Technology management: a process approach

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This paper proposes a framework for the management of technology based on process thinking. Technology management has traditionally focused on product-oriented research and development (R&D) and assumed a linear model of innovation, starting with science and progressing through technology and design to production. It is now increasingly recognized that this linear approach is only one of many and that production as well as product development can be a powerful and protectable source of competitive advantage.

The management of production operations has improved significantly over recent years. Manufacturing companies have begun to replace conventional functional and hierarchical organizations with process approaches to operational activity and management decision making. Such approaches can lend structure and transparency to business operations, link activities more clearly to customer requirements and allow wider involvement of staff and collaborators. It is argued here that the explicit management of product and production technologies, using process thinking, can yield similar benefits.

The paper links traditional views of technology management including R&D management, innovation and new product introduction with competence ideas from strategy and a resource perspective from economics. A preliminary 'process framework' for technology management is proposed, covering the range of activities from identification to protection. The framework is demonstrated, and its potential benefits explored, in the context of a pilot study of manufacturers in the measuring equipment and domestic appliance industries in Europe, the United States and Japan.

Key words: technology management, process approach, research and development, production operations, production technologies, process framework

1 INTRODUCTION

Over the last decade, there have been many attempts to set out the elements of manufacturing systems and understand their influence (**1–3**). In the early 1980s the emphasis was on robotics, flexible manufacturing systems and computer integrated manufacturing. Investments based on these technologies frequently proved disappointing, not because of any fundamental weakness in the technology but because the links between technology and the needs of businesses were not understood (**4**). More recently, attention has turned to operational issues including quality, production control, logistics and new 'lean' models for organizations (**5**). Many companies have achieved substantial improvements in operational efficiency through such developments, while technology has been afforded a relatively low priority (**6**).

The importance of technological competences has, however, been highlighted in recent studies of successful Japanese corporations. The superior performance of such companies as Canon and Honda is linked to their development and exploitation of key technologies (**7**). More sophisticated definitions of 'competence' seek to establish the importance of individual technologies to a business, and the ways in which they can be sustained and protected (**8**).

This renewed interest in the strategic importance of technologies comes at a time when the traditional linear model of a technology development is being called into question. The sequence from basic science through technology, products and processes remains important, but innovation arising from interaction between users, manufacturers and scientists is increasingly recognized (**9, 10**). Also the integration of existing technologies to provide entirely new capabilities, products and processes is seen to have great potential, and the term 'fusion' has been applied to such developments (**11**).

The clear need is to understand the potential of existing and new technologies and exploit them swiftly within the context of the business strategy (**12**). The approach outlined in this paper brings together key elements of traditional technology management thinking, with the techniques of business process analysis and design, drawing on the resource and competence ideas emerging from economics and strategy literature. The proposed framework allows manufacturing companies to assess the nature and level of integration of their technology management activities, and provides a vehicle for transferring 'good practice' between companies and industrial sectors.

2 THE STUDY

The study reported here set out to identify trends in technology management practice. More specifically it sought to propose methods and approaches that would reflect the process thinking which underlies many of the organizational changes being implemented by leading companies (**13**). The work was based on a series of preliminary consultations with manufacturing companies which highlighted the lack of systematic approaches to technology management. The possibility emerged that the 'generic' principles of manufacturing systems engineering, which have led to dramatic improvements in the integration and focus of production operations, might be paralleled by a more 'generic' approach to the management of technology. Given the appropriate models and processes, it might be possible for companies to treat their technologies more like physical stock, to be 'acquired, developed, exploited, and sold' (**14**).

A review of the literature identified a series of significant 'clusters' of work, which influence the field but

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were not explicitly linked. They included competence and capability, research and development (R&D) management, innovation, organizational learning and new product introduction. Critical issues for technology management were identified from each of these 'clusters'. A preliminary process framework for the management of technology was then drawn up with the aim of covering the essential elements of a comprehensive process-based technology management system for a company.

A field study identified patterns of practice in a diverse set of manufacturing companies with the aim of assessing the process framework and populating it with a range of examples. The industry sectors chosen for the study were precision measuring equipment, sometimes known as metrology equipment, and domestic appliances, particularly so-called 'white goods'. These industries were identified as being at opposite ends of a number of important dimensions, including scale, technology and style. The process framework was refined in the light of the results of the field study and an assessment made of the transferability of practices between companies and sectors.

Finally, the 'clusters' of technology management thinking were plotted against the new process framework and the strengths and weaknesses of the new approach reviewed.

3 ELEMENTS OF TECHNOLOGY MANAGEMENT

There are no generally accepted models that give a comprehensive view of the management of technology (**15**). In this section some major clusters of work relevant to technology management are briefly reviewed, highlighting issues that need to be incorporated in any comprehensive framework.

3.1 Competence and capability

Ideas of competence and capability are proving extremely popular in manufacturing companies which seek a fuller understanding of their non-financial assets. Competence analysis attempts to identify the strengths within a business and explore ways in which these strengths can be developed and 'leveraged' into new markets and opportunities (**12**).

In spite of some confusion over definitions, competence and capability approaches seek to represent the 'knowledge' assets of a firm as distinct from the ability to serve customers and respond to competitors. This has the advantage of capturing some of the more intangible aspects of technology and engineering. Much of the work in this cluster is based on case studies of interesting industry examples rather than systematic research. However, recent work has begun to link ideas of competence with the management of core products and patterns of development through successive generations of design (**16**).

Important issues from this area are:

(a) understanding opportunities to leverage technology,
(b) the importance of protecting key technology skills,
(c) technology 'trajectories'.

3.2 R&D management

Research into technology management has traditionally concentrated on research and development. Recurring themes in the literature are the resourcing and management of R&D projects. Classic studies involve detailed analysis of the flow of information and ideas within R&D groups (**17**). More recent contributions identify the need for close integration between the R&D function and other key functions, and argue for more active mapping and prioritizing of projects (**18**). The focus, however, remains very much around the R&D department as a function, rather than the capture and development of technology from all possible sources inside and outside the company.

Important issues from this area are:

(a) linkages between R&D and basic science,
(b) early visibility and assessment of technologies,
(c) product management.

3.3 Innovation

Early work in innovation studies concentrated on invention and entrepreneurial activity (**19**). Modern definitions describe innovation as the full set of activities from the first scientific, technical or market concept through to delivery to the customer. This interpretation recognizes that invention is only one step within a framework of industrial activity and market requirements (**9**). Throughout the innovation activity there are many aspects of team dynamics and the cohesiveness of groups that need to be addressed (**20**).

Important issues from this area are:

(a) iteration between the phases of the innovation activity,
(b) team structures and dynamics,
(c) contextual and environmental influences.

3.4 Organizational learning

Recently it has become apparent that some particularly successful companies in the United States and Japan have adopted highly 'designed' approaches to organizational learning (**21**). They aim to broaden the involvement in technology development beyond the R&D department and key specialists, to include the widest possible range of potential contributors from within a business. With the increasing mobility of scientific and technological ideas, many authors now highlight a company's ability to learn and to reconfigure its competences, so-called 'dynamic capability', as one of its most important assets (**22, 23**).

Important issues from this area are:

(a) wide involvement of company staff,
(b) systematic capture of knowledge,
(c) ability to reconfigure to tackle new tasks.

3.5 New product introduction

Recent developments in the area of new product introduction have been dominated by work on concurrent/

simultaneous engineering, particularly the creation of computer-based systems to support and improve communication between design and manufacturing engineering (24). Detailed studies of the auto industry (25) have described conditions for the effective management of the new product introduction process and a range of tools and techniques to support the activity (26). Many authors point to the effective management of multidisciplinary teams as critical and there is work to develop 'auditing' tools for product introduction (27).

Important issues from this area are:

(a) overlapping of key activities,
(b) the importance of appropriate communication between functions,
(c) speed and customer responsiveness.

4 SOME MISSING LINKS IN TECHNOLOGY MANAGEMENT

In spite of the many contributions to the field of technology management, there are still no agreed frameworks for the subject, and the tools available to practising managers are limited and not well integrated. A recent review of the technology management literature observed (15) that:

> all (the authors) identify the need for a set of instruments, for a methodology, to facilitate technology oriented decision making

and

> none of the current approaches relates to general management concepts, i.e. they do not lend themselves to integration in a unified concept of firm management.

These 'missing links' become more apparent as many of the other areas of a company's activities, such as marketing, operations, finance and sales, become better integrated.

4.1 Technology strategy versus technology management

Leading companies are aware of the importance of technology strategy and of the need to specify how technology will be deployed and managed to support the goals of the business. A variety of tools and techniques are available to support the formation of such strategies, with techniques for technology positioning, competitor analysis, etc. (28, 29). Traditional approaches to technology strategy, however, tend to focus on the identification of critical technologies and the allocation of research and development effort to the most important or promising. A strategy is only of value if mechanisms for its implementation and renewal are in place. For many businesses the rate of change in the determinants of the technology strategy is now so rapid that even annual reviews may be too infrequent to respond adequately to opportunities and threats. The successful implementation of a technology strategy therefore depends upon routines for the day-to-day management of technology, which will allow local decisions to be made where appropriate and ensure that critical changes are 'fed upwards'.

4.2 Lack of frameworks

Given the pervasive nature of technology within manufacturing companies, it is rather surprising that no comprehensive frameworks have yet emerged. Some might argue that technology is not a useful focus of analysis within a company. Indeed, there is some evidence that overemphasis on technology, rather than products and services, had led some companies to develop or acquire inappropriate technologies (4).

Nevertheless, failure to recognize the significance of critical technologies within a business may mean that the full potential of 'knowledge' is not fully exploited. In the worst cases, such critical technologies may be 'lost' through the casual subcontracting of apparently low-cost components (30) or unforeseen technological developments may eclipse a company position. Few companies appear to have in place frameworks and routines to capture the status and implications of technology across the business. They may, at best, be failing to optimize their assets and, at worst, be extremely vulnerable to competitors.

4.3 Language and integration

Technology, perhaps more than any other aspect of a company's operations, remains the domain of specialists. The widespread use of accounting measures and models arises, to some extent, from the difficulty of adequately representing technology in the strategic and operational considerations of a manufacturing business. There is an obvious need for a 'language' which can represent and link the important dimensions of a business, including technology, in the context of customer requirements. Process thinking appears to offer some of the characteristics of such a 'language', particularly if embodied in a framework that reflects the 'natural' issues of technology management.

5 PROCESS THINKING AND TECHNOLOGY MANAGEMENT

The increasing need for speed and robustness in the complex decision making that surrounds product development and manufacturing operations has encouraged the adoption of process-based views of the firm, as distinct from the conventional functional approach.

5.1 Business processes

Business processes represent the flows of information and material from supplier to customer (13). Such processes are independent of conventional functional groupings. Among other benefits, they:

(a) make explicit the normal working practices of a business,
(b) provide a framework for assessing the completeness of process strands,
(c) provide the basis for the analysis of the value contributed by each activity within a process stand and
(d) allow staff to recognize and assess the activities with which they are involved in the context of declared business processes.

So-called business process re-engineering is concerned with methods of mapping, analysing and designing business processes.

5.2 Management processes

Management processes are the explicit or implicit routines that determine how key decisions are made within a business. Typically such decisions will require an input of data and perceptions from various parts of the business and will not normally be amenable to straightforward mathematical modelling. Typical management processes include the formulation of strategies and the analysis and determination of constituent policies. Examples include the auditing of manufacturing strategies (**31**) and the determination of 'competences' (**32**). Among other benefits management processes:

(a) make explicit the way in which key decisions will be tackled without prescribing outcomes [in this way, they are different from 'best practice' or 'generic approaches' to decision making in which a company attempts to follow strategies that have proved successful in an organization that it identifies as comparable (**33**)],
(b) allow decision-making processes to become transparent and accessible to relevant staff within the business,
(c) enable managers to learn and refine a process over time and gain an improved understanding of actions and consequences,
(d) provide established processes that allow decisions to be systematically reviewed as circumstances change.

5.3 Process approach to technology management

The process approach offers the opportunity to overcome a number of the difficulties set out in Section 4. Technology management issues may be made explicit and can be operationalized and integrated into the normal management activities of the firm. Technology management may be seen as a flow through the business, not dissimilar to the way in which operational information and materials flow. The technology management practices may now be identified, and their continuity and contribution assessed, using the business process approach. Again the way in which key technology decisions are taken can be modelled and checked for consistency and completeness, using the management process approach. The business processes and management processes, taken together, provide the means for implementing technology strategy.

The particular requirements of a technology management process model will vary from company to company, and are dependent upon circumstances and company characteristics. However, there are a number of benefits in developing a reference model which is to some degree generic. It provides the opportunity to:

(a) check company models for completeness,
(b) capture and transfer practice and
(c) allow techniques from other disciplines to be drawn into technology management

6 A TECHNOLOGY MANAGEMENT PROCESS FRAMEWORK

The framework (Fig. 1) draws on the established strands of thinking in technology management (see Section 3), coupled with a review of the technology management decisions that companies identify as of particular significance (**34**). By adopting 'natural' labels for key processes it seeks to be readily understandable to industrial managers. Although the model may sometimes be used 'linearly', starting with the identification of technology, it should more appropriately be seen as circular, with entry and exit possible at many points and loops and iterations of various kinds necessary in particular cases. A clear distinction is made between internal and exter-

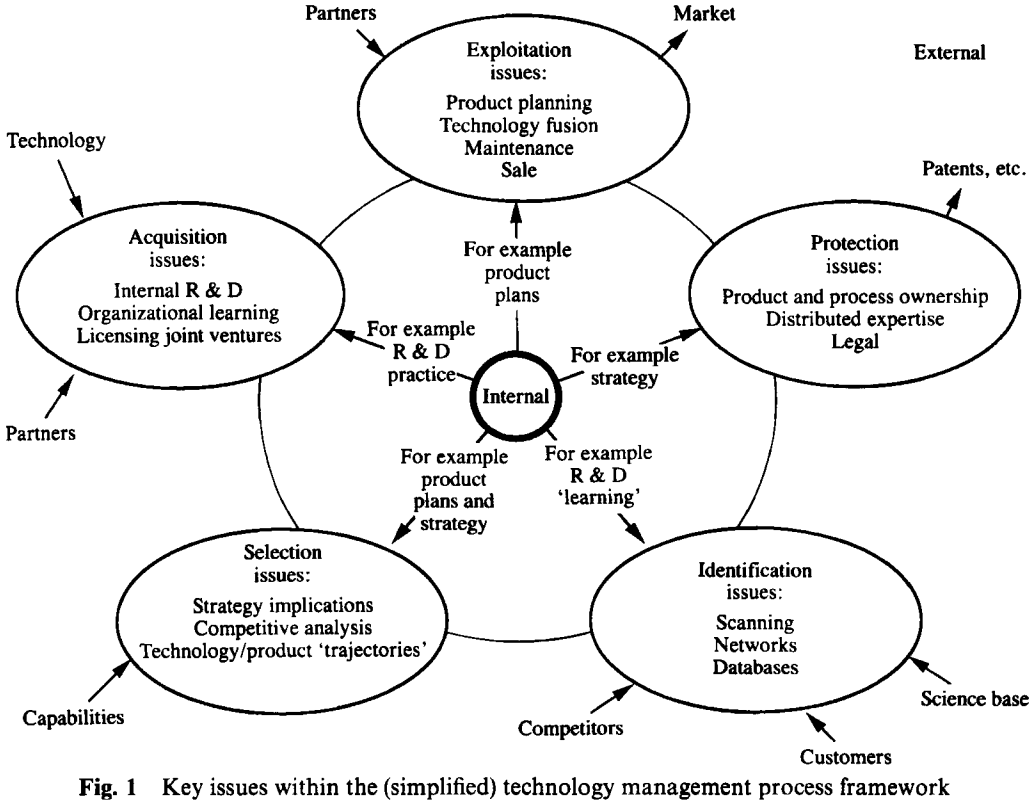

Fig. 1 Key issues within the (simplified) technology management process framework

nal linkages to facilitate the detailed design of processes. Each of the processes will be discussed in turn.

6.1 Identification

Identification involves developing an awareness of all the technologies which are, or may in the future be, important to the business. It includes routines for the systematic scanning of existing and emerging technologies, as well as the capture of internally generated technologies (22). Taking Leonard-Barton's view, it is possible 'to create a virtual research organisation through extensive networking and alliances' in which the traditional R&D organization is dramatically widened to involve many individuals, disciplines and functions inside and outside the company. The identification activity will be supported by access to appropriate external networks and internal databases and communication routes structured according to the company's particular needs.

6.2 Selection

Selection involves the choice of technologies that should be supported and promoted within the organization. Selection is critical as it may result in the commitment of large human and financial resources as well as limiting the company's future options. Selection criteria will be drawn from a variety of sources. The technology strategy will suggest areas of technology that the company should pursue. Competence analysis might suggest those technologies that a company might be well placed to assimilate and develop (11) and product 'trajectories' might suggest appropriate increments of technology development that the company can feasibly manage (16). The essential task is to clearly set out the relative importance of identified technologies to the business. A very useful representation matrix is given by Abetti (35).

6.3 Acquisition

The acquisition activity is concerned with decisions about the appropriate means of acquiring selected technologies and embedding them effectively within the organization. Technologies may be acquired internally, through conventional R&D activities or 'organizational learning'. They may be acquired externally through licensing and joint venture arrangements, with the technology owners or partners who have an interest in developing the technology. Alternatively, they might be acquired through the outright purchase of the business that holds the technology. Both literature and practice provide an extensive background to the various acquisition routes and their strengths and weaknesses. Within a comprehensive process-based model, however, it will be necessary to be explicit about the rationale for choosing a particular acquisition approach and the detailed processes needed to execute the chosen approach.

6.4 Exploitation

Exploitation is concerned with the systematic conversion of technologies into marketable products, or alternatively the realization of their value through sale or joint venture. The technological path from scientific and technological development to marketable product can, with hindsight, be charted relatively easily, but the ways in which a given technology can best be exploited to give the maximum 'return' need to be formalized. Issues of core products, product platforms and the link between technologies, platforms and markets are important (36). The second aspect of exploitation that deserves further attention is the concept of technology fusion (16). Kodama has demonstrated, albeit historically, how leading Japanese corporations have derived radically new products through the integration of discrete technologies to provide quite new functionality. Such exploitation is increasingly important if companies are to recover the high costs of technology investments. Finally, within this process it is most important for companies to have mechanisms to 'maintain' their technologies so that critical technologies do not become obsolete or 'leak away'.

6.5 Protection

Protection is concerned with the preservation of the knowledge and expertise that are embedded in products and manufacturing systems. It may be appropriate, for example, to incorporate product features that do not increase functionality but protect the knowledge that the product represents and the heavy investments that may have been made in its creation. Alternatively, it may be essential to ensure compatibility with established manufacturers' products to access a large market. Computer peripherals are an example. Traditionally, protection has been sought through legal routes such as licensing and patenting. In the proposed framework, processes are required which will ensure that issues of protection are routinely considered during technology development, acquisition and product design activities.

6.6 Characteristics of the process model

The process framework set out above has a number of advantages. Firstly, it is capable of capturing and representing many of the issues highlighted in the technology management literature (see Table 1). Secondly, it provides a 'comprehensive cycle' and forms a reference model on which to base an 'audit' of practice within a company.

Finally, the process model has the advantage of being in harmony with current process thinking in strategy and operations so that technological considerations can more easily be integrated with the other functions within the business. There are clearly opportunities for general progress in the understanding of business processes to be transferred into the routines for managing technology.

6.7 Assessing the model

As a first step in assessing the robustness and potential benefits of the process approach, a representative selection of companies in the measuring equipment and domestic appliance manufacturing sectors was studied. The sectors were chosen to provide a wide spectrum of product and manufacturing technologies. If the process framework could be usefully applied in two largely dissimilar sectors this would provide a first indication of its generality. Companies in Europe, the United States and Japan were visited—essentially to test the applicability of the model, but also to assist in populating it

Table 1 Linkages between key issues in technology management subject 'clusters' and proposed 'process' framework

Technology management		Process approach					
'Clusters'	Issues	Identification	Selection	Acquisition	Exploitation	Protection	Process framework*
Competences and capabilities	Opportunities to leverage technology				✓		
	Protection of key skills					✓	
	Technology 'trajectories'		✓	✓	✓		
R&D management	Linking R&D and basic science	✓		✓			
	Visibility and assessment of new technologies	✓	✓				
	Product management				✓		
Innovation	Integration of innovation activities			✓	✓		✓
	Team structures and dynamics						✓
	Contextual and environmental influences		✓	✓	✓		
Organizational learning	Involvement of company staff						✓
	Systematic capture of knowledge	✓		✓			
	Ability to reconfigure for new tasks				✓		
New product introduction	Overlapping of key activities				✓		✓
	Communication between functions						✓
	Speed and customer responsiveness				✓		

* 'Process framework' benefits are those that arise from having a comprehensive set of processes from identification to protection in place.

with examples of practice from different manufacturing environments.

7 MANAGEMENT OF TECHNOLOGY IN THE MEASURING INSTRUMENT AND DOMESTIC APPLIANCE INDUSTRIES

A pilot study in the measuring instrument and domestic appliance industries could not constitute comprehensive testing and validation of the framework. It could, however, provide some evidence for the claimed benefits of the process approach, particularly in facilitating the transfer of good practice and through the clear articulation of technology issues in the context of business, marketing and operational considerations. The following two sections report upon observations in the two sectors.

7.1 Measuring equipment

7.1.1 The industry

The typical measuring instrument company is made up of small (< 500 employees) privately owned companies often with a strong local skill base and long-serving staff. The companies visited in the context of this study offered a broad range of products from traditional hand-held measuring tools such as micrometers to complex, software-driven, co-ordinate measuring machines. The companies are strongly product focused with stringent demands on accuracy and repeatability within declared limits.

Low-cost manufacture to high-quality standards has been achieved by some companies such as Mitutoyo. The more significant manufacturing requirement, however, is the ability to generate the necessary preci-

sion in an instrument. This frequency depends on specialist craft skills and experience. Instrument companies often have less to gain from general improvements in manufacturing technology and are more concerned with product innovation and integrity.

The environment for measuring instrument businesses has changed dramatically in recent years. An industry traditionally driven by incremental improvements to established products through the application of 'classical' mechanical engineering has to become more 'science' based. Sophisticated scientific knowledge is essential to the understanding of physical effects at the micrometre and nanometre levels. One company described technological forecasting by the extensive and systematic review of scientific publications, but generally very informal approaches are used.

An example of the rapid and radical nature of change is the strong pressure for the application of electronics and software in the full range of measuring instruments—technologies that are far removed from gauge and instrument-making traditions.

7.1.2 Examples of technology management practice in the measuring equipment industry

Mitutoyo actively encourages young engineers to initiate their own projects and to gather the necessary support and knowledge from inside and outside the organization. Involvement in professional engineering societies is encouraged and engineers tend to maintain strong links with their college and university peer group. The senior management of the company see these activities as representing extremely important knowledge 'identification' and 'acquisition' processes for the business, but there is a minimum of formal central technical support.

Nikon has three levels of product development from fundamental (but strategically initiated) discipline-based research to detailed product development. The essential mechanical and optical engineering competences have been systematically developed over many years. Initially the expertise was 'acquired' from outside the company. Now the business has proprietary 'protectable' skills and knowledge and is able to 'exploit' these in a range of applications from cameras and optical instruments to microcircuit manufacturing equipment.

Browne and Sharpe is introducing CAD (computer aided design)-based concurrent engineering. In an industry that has traditionally concentrated on product functionality the design-to-manufacture link is now seen as critically important. The 'exploitation' of product knowledge is seen to depend upon production innovations.

Rank Taylor Hobson has used an advanced technological forecasting approach to systematically scan the scientific literature. The rate of growth of ideas can be plotted over time and judgements made about their likely future significance and the time-scales within which they will have an impact. This 'identification' process can flag-up market opportunities for the company as well as product and production technologies that it might wish to adopt.

The picture that emerges is one of a traditional industry seeking to respond to rapid customer and technology changes. With the possible exception of Nikon, companies did not seek to achieve a comprehensive, systematic and explicit management of their technologies, though in discussion they acknowledged the potential benefits of such approaches. Indeed, all the companies visited described, using various terminologies, elements of technology management processes that were well established within their businesses. As with the examples given above, many of these processes were essentially independent of the industry and company context.

7.2 Domestic appliances

7.2.1 The industry

The domestic appliance industry is, in a number of ways, at the opposite end of the manufacturing industry spectrum to measuring equipment. Products are typically manufactured in large complex assembly facilities with a substantial degree of vertical integration. Volumes are high and companies are often part of larger industrial conglomerates.

The importance of product technology in such businesses is matched by the importance of aesthetic design, low-cost manufacturing and comprehensive sales and distribution networks. The fashion nature of the product has major consequences for the design of manufacturing systems which must be flexible and responsive. Product design for manufacture suggests a modular construction which can be finally configured very late in the production cycle.

There are marked differences between the industries in the major industrial blocks. In the United States, GE of America has been dominant for many years and has successfully responded to a number of challenges from domestic and overseas producers. There has been virtually no Japanese penetration of the American domestic appliance market. Similarly, American makers have virtually no market in Japan, where most of the major electrical companies appear to have 'white goods' businesses. In both countries the situation appears relatively stable. In Europe, on the other hand, there has been a great deal of change with acquisitions by Electrolux and alliances between GE and GEC, Whirlpool and Philips.

7.2.2 Examples of technology management practice in the domestic appliance industry

Sharp make extensive use, at divisional level, of suppliers to 'identify' emerging materials and technologies. It is not uncommon for the company to 'acquire' a new technology by funding a development programme at a supplier. At the corporate level the company regularly calls half-day meetings on emerging topics. Engineers may go to two per year as of right—if necessary against their managers' wishes. This example of an 'identification' process is lightly structured but an integral part of the company's business activity.

GE of America has a highly structured and sophisticated approach to many aspects of technology management. 'Identification' activities are pursued by specialists for each of the key technologies that have been identified through a regular process of strategic review. 'Acquisition' priorities are regularly revisited with a

variety of inputs. Plots of manufacturing problem frequency versus difficulty of resolution assist in determining such priorities. 'Protection' of key technologies is achieved by ensuring that an identified technology owner *and* a second in line are identified within the organization.

Hotpoint in the United Kingdom, along with Creda, form part of the GEC contribution to the joint venture with GE of America. This arrangement allows both sides potential for increased 'exploitation' of their technologies in new markets and through new product ranges. It also affords some 'protection' against hostile bidders.

The picture that emerges is one of an industry with a relatively stable product technology seeking to reduce costs and increase flexibility in anticipation of more volatile market demands. The companies are primarily assembly operations and the ability to manage a supply network is therefore critical. Again, with the possible exception of GE, there was little evidence of comprehensive, structured and explicit approaches to the management of technology. As with measuring equipment, however, many managers believed that such systems would be of great value. Finally, many of the processes in use, as exemplified by those set out above, are more or less independent of industrial context.

8 DISCUSSION

The study described in this paper set out to review frameworks for the management of technology and propose improvements where appropriate. The lack of systematic and comprehensive approaches to the management of technology in many manufacturing companies had already been identified, but there seemed to be few unifying theoretical frameworks or acknowledged comprehensive examples of good practice. By approaching the subject from an operations background rather than a science policy or technology transfer view, the study sought a broader view of technology management and one that might be readily assimilated by industrial managers. A review of the key areas of relevant literature and practice in leading companies sought to structure a framework that could capture the 'knowledge' from a diverse body of research and practice in an operationally useful format. In this section the extent to which the objectives have been met is explored.

8.1 The process framework

The 'operations' approach to the study is reflected in the adoption of the process framework. The benefits of process approaches have been widely reported elsewhere and referred to in the foregoing sections. The framework adopted is not definitive but it does reflect a 'natural' way for managers to think about technology and is readily understandable. It also provides an 'unconventional' perspective on technology, revealing issues that are not normally made explicit but influence both product and production technologies. The 'identification' of product technologies at Mitutoyo and the 'protection' of production technologies at GE are examples. Finally, the process framework is in harmony with many of the management and organizational trends in companies. It offers the opportunity for closer integration of technological considerations into the strategic and operational management of companies and a mechanism for bridging the traditional divide between product and production perspectives.

8.2 Accessing established research findings

Any attempt to design operational frameworks runs the risk of failing to access leading research findings. Such findings are often 'invisible' to practitioners who may therefore miss the results of important discipline-based research. An approach based on project management, for example, may neglect developments in the understanding of organizational learning. The approach adopted here is based on a broad review of the relevant literature and the key dimensions are explicitly accommodated in the proposed framework (Table 1).

8.3 Capturing 'good practice'

The proposed framework lends itself to the capture of existing practice. There is a continuing debate about what constitutes 'good' and 'best' practice. In fact, such assessments are likely to be highly dependent on a wide range of factors, including company structure, technology and industry sector. The study of such contingency relationships might form the basis of a more extensive research programme but the ability of the framework to capture and represent practice in very different circumstances has been demonstrated. The 'identification' routines at Sharp and the 'exploitation' activities at Browne and Sharpe are examples of the capture of practices. These particular practices, and others identified in this paper, are largely industry independent. Even before the contingency relationships are established, the identification of a range of practices can be valuable in providing a 'menu' of options and approaches within a particular element of the process framework. Some examples identified during this study are given in Table 2, with an indication of their potential 'transferability' across sectors.

8.4 Elements of the process framework

The selection of elements for the process framework proposed here is intended to capture the best discipline-based thinking, to be accessible to managers and to be comprehensive. The first two characteristics have, to some extent, been demonstrated, but comprehensiveness can never be fully established. It can be said, however, that all the practices revealed in the field studies could be accommodated within the framework and could provide the first steps in populating the framework with detailed 'sub-processes'. Such refinement will be necessary in the development of fuller 'reference models' which are sufficiently detailed to allow application and tailoring to specific sectors and businesses. A summary of the linkages between 'traditional' clusters of technology management and the proposed process framework is given in Table 3.

8.5 Auditing and tailoring

The framework, insofar as it is comprehensive, can provide a basis for auditing the practices in a business. Such an auditing activity requires a business to be explicit about the approaches it adopts to technology management and to be able to compare them against

Table 2 Examples of technology management practices

Technology management process	Measuring equipment	Domestic appliance
Identification	Scanning of scientific literature of emerging trends (RTH) T	Supplier scanning (Sharp) T
Selection	Customer specification (Mahr)	Headquarters organization of technology 'seminars' (Sharp)
Acquisition	Networking among young engineers (Mitutoyo) T	Supplier integration (GE)
Exploitation	Production innovation to support rapid product delivery (Browne and Sharpe) T	International alliance (GEC) T
Protection	Unique in-house technology developments (Nikon)	Process ownership (GE) T

T = transferable
Company names are given in parentheses.

the declared objectives and strategies of the business. As a result of the audit, the need for improved processes can be identified and appropriate improvements adopted in line with the reference model. These new approaches can be refined over time and tailored to the company's needs. The process approach with its transparency and structure provides a mechanism for organizational learning at operational and managerial levels.

8.6 Further work

The approach presented here is the result of an exploratory study and the conclusions, while promising, need to be validated through more extensive application and testing. There are a number of steps that should be taken to allow the framework to be applied to practical advantage while, at the same time, developing its detail and robustness. Next steps might include:

(a) the development of audit methodology, for use by companies to reveal the ways in which key processes within the proposed framework are conducted within their businesses,
(b) detailed sectoral studies to identify good practice for each of the key processes,
(c) transfer studies to assess the conditions and mechanisms for the transfer of technology management processes between sectors.

Preliminary applications of the framework in telecommunications and scientific instrument businesses in the United Kingdom have yielded very promising results.

9 CONCLUSIONS

In this paper a series of arguments for a process-based approach to technology management has been set out and a possible framework has been described and demonstrated. The need for such an approach is driven by the increasing pressure upon companies to innovate and the lack of established frameworks for managing the technical aspects of innovation. Managing technology is only one strand of a comprehensive process of innovation, but it is, perhaps, the area least well served by operational models.

Table 3 Simplified linkage between proposed technology management process and conventional 'clusters'

	Identification	Selection	Acquisition	Exploitation	Protection	Process framework
Competences and capabilities	✓	✓	✓			
R&D management	✓	✓			✓	
Innovation	✓			✓		
Organizational learning					✓	✓
New product introduction		✓	✓	✓		

The approach has been shown to be capable of representing the key elements of established technology management models, while improving comprehensiveness and integration. To reiterate, the principal findings are:

1. Very few companies appear to have systematic and comprehensive approaches to the management of their technologies, but many believe that such routines would be beneficial.
2. The literature, tools and expertise relevant to technology management are diverse and fragmented.
3. A process-based approach offers benefits in operationalizing technology management practices and making them structured and transparent. These characteristics support organizational learning at strategic and operational levels within the firm.
4. A preliminary 'reference model' has been proposed based around the processes of identification, selection, acquisition, exploitation and protection.
5. The adoption of a process-based 'reference model' provides the basis for internal activities of auditing companies and a vehicle for the comparison of process practice between apparently widely differing environments. Such comparisons have been demonstrated through examples taken from measuring equipment and domestic appliance industries in Europe, the United States and Japan.
6. Further work has been proposed to refine the process framework, develop an auditing methodology and explore contingency issues across industrial sectors.

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