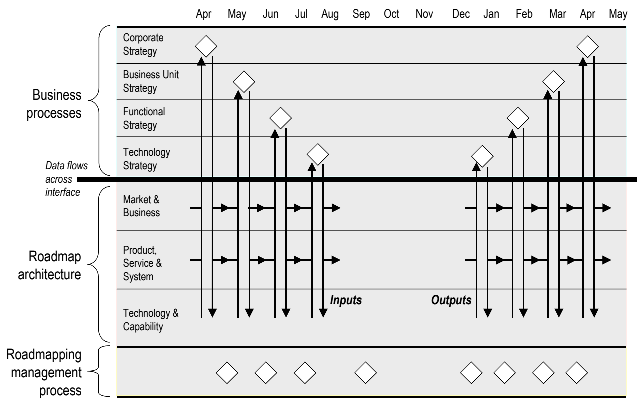

Figure 7. Aligning roadmapping with business processes [Phaal et al. (2005b)], showing how roadmaps provide a repository for strategic information, linked to process milestones and stage gates

4. Generalized Technology Management Toolkit Concept

4.1. Principles of an integrated toolkit

The generalization and customization of the roadmapping approach was considered in Section 3, together with how roadmaps can provide an integrating mechanism with respect to other management tools and processes. The ideas introduced in the previous section will now be extended to propose the concept of a 'universal' strategic technology management toolkit. The vision is that when confronted with a strategic technology-related business decision or issue, a manager or consultant would be able to reach into their toolkit to select the appropriate set of frameworks and tools, which can be adapted, linked together and configured to address the issue in an effective manner. The toolkit would comprise the minimum set of generic tools required to solve the class of problem for which they are designed, together with guidance on how to integrate, configure and deploy them.

A number of issues are still not clearly understood at this stage, and will require further research: How can technology management problems be classified appropriately? What is the minimum set of tools that can be used to build the toolkit? What are the rules for generalizing, integrating and configuring these tools? However, the examples described in Section 3 suggests that this vision may at least in part be achievable with further work, discussed further in Section 5.

Three key concepts that underpin the vision of having a universal strategic technology management toolkit are proposed (see Fig. 8):

(1) *Generalization.* Most management tools need to be customized to a greater or lesser extent when applying them within an organization, depending on the business purpose and context (internal and external – see Fig. 2). The question then arises as to what form does the most generic version of the tool take, and what range of specific forms are possible when applying the tool. Understanding the generic form of a tool enables the approach to be transferred between different applications, which can be quite different in their specific nature, while belonging to the same general class of problem or issue (e.g. strategic planning and innovation for roadmaps). Learning gained from one application can then be translated to another domain.

(2) *Combination (integration).* Most management tools cannot be applied in isolation, as they cannot alone address all of the issues in complex management situations. Tools need to be able to link to other tools (see Fig. 4 and Phaal *et al.* [2005b]), and also need to fit with business processes and systems in place.

(3) *Configuration.* Once the generalized form of the tool is understood, allowing the method to be translated between different application domains, then a set of design rules and guidelines need to be established in order to customize the tool to fit the particular situation being addressed.

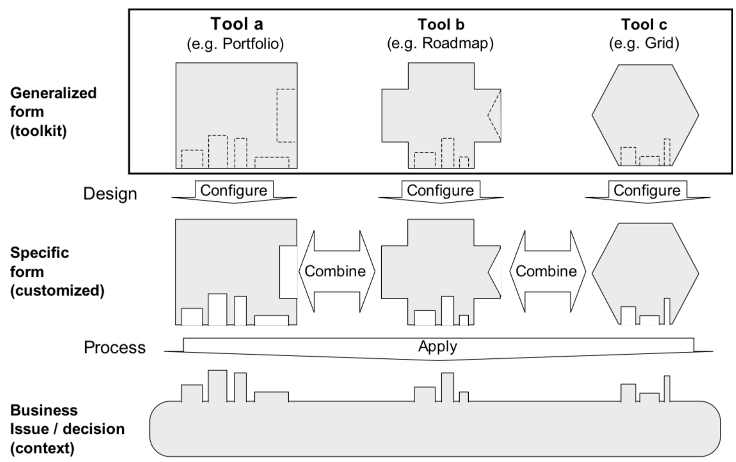

Fig. 8. Toolkit concept, showing how a core set of generalized tools can be configured and combined to fit a particular business context

4.2. Illustration of integrated toolkit principles

The application of the three key concepts described above are illustrated below, with reference to the three technology management tools discussed in Section 3.

Roadmaps

- Generalization: A 'dynamic systems' framework (business model) comprising a series of layers and sub-layers set against time ('know-when'). The layers form a knowledge-based architecture, typically representing business or sector-level innovation systems, providing a framework to capture, store and disseminate key strategic information and relationships. At the broadest level, roadmaps tend to include three generic layers, enabling different perspectives to be aligned:
  - Top: 'purpose' ('know-why'), representing organizational goals and the factors that influence these (e.g. market and business layers in a typical roadmap, including strategic goals and milestones).
  - Middle: 'delivery' ('know-what'), representing the tangible mechanisms through which the purpose is achieved (e.g. revenue generating elements of the innovation system, such as products and services, including performance, functions and attributes).
  - Bottom: 'resources' ('know-how'), including technology and other resources (e.g. competences, partnerships and capital) that need to be acquired and integrated to develop the delivery mechanisms.
- Combination: Roadmaps provide a core integrating focus in the strategic planning process – the relationship between portfolio methods and analysis grids – see below.
- Configuration: The timeframes and layers (roadmap architecture) can be configured to suit the particular context and business issue being addressed, reflecting the particular organizational structures, functional dimensions, terminology and themes of relevance.

Portfolio matrices

- *Generalization:* Relatively simple two (or sometimes more) dimensional orthogonal structures, relating key dimensions of the particular management issue being addressed. The axes are divided into categories, or define variables that may be qualitative, quantitative, discrete or continuous in nature. A number of measures are often incorporated into the portfolio matrix axes, using weighted scoring techniques. The matrix may contain text, providing information or guidance structured by the axes and associated categories, or may be 'empty', enabling the user to explore the relative positioning of various options, or the relationships between the key dimensions and categories [Phaal *et al.* (2005a)]. Typical axes of portfolio tools include:
  - Business benefits, including financially oriented measures (e.g. NPV), together with other factors relating to strategic position, such core competence building.
  - Commercial and technical risks, constraints (e.g. legislation and legal) and costs.
  - Aspects of 'balance' within the portfolio, such as life-cycle, business units, market segments and areas of core competence.
- Combination: Portfolio methods are closely related to roadmaps, in terms of supporting the decisions about which options (e.g. product and technology selection) to incorporate into the roadmap. In addition, more detailed roadmaps can be developed to understand specific context of each 'bubble' in the portfolio matrix.

- Configuration: The axes and measures used in a portfolio tool should be compatible with the business processes and performance measures used within the company, in terms of type, terminology and values (culture).

Linked analysis grids

- Generalization: Relatively simple two (or sometimes more) dimensional orthogonal structures, relating key dimensions of the particular management issue being addressed. The axes are divided into a number of distinct and specific categories, with the number and definition of these categories determined by the user. The grid is empty, providing a structure that enables the user to explore the relationships between the axes and associated categories, and also for prioritization (Phaal *et al.,* 2005a). Grids can be linked together, forming a 'cascade', provided that consistent row and column definitions are used.
- Combination: The rows and columns can be defined in a way that is compatible with the layers and sub-layers in the roadmap, using the same hierarchical structure. Grids can help to understand and manage the linkages between elements and relationships between themes on the roadmap.
- Configuration: Definition of rows and columns of the grids should be compatible with themes relevant to the business (e.g. market segments, product families, functions, technology areas), in terms of both type and terminology.

5. Conclusions and Way Forward

This paper has addressed the issue of how management tools can be designed, developed and deployed in a coherent, robust and integrated fashion, based on definitions and structures described by the 'meta-framework' presented in Section 2. These ideas have been illustrated in Sections 3 and 4, with reference to three widely used approaches for supporting the strategic management of technology (portfolio matrices, linked analysis grids, and in particular technology roadmapping). A vision of a 'universal' technology management toolkit has been proposed, to counter the trend towards the proliferation of management tools and frameworks that can be observed in practice and the literature.

A toolkit that is designed according to these principles would be very flexible and powerful, and armed with such a toolkit, a manager or consultant could address the wide range of strategic technology management issues that can arise in business. The appropriate way in which to address these issues depends on many factors, such as the specific nature of the strategic concern at that time, the sector, size of company, market dynamics, type of technology, pace of change, availability and uncertainty of information, organizational culture and structure, and the personalities and preferences of those involved. Given all of these factors, it is unreasonable to expect that a particular tool will be suitable without customization (it is important to adapt the tool to fit the situation, rather than compromise requirements to fit the available tool). The key concept of tool generalization provides a solution to this difficulty, if a general form of the tool can be identified, understood and described, together with the rules and principles for combining and configuring tools to address the specific issue at hand.

The principles of tool generalization, integration and configuration have been established through the application of the roadmapping approach in a wide range of contexts, focusing on strategic technology management. It is hypothesized that these concepts can be extended to other management fields, such as innovation management, knowledge management and other areas. However, if the vision of a truly university management toolkit (or set of toolkits) is to be achieved, then a number of issues need to be addressed:

- A typology of management problems and issues is needed, including the nature of these problems, the context within which they exist (e.g. business models, market environment and organization), and how they relate to each other and management theory.
- Management tools and frameworks need to be classified, and generic forms established, together with the rules for their customization and integration (with each other and business processes and systems).
- The relationship between the management tools, frameworks and problem domains needs to be established, as various toolkits may be required to suit different classes of problem. The aim should be to develop the minimum number of toolkits required to address the set of problem domains, with each toolkit containing the minimum number required tools, and the relationship between the toolkits understood so that they support and do not conflict with each other.
- Tools and tool sets need to be developed in a robust manner, using appropriate research methodologies, based on well-founded frameworks (underpinned by appropriate management theory), and tested in a wide range of practical management contexts, addressing real-world problems.
- Guidance needs to be developed on how to deploy tools and tool sets, so that they can be used in a consistent and professional manner, and systems should be in place so that experience can be shared and improvements made, supported by communities of practice.

Achieving the vision of a universal management toolkit (or set of toolkits) requires research, support and consensus from both the academic and industrial communities, in terms of research, teaching and practice. Collective action is required to counter the trend towards proliferation of management tools and frameworks, supported by standardization where appropriate. The BSI 7000 series of standards for design management systems[2] demonstrates a mechanism through which such consensus could be achieved.

6. References

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