

# Technology management tools: concept, development and application

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## Abstract

Effective systems for managing technology in complex business environments require integrated sets of management tools and processes, underpinned by well-founded conceptual frameworks. Understanding how such systems operate, and how best to implement them, represents an ongoing challenge, especially considering the multidisciplinary and multifunctional nature of technology management. This paper describes the development of a technology and general management tool catalogue, which focuses on the ‘matrix’ class of tools, classified into four generic types. The practical development and application of such tools is discussed, illustrated by two case examples.  
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## 1. Introduction

Industrial and academic interest in how to more effectively manage technology is growing as the complexity, cost and rate of technological innovation increase, at a time of increasing organisational and industrial change on a global scale. Emerging technologies, such as nanotechnology, biotechnology and information and communications technology provide significant opportunities for enabling innovation, profit and growth, but also present a potential threat to firms’ existing activities.

Technology management is a challenging topic, in terms of both theory and practice, owing to its multidisciplinary and multifunctional nature. A number of disciplines are relevant from the academic perspective, such as science, engineering, economics, sociology and psychology. In business, contributions from both the commercial and technological functions are critical if innovative and successful products and services are to be delivered to the market.

The implementation of effective technology management solutions requires a number of elements to be in place. Firstly, practical tools are needed for supporting management decisions and action, together with techniques for their application. Secondly, management processes are required

for combining tools and techniques to address specific business problems. Finally, conceptual frameworks are needed to guide thinking about technology management, based on well-founded theoretical principles.

It is important that the tools, processes and frameworks that are implemented to support technology management should aim to be robust (theoretically sound and reliable); economic and practical to implement (not too complex or resource intensive); integrated (work together, and link to other frameworks, processes and tools deployed in the business); and flexible (adapt to suit the particular context, in terms of business purpose, market environment, available resources and information, and corporate culture).

## 2. Management tools

A large number of approaches (‘tools’) have been developed by managers, consultants and academics to understand the practical and conceptual issues associated with the management of technology (see, for example, Twiss, 1992; Gaynor, 1986; Cotec, 1998). Such tools can take many forms, including matrices, grids, tables, graphs, checklists, taxonomies, lists and software, together with combinations of these forms. 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?

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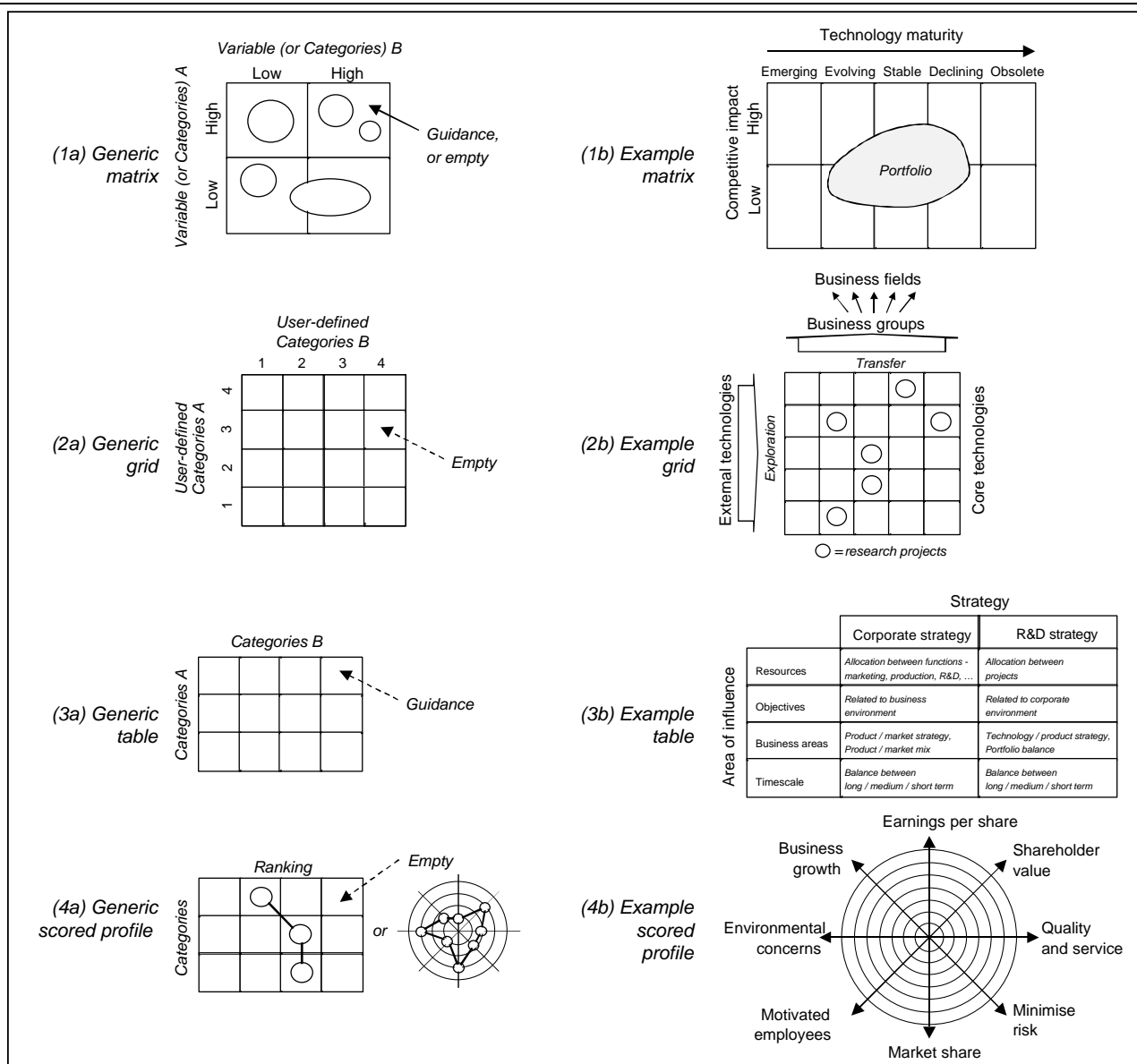
The nature and application of technology management tools have been considered by a number of authors. Brady et al. (1997) define a management tool as ‘a document, framework, procedure, system or method that enables a company to achieve or clarify an objective’. It should be noted that ‘management tools’ in the broadest sense include devices for supporting both action and conception (achievement and clarification, as defined by Brady et al.). More precise definitions for related terms such as ‘tools’, ‘techniques’, ‘procedures’, ‘processes’, ‘models’, ‘maps’ and ‘frameworks’ are provided by Phaal et al. (2001a), with

tools relating to practical application and frameworks to conceptual understanding.

Rigby (1995) has compared overall satisfaction with management and organisational tools to their levels of usage, demonstrating a broad correlation, but with some approaches such as competence-based methods being more widely used than their success seems to warrant. Farrukh et al. (1999) have summarised findings from the literature on technology management tools, together with further research, to define a number of key issues relating to tools, including the characteristics of ‘good’ tools,

#### Exhibit 1

Types of matrix management tools, showing (a) generic forms of matrix, grid, table and scored profile, together with (b) examples: technology portfolio matrix (Dussauge et al., 1992); Siemens’ central research laboratory grid (Chester, 1994. Reproduced with permission of Siemens); comparison between corporate and R&D strategies (Twiss, 1992); and corporate objectives profile (Doyle, 1992. Reproduced with permission of Westburn Publishers Ltd)



and dimensions that differentiate tools. The initial development of the tool catalogue discussed in this paper is described by Phaal et al. (2000); Farrukh et al. (2001).

A number of research programmes have resulted in the publication of practical guides to support the application of technology management tools (such as Gardiner et al., 1998; Farrukh et al., 2000a; Phaal et al., 2001b), and some tools have been collected together in catalogues (Cotec, 1998; Brown, 1997; Harding and Long, 1998). However, there is still progress to be made in terms of understanding the nature and structure of such tools, to enable the development of improved tools and the more effective application of management tools in industry.

Brown (1997) and Farrukh et al. (1999) list some principles of good practice for tool design. Tools should be: founded on an objective best-practice model; simple in concept and use; flexible, allowing ‘best fit’ to the current situation and needs of company; not mechanistic or prescriptive; capable of integrating with other tools, processes and systems; result in quantifiable improvement; and support communication and buy-in.

In addition, Farrukh et al. (1999) identify a number of desirable characteristics of a tool catalogue, which should be: well structured, with clear definition of terms and consistent terminology; complete in terms of coverage (subject areas and sources); implemented in software, delivered over the Internet; focused on practical business application, including useful features such as multiple entry points, intelligent navigation, customisation and expansion; and supported, with provision of services such as updates, advice and feedback.

The particular class of ‘matrix’ tools is discussed in the next section, including a system for classification. More than 850 of these tools and frameworks have been collected

together in a catalogue, representing a wide range of management disciplines.

### 3. Matrix management tools

As noted above, there are many different types of management tools, techniques, processes, models and frameworks. To provide focus for the tool catalogue it was decided to restrict the scope to the particular class of ‘matrix-based’ tools (see Exhibit 1). This class of tool is characterised by simple diagrammatic representations that capture key dimensions of a problem or issue within an orthogonal structure, supporting understanding or decision making, or recommending particular management actions. The classic ‘2×2 matrix’ is a common example of this type of tool, widely used by consultants and managers in business, as well as by academics. Such tools appear in abundance in the literature, although typically there is little guidance included about how to apply them in practice. Based on the large sample of more than 850 matrix-based tools and frameworks collected for the catalogue, described in the next section, four different types of tool have been identified, defined in Exhibit 2.

In terms of the characteristics of ‘good’ tools presented by Brown (1997) and Farrukh et al. (1999), the matrix-based tools have a number of key advantages. Firstly, they are relatively simple, in terms of concept and application, supporting communication and buy-in. Generally the main aspects of such tools can be communicated in the form of a simple diagram. Secondly, matrix-based tools tend to be fairly flexible, in terms of being applicable to particular company situations, perhaps with some customisation required. Finally, provided the axes and parameters are

Exhibit 2  
Matrix-based tool classification

Classification	Description
Class: Matrix-based tools	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. 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
Type 1: Matrices	Categories (if used) tend to be broad—i.e. several broad divisions are included for each axis. If the matrix is empty, the focus tends to be toward enabling the user to explore the relative positioning of various options (portfolio-type approaches). This is the most common type of tool in the catalogue
Type 2: Grids	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 matrix is empty, providing a structure that enables the user to explore the relationships between the axes and associated categories
Type 3: Tables	The axes are divided into a number of distinct and specific predetermined categories. The matrix typically contains text, providing information or guidance structured by the axes and associated categories. This type, although common, has not been the focus of tool collection, although several have been included in the catalogue for illustrative purposes
Type 4: Scored profiles	One axis is divided into a number of distinct and specific predetermined categories, with the other specifying a scale, enabling the user to assess or audit performance in terms of the defined categories. The tool may take the form of a radial graph. This type has not been the focus of tool collection, although several have been included in the catalogue for illustrative purposes

compatible, matrix-based tools have the ability to link together, forming more powerful integrated tool sets.

However, matrix-based tools also have potential disadvantages. Many practical problems or issues cannot be simplified to only two dimensions, and thus matrix-based tools may ignore other important factors. Also, the process whereby such tools are applied in practice typically requires some development or customisation, which may not be a straightforward task. The relative simplicity of these approaches, combined with their abundance, may leave scope for misuse in cases where the theoretical foundations of the tool are not clear, or if the knowledge and skills required for their effective application are inadequate.

#### 4. Development of a tool catalogue

A tool catalogue ('T-Cat') has been developed, incorporating a range of published technology and general management matrix-based tools and frameworks, with the dual aims of producing a tool catalogue that is useful for industry, and improving understanding of the range, purpose, structure and organisation of tools.

A number of principles guided the development of the tool catalogue, building on work by Farrukh et al., 1999. While the focus was on matrix-based technology management tools, the scope of the catalogue is broad. It is recognised that this is a truly multidisciplinary and multi-functional topic, and so coverage of other management areas was desirable. In addition, the catalogue was intended

to be practical in application, so that the user can easily and quickly locate tools relevant to their interest, and simple and economical to develop and maintain.

Two main sources were identified for tool collection, providing broad and fairly comprehensive coverage of business-related literature, with a focus on technology management: (1) technology management oriented material directly available within the Centre for Technology Management in the University of Cambridge, which includes a collection of books, journals, conference proceedings and research archives; (2) the collection of management books in the library of the Judge Institute for Business Studies at the University of Cambridge.

Each tool is presented in a standard format on one page, including a unique identifying code, title, picture, notes and reference. Tools can be accessed by means of a hierarchical topic-based structure (see below), supplemented by an author index. This structure was defined in such a way that the 11 groups and 42 sub-groups of tools were organised into sets of no more than about 20, to facilitate browsing by the user. These groups are defined by the area of management activity that they relate to (intended purpose or application domain)—see Exhibits 3a–k. This approach is less comprehensive than the intentions expressed by Farrukh et al. (1999) and Phaal et al. (2000), because compromises had to be made between structure and simplicity as the size and scope of the catalogue expanded. A standard presentation/graphics software system has been used to store tools in the catalogue, which is capable of writing hypertext mark-up language (HTML) files for publication on the Internet.

Exhibit 3a

Group 1 of tool catalogue (Technology management)

Group 1	Notes—Groups	Sub-groups	Notes—Sub-groups
Technology management (13.7% of catalogue)	Technology management in the business, including portfolio, strategy, acquisition and R&D management	Portfolio methods for strategy and selection	Management and assessment of technology/R&D portfolios or options, linking investment, risk, competence or strength to business benefit (market, financial or competitive reward), supporting strategy, benchmarking, assessment and audit
		Technology strategy—general	General technology and R&D strategy development and deployment, aligning technology development with business goals, in terms of markets potential or product innovation
		Grids for linking technology to the business	Exploration and assessment of current and new technology, in terms of the linkages to markets, business areas, products, competences and goals, for supporting decision-making, strategy and management of R&D
		Technology and the management of technology	Types, classification and structure of technology, and the management of technology, including audit, assessment and protection of the technology base (intellectual property)
		Technology acquisition and sourcing	Technology sourcing and acquisition options, R&D collaborations and alliance types and make vs. buy decisions
		R&D management	R&D management and decision making, including strategy and portfolio methods, linkages to product and market requirements, evolution of R&D in the business, organisational aspects and performance
		Miscellaneous	General technology management

## Exhibit 3b

## Group 2 of tool catalogue (Innovation management)

Group 2	Notes—Groups	Sub-groups	Notes—Sub-groups
Innovation management (5.5% of catalogue)	Innovation management in the business	Innovation and the management of innovation	Types, classification and structure of innovation, and the management of innovation in the business context (markets, products, technology and research)
		Miscellaneous	Innovation in organisations, including internal venturing, entrepreneurship, product and competence development, creativity, performance assessment, change and evolution

## Exhibit 3c

## Group 3 of tool catalogue (Knowledge management)

Group 3	Notes—Groups	Sub-groups	Notes—Sub-groups
Knowledge management (11.4% of catalogue)	Knowledge management in the business, including learning and the management of IT systems	Knowledge and the management of knowledge	Types, classification and structure of knowledge, and the management of knowledge, including systems, processes, organisational context, competences, capabilities and skills, together with applications and approaches
		Learning and organisational development	Management of individual, group and organisational learning and development, including learning cycles, knowledge creation, processes, approaches, strategy, performance/benefit/outcomes, assessment and training
		Management processes and knowledge flows	Processes for managing knowledge and its flow within the organisation for business benefit, including scanning, analysis, creation, translation, sharing, portfolio management and skills management
		Information systems and technology	Management of information systems and technology, including classification and types, systems and environment, together with application in the business: communication, networks, groups and teams, processes, applications, investment, R&D, risk, outsourcing and strategy

## Exhibit 3d

## Group 4 of tool catalogue (New product/service and process development)

Group 4	Notes—Groups	Sub-groups	Notes—Sub-groups
New product/service and process development (6.5% of catalogue)	Management of the development of new products, services and processes	New product development process	New product development/introduction process and its management, including product context: product performance, life cycle, links to marketing and technology and strategy
		Product creation and design	Design and creation of new products, including product strategy: platform management, product dimensions and enhancements and service aspects of products
		Production processes/manufacturing	Production processes and manufacturing systems and technologies, including logistics, and links to product context: life cycle and innovation

## Exhibit 3e

## Group 5 of tool catalogue (Business strategy)

Group 5	Notes—Groups	Sub-groups	Notes—Sub-groups
Business strategy (11.4% of catalogue)	Strategy development and deployment in the business	Portfolio methods for strategy and selection	Management and assessment of business portfolios or options, linking investment, risk, competence or strength to business benefit (market, financial or competitive reward), supporting strategy, benchmarking, assessment and audit
		Structure and process	Types of strategy, process, structure and links to the organisation, together with assessment and evolution of strategy in the business
		Competitive sector/industry assessment	Assessment of the competitive industrial environment, including competitive forces, entry and exit barriers, strategies for emerging and declining industries and benchmarking
		Miscellaneous	Strategy development and deployment, including strengths and weaknesses, generating and evaluating strategic options

Exhibit 3f

Group 6 of tool catalogue (Management/business)

Group 6	Notes—Groups	Sub-groups	Notes—Sub-groups
Management/business (15.1% of catalogue)	General management in the business, including topics such as leadership, e-commerce, sustainability and globalisation	Leadership	Aspects of leadership and the application of power, including governance, control, politics, persuasion and delegation
		E-commerce and the internet	Impact of the internet and information systems on business, particularly e-commerce
		Sustainability and environmental management	Incorporation of environmental and sustainability concepts into business strategy, planning and design processes, including ethics and social issues
		International business	Business in the global environment, including organisational structure, national cultures, global marketing and strategy
		Management and business models	Management, business and enterprise models, including structure, processes and systems aspects
		Miscellaneous	General business management

Exhibit 3g

Group 7 of tool catalogue (Marketing and customers)

Group 7	Notes—Groups	Sub-group	Notes—Sub-groups
Marketing and customers (10.7% of catalogue)	Marketing, including customer, brand and product management	Segmentation of markets and customers	Segmentation of industries, markets and customers, together with assessment and understanding of customers and their needs
		Brand management	Management of brands, together with aspects of advertising, promoting and selling products and services
		Product management	Products, from the perspective of the customer and marketing, including product attributes (such as applications, quality and pricing)
		Miscellaneous	General marketing and customer management

Exhibit 3h

Group 8 of tool catalogue (Behaviour, culture and human resources)

Group 8	Notes—Groups	Sub-group	Notes—Sub-groups
Behaviour, culture and human resources (8.2%)	Management of behaviour, culture and human resources	Organisational culture	Understanding, assessment and management of organisational culture
		Human behaviour	Human and employee behaviour, personality, psychology, modes of thought and action and performance, together with its management
		Human resource management	Nature and scope of human resource management, together with a range of associated topics, such as roles, types of activity, teams, job design and performance

## 5. Development and application of management tools

The development of the tool catalogue described above formed part of a wider research programme, with the broad aims of developing practical management tools and techniques for supporting technology strategy and planning

in the firm, and well-founded conceptual frameworks to support the application of the tools.

Developing management tools that are both practical to apply and well founded in theory requires a research and development process that includes both dimensions. A ‘process approach’ is recommended (Maslen and Lewis,

Exhibit 3i

Group 9 of tool catalogue (Organisation and collaboration)

Group 9	Notes—Groups	Sub-group	Notes—Sub-groups
Organisation and collaboration (5.7%)	Organisational design, including collaboration	Organisational structure and design	Structure and design of organisations, including centralisation, hierarchy, networks, functions and context
		Alliances and other forms of collaboration	Types and characteristics of collaboration, such as mergers and acquisitions, joint ventures and alliances, together with supply chain management and outsourcing
		Miscellaneous	Understanding, assessment and management of the organisation (such as relationships, integration and synergy)



Exhibit 3j

Group 10 of tool catalogue (Change management, planning and projects)

Group 10	Notes—Groups	Sub-group	Notes—Sub-groups
Change management, planning and projects (7.4%)	Change management, including planning and projects	The nature of change	Change management in the business, including the nature, scope, types and causes of change, together with methods for supporting the assessment of the impact of change, and the development of an appropriate response
		Human response to change	Understanding and managing the human response to change in the business context
		Business and change management	Understanding of organisational change and evolution
		Planning and project management	Planning and project management in the business

Exhibit 3k

Group 11 of tool catalogue (General problem solving)

Group 11	Notes—Groups	Sub-group	Notes—Sub-groups
General problem solving (4.3%)	General problem solving and decision making	Nature, structure and classification of problems Approaches to problem solving	Nature, structure and classification of problems Problem solving and decision-making

1994; Platts, 1995; Shehabuddeen, 2001; Phaal et al., 2001a), which emphasises the need to develop management tools in an iterative and controlled fashion, underpinned by appropriate theoretical frameworks. Typically a number of phases are involved during which the tools and frameworks evolve until they are mature and stable:

- *Exploratory phase.* Early testing of management frameworks and tool concepts in practical applications, to test utility and to ensure that key dimensions of the problem are captured.
- *Development phase.* Refinement of frameworks and tools in practical applications, assessing the utility of the approach at each step.
- *Testing phase.* Ensuring the frameworks and tools are stable and useful in a variety of contexts without significant changes.

### 5.1. Case example—R&D project selection

The use of portfolio matrix management tools to support R&D project selection is fairly widespread (many examples are included in the tool catalogue described earlier in this paper). Such approaches are attractive to managers owing to their apparent simplicity. However, their application can be challenging for reasons described, and to get the most value from such methods it is often necessary to customise them to suit the particular context, and to develop a process for working with the tools.

The portfolio matrix shown in Exhibit 4 is used by BAE SYSTEMS to prioritise R&D programmes (Farrukh et al., 2000b). The tool was developed collaboratively with

the key company stakeholders, in a series of iterative workshops, resulting in a tool and associated process that was highly customised to the particular needs of the company. Each of the two tool axes (customer focus and technology benefit/cost) included a set of factors against which potential programmes could be evaluated, using a simple weighting and scoring method. The approach has become embedded within the organisation, and the team that developed it won a ‘Chairman’s Award for Innovation’ for the work they had done.

### 5.2. Case example—integrated strategic planning

Technology roadmapping is an approach that is used widely in industry to support integrated strategic planning, both at the firm and sector levels (Willyard and McClees, 1987; Groenveld, 1997; EIRMA, 1997; Kostoff and

Exhibit 4

R&amp;D project valuation tool (Farrukh et al., 2000b)

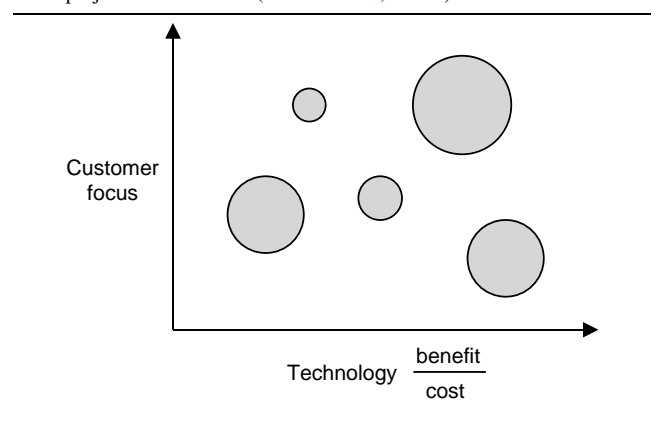
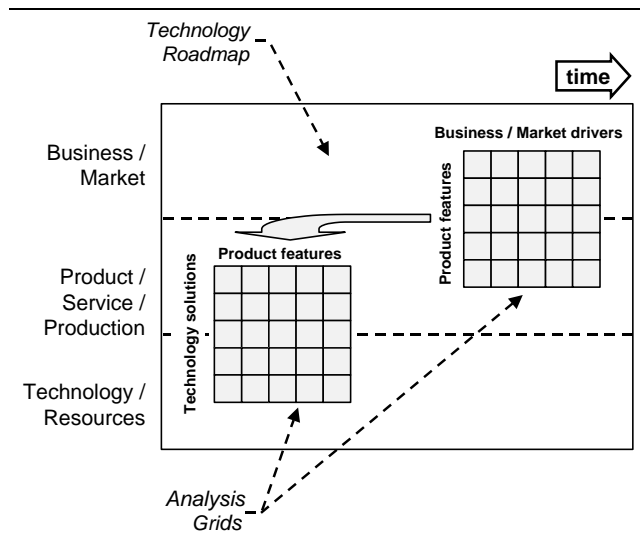


Exhibit 5

Linked analysis grids connect layers of the technology roadmap, providing both structure and a means for prioritisation (Phaal et al., 2001b)



Schaller, 2001). There are many types of roadmaps, but the most common format comprises a graphical framework that shows how technology and product developments align with business and market goals, as a function of time (see Exhibit 5).

A workshop-based ‘fast-start’ approach for initiating technology roadmapping (‘T-Plan’) has been developed (Phaal et al., 2001b), as part of a three-year research project funded by the UK Engineering and Physical Sciences Research Council. The approach has been applied more than 40 times, in a wide range of sectors and company types (in terms of size, product, technology and strategic context).

The technology roadmap provides a framework within which the integrated business strategy can be charted, incorporating all key perspectives (market, business, product, service, technology, resources, etc.). However, the roadmap itself does not include any inherent decision-making elements, and so must be supported by an appropriate process and set of tools to enable the roadmap architecture to be defined (in terms of sub-layers within the roadmap), and product attributes and technology solutions to be prioritised. The T-Plan process includes the use of linked analysis grids to enable this, shown in Exhibit 5. These simple grids, which are similar to the well-known quality function deployment (QFD) method, enable the different layers of the roadmap to be connected. The use of a simple weighting and scoring approach encourages workshop participants to explore and discuss the relationships between markets, products and technology.

The technology roadmapping approach provides a useful integrating mechanism, acting as the focal point for company strategy and planning activities. Many other activities that precede or follow on from the technology

roadmapping workshops may be relevant, ranging from market assessment to change management. For this reason it was decided to develop a general management tool catalogue, described earlier in this paper, to provide a resource for supporting the roadmapping process.

## 6. Summary and conclusions

This paper describes the development of a management tool catalogue, which contains more than 850 examples of the ‘matrix’ class. Collection of these tools has enabled a classification system to be developed, which identifies four generic types of matrix tool: matrices, grids, tables and scored profiles. The development of integrated, well-founded and useful tools, processes and frameworks presents a challenge to managers, consultants and researchers, and an iterative ‘process approach’ is recommended, which has been illustrated by means of two short case examples.

The development of practical and well-founded tools and frameworks requires active collaboration with industry, working together on ‘live’ management problems and challenges. The effective management of technology for business benefit typically requires engagement of both the technological and commercial functions in the firm. Management tools such as the R&D project selection and technology roadmapping approach described in this paper incorporate both technical and commercial aspects explicitly, and it is considered that this is a key attribute for such approaches. Both of these tools require multifunctional workshops to be used effectively, providing a mechanism for bringing these technical and commercial stakeholders together, stimulating communication and mutual understanding. The importance of linking the commercial and technical perspectives is a key theme of the conceptual framework that was developed in parallel with the fast-start technology roadmapping approach (Phaal et al., 2001a), ensuring that an appropriate balance is struck between market ‘pull’ and technology ‘push’.

Future work will focus on expanding the content and functionality of the management tool catalogue, to provide a resource to academics and managers in industry. Research is planned to explore further the theoretical and practical aspects of tool development and application, with the aim of improved understanding of the principles of good tool design, including integration and customisation.

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