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Understanding technology management as a dynamic capability: A framework for technology management activities

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Abstract

This paper explores the topic of technology management (TM) through the lens of dynamic capabilities theory. Technological changes are continuously creating new challenges and opportunities new product, service, process and organisational development. However, these opportunities need to be captured and converted into value through effective and dynamic TM. This requires a new way of understanding TM that captures its dynamic nature as well as managerial aspects. A TM framework is presented that is based on dynamic capabilities theory, emphasising the development and exploitation of technological capabilities that are changing on an ongoing base. Dynamic capabilities theory is not primarily concerned with fixed assets, but rather aims to explain the way in which a firm allocates resources for innovation over time, how it generates and deploys its existing resources, and where it obtains new resources. This is highly relevant for developing an approach to TM that can explain how combinations of resources and processes can be developed, deployed and protected for each TM activity. A framework is proposed that positions TM activities with respect to the wider business context, supported by a case study to illustrate the value of the TM framework.

Keywords: Technology management; Dynamic capabilities; Technology management activities; Framework; Case study

0. Introduction

This article is a theoretical attempt to understand technology management (TM) using the dynamic capabilities approach. Key concepts are discussed in Section 1, and developments in the field of TM are summarised in order to explain how these have become blurred and confused over the years. The TM framework is then presented in Section 2, demonstrating the context within which TM activities take place, described in more detail in Section 3. The TM framework is illustrated with a case study in Section 4, concluding with an overview of the benefits of the new approach in Section 5.

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1. Definitions and history of TM thinking

1.1. Definitions

A widely used definition describes TM as "a process, which includes planning, directing, control and coordination of the development and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organization" (NRC, 1987). This definition to some extent combines both 'hard' aspects of technology (science and engineering) and 'soft' dimensions such as the processes enabling its effective application (Phaal et al., 2004). However, it does not make explicit distinction between technical and managerial issues associated with TM, and is a rather static definition.

Considering that technological changes are continuously creating new challenges and opportunities for new product development and industrial diversification, these opportunities need to be captured and converted into value through effective and dynamic TM. This, however, requires a new way of understanding TM that captures its dynamic nature as well as the managerial features. An appropriate paradigm or perspective for understanding TM could be the dynamic capabilities theory. In its most elaborate form, dynamic capabilities are the ability to reconfigure, redirect, transform, and appropriately shape and integrate existing core competences with external resources and strategic and complementary assets to meet the challenges of a time-pressured, rapidly changing Schumpeterian world of competition and imitation (Teece et al., 2000).

There are three main reasons why dynamic capabilities theory could enhance the understanding of TM. Firstly, it is not specific technological innovations but rather the capability to generate a stream of product, service and process changes that matter for long-term firm performance (Rush et al., 2007). Secondly, it becomes possible to break with highly aggregated and static models in favour of observing the dynamics taking place in the organisation of firms since the unit of analysis becomes the capabilities (Best, 2001). Thirdly, this theory does not take the market or the product as given, but as objects of strategic reconstitution, emphasising the key role of strategic management in appropriately adapting, integrating, and re-configuring internal and external organisational skills, resources, and functional competences towards a changing environment (Teece et al., 1997). Putting together these three advantages, the dynamic capabilities theory helps to highlight the most critical capabilities management needs to sustain for competitive advantage.

TM can be conceived as the development and exploitation of technological capabilities that are changing continuously (Best, 2001; NRC, 1987). There are many definitions in the literature regarding technological capabilities. Some consider it as an ability to find and use technology to secure and sustain competitive advantage (Rush et al., 2007), while others use a narrower definition of executing all technical functions entailed in operating, improving and modernising a firm's productive facilities (Lall, 1990). A recent study defines TM as the capability to make effective use of technical knowledge and skills, not only in an effort to improve and develop products and processes but also to improve existing technology and to generate new knowledge and skills in response to the competitive business environment (Jin and Zedtwitz, 2008). This latter definition emphasises the difficulty of managing technology compared with developing technology itself, as indicated by Teece (2007): "the invention and implementation of business models and associated enterprise boundary choices involve issues as fundamental to business success as the development and adoption of the physical technologies themselves".

Capabilities might be dynamic or operational (Helfat and Peteraf, 2003). Dynamic capabilities build, integrate, or reconfigure operational capabilities that are defined as 'a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organisation's management a set of decision options for producing significant outputs of a particular type' (Winter, 2000, p. 983). A routine refers to a 'repetitive pattern of activity'. Similarly, competencies refer to activities to be performed by assembling firm-specific assets/resources such as miniaturisation and systems integration. Considering that competence describes routines/activities and capability comprises both dynamic and operational abilities, these two terms are used interchangeably in the literature (Teece et al., 1997). That is why dynamic capabilities are conceived as routines/activities/competencies embedded in firms (Eisenhardt and Martin, 2000; Bergek et al., 2008). Defined as such, technological capabilities consist of both dynamic and operational capabilities that are a collection of routines/activities to execute and coordinate the variety of tasks required to manage technology. Thus, this article will analyse the core activities by which firms perform in order to achieve effective TM.

Dynamic capabilities theory is not interested in fixed assets *per se*, but rather it aims to explain the way in which a firm allocates resources for innovation over time, how it deploys its existing resources, and where it obtains new resources (Teece et al., 1997). This is highly relevant for understanding TM that aims to explain how combinations of resources and processes can be developed, deployed and protected for each TM activity.

The quest of TM becomes the quest of TM activities that will help to build technological capabilities. Therefore, the main elements of a TM system in this article are TM activities. In order for the performance of an activity to constitute a capability, the capability must have reached some threshold level of practiced or routine activity. Each TM activity is related to a certain technological capability, comprising one or more processes/routines/competencies. Process can be described as an approach to achieving a managerial objective, through the transformation of inputs into outputs. So, the term activity is used interchangeably with process or routine even though it refers rather to an aggregate level as an umbrella term to associate it with the concept of capability.

Every firm is a collection of activities that are performed to design, produce, deliver and support its products and services. Individual activities are a reflection of their history, strategy, resources, approach to implementing their strategy, and the underlying economics of the activities themselves. Dynamic capabilities theory does not imply that any particular dynamic capability is exactly alike across firms. While dynamic capabilities are certainly idiosyncratic in their details, specific dynamic capabilities exhibit common features that are associated with effective processes across firms (Eisenhardt and Martin, 2000).

1.2. Historical developments in TM

The TM discipline has a history of over 50 years, as indicated in the special issues of the IEEE Transactions on

Engineering Management Journal in 2004 and Research-Technology-Management journal in 2007 (Roberts, 2004; Larson, 2007). TM has become a self-sustained discipline in the last 20 years with the emergence of specialised professional organisations (such as IAMOT, PICMET and EITIM) and the rapid increase in the number of publications and degree programs in the field that came about after the late 1980s (Allen, 2004; Roberts, 2004; Ball and Rigby, 2005). Initial studies had a limited view of TM activities/processes. The main focus was research and development (R&D) activities in firms. Since then, the discipline of TM has evolved from R&D management to strategic TM, in terms of three dimensions: scope (i.e. R&D, corporate and strategic focus), view of technology (as a tool, system or source of value in the business), and associated issues (product development, development of other technologies and integration of technology) (Drejer, 1996). The evolution of TM is observed to take place from a stable and predictable situation within an R&D department to a discontinuous and unpredictable situation taking place at the strategic level.

If the observation of the changes in the TM discipline is expanded to the period of 1996–2008, it becomes clear that *innovation* has become the leading topic in TM (Cetindamar et al., forthcoming). For example, a study which examined papers published in the journal of *Technovation* has identified two major themes (Nambisan and Wilemon, 2003): technology innovation and TM. The former theme covers 84% of the journal's articles and deals with issues related to technology innovation process or policies that inhibit or stimulate that process. The second theme, TM, takes the form of organisational structures intended to facilitate innovation. Another example comes from a different journal, *IEEE on Transactions on Engineering Management*. The study of co-citations in this journal indicates that academic antecedents of TM fall into one of four themes (Pilkington, 2006): new product development, diffusion, innovation and technological development. In short, innovation as a broad topic dominates the content of important journals in the field.

The innovation theme is pervasive across the board in almost all areas of management as well as in TM. But the dominance of one topic starts to misrepresent the field, resulting in confusion. Two recent articles further illustrate the level of confusion. Firstly, the study of Levin and Barnard (2008) categorises the routines/processes used by technology managers around the innovation processes. Accordingly, TM processes fall into three innovation processes identified by Pavitt (2002) plus an additional category, listed, respectively as follows (Levin and Barnard, 2008): producing scientific and technological knowledge; transforming knowledge into working artefacts, reflecting that technological or scientific possibility does not necessarily imply practical feasibility; matching artefacts with user requirements, whether internal or external; and organisational support routines. This might be an interesting way of classifying TM activities but it can be a source of many misperceptions about TM as well. Secondly, the study of Hidalgo and Albors (2008) gives an account of innovation management tools based on an understanding that innovation management is related to six specific areas in the management of technology innovation: R&D, new product development, commercialisation of innovation, operations and production, technological collaboration and technology strategy.

The increased use of TM and innovation management in an interchangeable fashion is also observed in practice. For example, BP developed an innovation process with its Engineering and Production Technology (EPT) group in 2000 (Brown and Markham, 2007). The EPT set up an "Innovation Board" in order to seek innovative ideas from any member of EPT, which would then be supported to develop the project to the point where it represented enough value for development by a formal R&D programme or practical application by a business unit. As the example shows, TM and innovation management practices are increasingly becoming intertwined. An analysis of the last 50 years (Larson, 2007) shows that R&D central labs are still considered essential in the 2000s, but that these labs are now known as Global R&D Centres or Global Innovation Centres. This confusion is further strengthened with a new business buzzword: open innovation systems (Chesbrough, 2003). The central idea behind open innovation is that in a world of widely distributed knowledge, companies cannot afford to rely entirely on their own research, but should instead buy or license processes or inventions (i.e. patents) from other companies. In addition, internal inventions not being used in a firm's business should be taken outside the company (e.g., through licensing, joint ventures, spin-offs). Described as such, the concepts of innovation, knowledge and technology all become confusing, necessitating a clarification.

In simple terms, innovation is doing something new (i.e. a product, process or service), but this newness is not limited to the world or market, including newness to the firm (Hobday, 2005). Although it is implicit in this definition, the critical issue is the fact that innovation is not limited to technology. Innovations might be organisational and come from many sources, i.e. a marketing or financial innovation. For example, Amazon's offering of book delivery over the Internet was a service-related innovation.

As a further clarification, technology and knowledge are different concepts. Knowledge constitutes not only the cognition or recognition (know-what), but also capacity to act (know-how) as well as understanding (know-why) that resides within the mind (Desouza, 2005). Knowledge management aims to add and create value by more actively leveraging know-how, experience, and judgment resident within and outside of an organisation (Easterby-Smith and Lyles, 2003). It comprises a range of practices used by organisations to identify, create, represent, and distribute knowledge for reuse, awareness and learning. Therefore, the TM field includes aspects of both innovation management and knowledge management, as shown in Fig. 1.

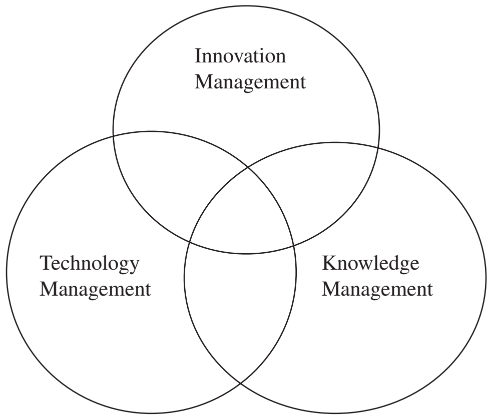

Fig. 1. Boundaries among innovation, technology and knowledge management.

The concern in this article will be mainly technology innovations, adopting the OECD's definition (1995), namely:

> Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation). TPP innovations involve a series of scientific, technological, organisational, financial and commercial activities. The TPP innovating firm is one that has implemented technologically new or significantly technologically improved products or processes during the period under review.

In this definition, 'product' comprises not only manufacturing output, but also all services. This definition clearly highlights how technological innovations are increasingly intertwined with other innovation types and have become more complex. So, it becomes harder to explain the differences between innovation, technology and knowledge management. Therefore there is a need to have a TM framework that will draw the boundaries and clarify the relationships between TM and other management principles, particularly with respect to innovation.

2. The TM framework

While TM studies are abundant, they offer very few widely adopted methods for the practical application of TM principles, and few universally accepted conceptual models or frameworks to underpin them (Phaal et al., 2004). The term framework refers to understanding and communication of structure and relationship within a system for a defined purpose. In this case, the purpose is to understand the TM system. This paper integrates the theory of dynamic capabilities into a TM framework developed by Phaal et al. (2004).

TM activities are needed to achieve technological capabilities—but where do firms exercise these activities? How can we depict the context within which TM activities as a whole take place? In Porter's value chain, TM is considered as a cross-cutting supporting activity to the core business processes (Porter, 1990). In the TM framework presented in Fig. 2, TM activities (identification, selection, acquisition, exploitation and protection of technology) are typically linked to or embedded within core business processes (Phaal et al., 2004): *strategy*, *innovation and operations*. For instance, technology selection decisions are made during business strategy and new product development. The same abstraction takes place in the dynamic capabilities theory where strategy is the main business process. Therefore, the TM framework allows us to conceive that TM activities might operate in any business process, department, or business system level (i.e. project, strategic business unit, corporate) in the firm.

The TM framework indicates that the specific TM issues faced by firms depend on the context (internal and external), in terms of organisational structure, systems, infrastructure, culture and structure, and the particular business environment and challenges confronting the firm, which change over time. Although not explicitly depicted, time is a key dimension in the TM framework, in terms of synchronising technological developments and capabilities with business requirements, in the context of evolving markets, products and technology. Thus the TM framework is in line with the dynamic capabilities framework. While the former focuses on managing technological capabilities, the latter covers all capability types.

An advantage of the TM framework is its applicability to all firms regardless of their size. In general, the critique raised by Hobday (2005) for innovation management holds for TM as well, where most of the frameworks/models implicitly assume firms with leadership status and most are oriented towards large firms (e.g. with R&D departments and elaborate organisational divisions of labour), rather than medium or small firms that might operate with more informal processes (with perhaps no official R&D or engineering department). Many small and medium-sized

Fig. 2. TM framework. *Source*: Phaal et al. (2004).

companies lack R&D departments and they are followers, so the TM framework can be applicable in these sets of firms as well.

The framework is based on the idea that technology is a resource and the technology base of a company represents the technological knowledge that needs to be turned into products, processes and services through technological capabilities developed by effective TM.

The framework emphasises the dynamic nature of the knowledge flows that must occur between the commercial and technological functions in the firm, linking to the strategy, innovation and operational processes, if TM is to be effective (Phaal et al., 2004). An appropriate balance must be struck between market 'pull' (requirements) and technology 'push' (capabilities). Regardless of the trigger of technological change, managers need to link both domains, namely market and technology. Various 'mechanisms' can support the linkage of commercial and technical perspectives, including traditional communication channels, cross-functional teams/meetings, management tools, business processes, staff transfers and training.

The TM framework concentrates on broad-level core business processes: strategy, innovation and operations. The reason behind this is to identify a small set of processes that address fundamental but common business tasks that are critical to achieve the organisation's goals (Porter, 1990). It is clear that organisations design and execute many work practices/routines/activities, most commonly referred to as 'business or operating processes' and each of these processes demand integration of a sequence of related work tasks to accomplish goals that vary a lot from one organisation to another. Strategy, innovation and operations are macro-level processes that subsume a large number of sub-processes, each being shaped within the organisation to address its particular aims and context.

Firms vary widely in size and scope, ranging from a one-person firm to a company with multi-department/multi-country operations. In each case, this basic TM framework can be applied, adapted appropriately for the particular organisational context. After identifying the actual business processes behind strategy, innovation, and operations, managers could integrate TM processes into these business processes. Section 3 will focus on the generic TM processes that can be observed within firms.

3. TM activities behind technological capabilities

Even though there are a number of TM handbooks, they do not offer any clear set of TM activities and in fact, many of them result in confusion on what technology managers need to do, since their coverage consists of numerous managerial tasks that are very general and have no explicit link to specific TM concepts (Dorf, 1999).

This paper considers that the management of technology is a professional task, and thus it focuses on the micro-level analysis of TM in order to understand, particularly how firms carry out their TM activities and what tools and techniques are needed to carry out these activities. So, this study tries to offer a simple and generic TM activities model that helps to develop and implement a set of core technological capabilities. This model aims to understand the dynamic interaction among the elements of a TM system. The firm's knowledge base includes its technological competencies as well as its knowledge of customer needs and supplier capabilities. These competencies reflect individual skills and experiences as well as distinctive ways of doing things inside firms. As Rush et al. (2007) explain: "Capability results from an extended learning process gradually accumulating processes, procedures, routines and structures, which, when embedded, is often referred to in practice as 'the way we do things around here'." Thus, the goal is to identify various common processes/routines forming the key technological capabilities that reflect what goes on within companies. An emphasis is given to processes since the dynamic capabilities approach emphasise the process rather than the asset *per se*.

Although the proposed models do not necessarily cover all possibilities, at least they provide 'a guide to action'. As long as firms tailor the models to suit their own particular circumstances, resources and purposes they can be a valuable input into TM. So, the purpose is to achieve four major goals:

(1) To develop a core set of generic TM activities that can be customised by any organisation (manufacturing or services) and applicable at any level (i.e. R&D unit or business unit) and at any size (small or large firms).
(2) To reduce confusion between TM and other management activities such as innovation.
(3) To avoid linear and limited perceptions on TM activities, highlighting the dynamic links between them.
(4) To show managers as well as engineers and management students who want to pursue careers in TM what skills and knowledge are necessary to manage technology.

3.1. Literature review

Similar to business processes, there are many particular TM activities, but it is possible to identify a small set of processes/routines that addresses the fundamental and common tasks needed to manage technologies and build technological capabilities. As shown in Fig. 2, the technology base lies at the heart of the TM framework (Phaal et al., 2004), on which five generic TM processes operate: identification, selection, acquisition, exploitation and protection (as originally developed by Gregory, 1995)—this study aims to expand this five-process model.

The National Research Council's (NRC) definition in 1987 puts a clear emphasis on understanding TM as a *process*, which can be conceptualised as an approach to achieving a managerial objective, through the transformation of inputs into outputs. This Council further sets the key processes of TM in industrial practice as: (1) the identification and evaluation of technological options; (2) management of R&D itself, including determining project feasibility; (3) integration of technology into the company's overall operations; (4) implementation of new technologies in a product and/or process; and (5) obsolescence and replacement (National Research Council, 1987).

Further analysis of the literature shows that there are a number of lists of TM processes/activities/capabilities (Cotec, 1998; Levin and Barnard, 2008; Dogson, 2000; Roberts, 1988; Rush et al., 2007). As shown in Table 1, many of these activities might have different names but in practice they are actually trying to achieve technological capabilities. For example, what Roberts's study (1988) refers to as 'commercialisation' is in fact in line with what Gregory (1995) calls 'exploitation'. The diversity of language in the academic literature is also reflected in practice. For example General Electric recently renamed its Global Research Centre as the House of Magic (Larson, 2007).

The capability-based model described here is not intended to replace any process names existing in companies or in literature; its main aim is to simplify the TM concept in order to provide a general understanding of what kind of core activities form the body of TM. Choosing the unit of analysis as technological capabilities, this article uses the terminology given in the first column in Table 1. By doing so, the goal is to simplify the links between activities and capabilities. In the proposed model, the activity name is the same as the specific technological capability it aims to develop.

Analysis of Table 1 shows that there might be consensus on a general TM model. The resulting list of activities is particularly a combination of two major studies, namely Gregory (1995) and Rush et al. (2007). The final model has six generic TM activities, as follows:

(1) *Identification* of technologies which are (or may be) of importance to the business. Identification is not limited to technological developments alone, including market changes as well. Identification includes search, auditing, data collection and intelligence processes.
(2) *Selection* of technologies that should be supported by the organisation. Selection is a de cision-making process that takes account of relevant strategic issues, which requires effective assessment or appraisal capacity. This is why selection starts with a good grasp of strategic objectives and priorities developed at the business strategy level, and then it helps to align technology with business strategy.
(3) *Acquisition* of selected technologies. Acquisition decisions are concerned with choices among buy-collaborate-make alternatives, since technologies might be developed internally, in some form of collaboration, or acquired from external developers.
(4) *Exploitation* of technologies to generate profit or other benefits the firm desires to achieve. Exploitation refers to commercialisation but it is a wider managerial function, since the expected benefits might be accrued through implementation, absorption and operation of the technology within the firm. Clearly, after acquisition, there is a need for assimilation that includes technology transfer either from R&D to manufacturing, or from external company/partner to internal manufacturing department. Other example processes include incremental developments, process improvements and marketing.
(5) *Protection* of knowledge and expertise embedded in products and manufacturing systems. To achieve this

Table 1
TM activities in the literature.

Terminology of the article	Gregory	Rush et al.	NCR	Sumanth	Dogson	Cotec	Roberts	Levin and Barnard
Identification	Identification	Search, awareness	Identification, evaluation	Awareness		Scan	Recognition of opp.	
Selection	Selection	Strategy, select-assess			Strategy	Focus		
Acquisition	Acquisition	Acquisition, building competencies	R&D	Acquisition, advancement	Collaborations, R&D, NPD	Resource	Idea formulation, problem solving, prototype solution	Producing knowledge and transforming into working artifacts
Exploitation	Exploitation	Implementation, exploitation	Integration, implementation, obsolescence	Adaptation, abandonment	Commercialization, operation	Implement	Commercial development, utilization, diffusion	Matching artefacts with user requirements
Protection	Protection							
Learning		Learning				Learn		Org support (performance, personnel, all)

capability, processes such as patenting and staff retention need to be in place.

(6) *Learning* from the development and exploitation of technologies. This activity forms a critical part of technological competency; it involves reflections on technology projects and processes carried out within or outside the firm. Clearly, there is a strong link between this process and the broader field of knowledge management.

The list of TM capabilities does not include innovation capability *per se* for two reasons. Firstly, innovation capability is defined as a higher-order integration capability—that is, the ability to mould and manage multiple capabilities (Lawson and Samson, 2001; Wang et al., 2008). The set of TM capabilities is one of the streams of capabilities that are integrated within the innovation system. Depending on innovation type, the required technological knowledge set and the way they interact with each other will differ as well (Tödtling et al., 2008). Secondly, each one of the TM capabilities involves an innovative element in itself. For example acquisition capability is to a large degree a major innovative activity by itself, dealing with product, service, and process innovations in a company.

It is important to remember that the level of TM activities will change over the life cycle of a firm due to many reasons such as market and product diversification or complexities in technologies. The development of a technological capability can be seen as a set of 'punctuated equilibrium' according to Rush et al. (2007). In other words, as firms evolve, they need a richer set of capabilities, a process of moving from low or zero capability to developing minimal capability up to a level of competency, ultimately to becoming high performers. For example, Bell's (2003) competency levels model for technological innovation shows that organisations pass from the point of 'acquiring and assimilating imported technologies' to reach a stage where the organisation is 'generating core advances at international frontiers'. Depending on the capability requirements, firms will naturally adapt their activities to meet the requirements. In addition, depending on where a firm operates (within an advanced or developing economy), technological capabilities of firms and their degree of development will vary a lot, as shown in the case of the mobile phone producers operating in China (Jin and Zedtwitz, 2008).

3.2. Activities supporting TM

Drawing a basic framework for describing the core TM activities is useful for understanding the relationship between TM with other management activities—particularly with project, knowledge and innovation management, as shown in Fig. 3. For example, project management refers to managerial activities associated with all types of projects (e.g. product development). Each TM activity can be considered as a project, hence necessitating knowledge and skills of managing them. In the same manner, knowledge management is a widely used term for managing knowledge accumulated in a company, including non-technology-based knowledge. However, all TM processes are involved with knowledge at some level and they necessitate adopting knowledge management. Innovation management is involved with various innovations being financial, organisational and technological; so, it naturally has much common ground with TM.

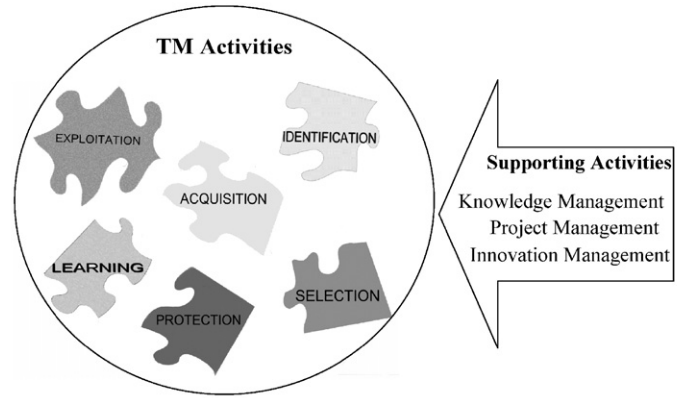

Fig. 3. TM activities and supporting activities.

The need for supporting activities will vary from case to case depending on the company size, objectives and technology characteristics. For example, a company with a few small product development projects will have different needs from project management while a multinational company with multiple-projects will have more structured and formal project management exercises embedded in its processes used to manage technology.

3.3. Non-linearity of TM activities

The TM activities proposed by Gregory (1995) are not explicitly linked with each other. However, the reason behind this is left unexplained. In the TM activities model proposed here, TM activities corresponding to each technology capability are represented as individual processes like pieces of a jigsaw puzzle, as shown in Fig. 3. This representation aims to avoid a linear model that enforces a hierarchy of processes. Further, it also avoids a perception that 'one-model-fits-all', as if all TM activities must exist in an organisation. It is very likely that some companies will focus particular activities at any one time, and that the set might change over the course of time depending on the need and circumstances of the company. Another advantage of the jigsaw puzzle representation is its emphasis on showing TM as an art where technology managers need to identify which processes are needed and find ways of making them work properly together.

The links between TM activities might not necessarily follow a linear relationship. Naturally, there will be process flows among them but it is not possible to generalise the input–output relationships in a deterministic way. Any process might be the starting point that triggers a number of TM activities to take place. For example, in contrast to the traditional product development approach, where the starting point for concept creation is the improvement of functional benefits and the reduction of associated negatives, it is possible to develop research, products and invention ideas from the patent strategy, regardless of whether or not there are functional benefits (Nissing, 2007).

The flexibility of the jigsaw puzzle pieces indicates that each organisation will have their specific set of pieces that show their own reality/picture. If the organisation is a large company with lots of R&D activity, the story/completed picture might include all pieces/elements in the TM activities model. However, if the organisation has no R&D and the innovation at hand is rather an incremental innovation and/or a design, the activities needed will be different, naturally its jigsaw puzzle picture too.

The recent critiques on innovation models focus on two critical concerns (Hobday, 2005): their static nature and their deterministic approach by explicitly indicating the non-linear feature of innovation activities. That is why the recent literature is increasingly interested in understanding the dynamic nature of innovations and technological change (Dercole et al., 2008; Wang et al., 2008). The TM activities model avoids these two critiques at least for TM. And further, the new model classifies TM activities in two categories: primary/core and supporting activities and by doing so it helps draw the boundaries between different disciplines.

4. A case illustrating the TM framework

The characteristics of a TM system based on the TM activities can be easily observed in real-life cases. Farrukh et al. (2004) describe how a TM system was developed within the pharmaceutical company Glaxo Wellcome (GW). This adopted a process-based framework, incorporating aspects of the five TM process model developed by Gregory (1995), developed in a series of cross-functional workshops facilitated by the authors of the paper. The GW TM system builds on active technology networks within the company, with some parallels to open innovation, providing a rich case to illustrate the use of the TM framework presented in this paper.

In early 2000, GW was a multinational pharmaceutical company with revenue exceeding £8 billion and R&D expenditures of over £1 billion. The company decided to implement a TM strategy across the development and manufacturing interface prior to the merger with SmithKline Beecham to form GlaxoSmithKline (GW). This was to augment the New Product Delivery Process that was being introduced.

4.1. TM activities

The resulting TM process is presented in Fig. 4. When this process is compared with the six TM activities, it is observed that neither acquisition nor protection process is explicit in GW's TM processes. Even though names are different, the ‘‘innovate, search and survey’’ step is similar to identification activity; the ‘‘evaluate and select’’ step is like the selection activity; the ‘‘develop and execute’’ step corresponds to both acquisition and exploitation activities; the ‘‘demonstrate benefits’’ step resembles the exploitation activity. The process model is depicted in a linear format, without showing any feedback/learning loops—in this regard Fig. 4 is a simplification of the real situation, aiming to provide an easy-to-understand framework for organising the complex set of TM activities and interactions in the organisation.

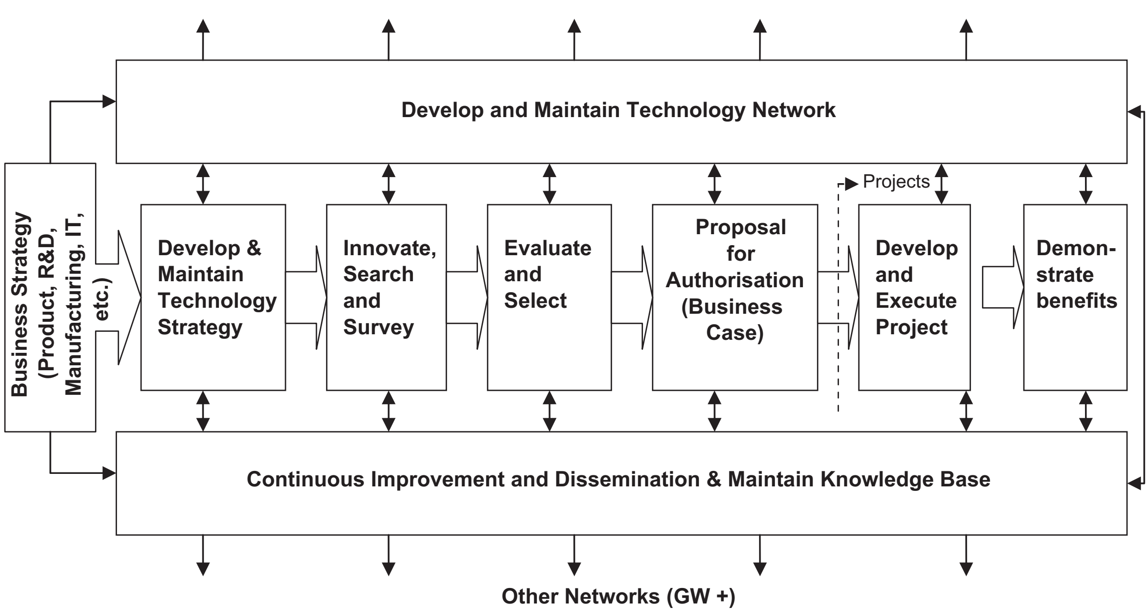

Fig. 4. The technology management system at GW.

4.2. Resources

Technology domains, centred on strategic functions or processes in new product development, have overall accountability for the technology strategy for that part of the business. The technology domains operate through a number of technology networks whose members are experts drawn from global development and manufacturing. Each technology network implements the generic TM process. Interestingly, GW had linkages with extended teams around the expert networks (or communities of practice) that are not only located within the GW but also all across the globe. This opens up possibilities for acquisitions and enriches the content of each TM process carried out in the company.

Domain leaders are one or more full or part-time members of staff, depending on the size and scope of the domain, and have budget responsibilities. A new product development technology steering team is set up, consisting of the technology committee and the leaders of the technology domains. This team reviews and prioritises the overall portfolio of technology projects. Shared databases and IT infrastructures were used to support the networks and the TM system.

4.3. Tools

For each TM activity, inputs and outputs (e.g. information, resources), individual tasks, and a list of information sources and available tools have been developed. In particular, an appropriate methodology was selected for valuing potential initiatives and conducting the portfolio analysis and prioritisation.

The GW case is a very good example to highlight the differences of core versus supporting TM activities as well as the relevance of the TM framework. As Fig. 4 shows, the technology process in GW is embedded in one important business process: the new product development process. This process is further integrated with strategy, project management, knowledge management and networks. The importance of open innovation systems for GW can be seen in a structure that puts high priority on the development and maintenance of technology networks in parallel to its internal TM activities so that the GW can tap into the resources not only within the company but also available knowledge sources in the external environment. Farrukh et al. (1999) do not describe specific tools that are used by GW to support implementation of their TM system, although this would be an important consideration for application (e.g. portfolio and project management).

5. Concluding remarks

TM studies face two main problems: (1) a lack of distinction between concepts and practice in innovation, knowledge management and TM; and (2) a lack of universally accepted conceptual models or frameworks to understand the practical application of TM. This study integrates the theory of dynamic capabilities into a TM framework (Phaal et al., 2004) and offers a model for explaining the core TM activities on the basis of technological capabilities. In this framework, TM is conceived as development and exploitation of technological capabilities on a constant basis. Technological capabilities, being a subset of dynamic capabilities, require a capacity/ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments (Teece et al., 1997). Furthermore, competences or routines refer to activities to be performed by assembling firm-specific assets/resources. Thus, the quest of TM becomes the quest of TM activities that will help to build technological capabilities.

The proposed TM framework offers several benefits in understanding TM. Firstly, it establishes boundaries and relationships between TM and other management principles, particularly with innovation. This is achieved by classifying TM activities into two categories: primary/core and supporting activities that come from other disciplines such as knowledge management. Secondly, it helps to avoid the recent critiques on innovation models that focus on two critical concerns (Hobday, 2005): their static nature and their deterministic approach by explicitly indicating the non-linear feature of TM activities in the framework. Thirdly, the framework is based on the management of technological capabilities, enabling the link between TM activities and technological capabilities to be established. Finally, the use of TM framework helps to develop a core set of generic TM activities that can be customised by any organisation (manufacturing or services) and applicable at any level (i.e. R&D or business unit) and at any size (small or large firms). The TM activities model is highly flexible, highlighting for managers as well as engineers and management students who want to pursue careers in TM what skills and knowledge are necessary to manage technology in order to develop and exploit particular technological capabilities at firms.

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