NORTH-HOLLAND

Technological Threat and Opportunity Assessment

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ABSTRACT

One of the major challenges in the management of innovation is a practical and useful implementation of technology forecasting. This article proposes the concept of aniticpating the technological future, and that a structured approach to this concept could be an invaluable aid to technical decision-making. The notion of technological threat and opportunity assessment is presented as a useful framework for anticipating technological change. This notion is based on a dual approach.

Firstly, a rapidly changing global technological landscape necessitates keeping track of technological developments. However, since we are dealing with innovation (rather than mere invention), the market implications are as important as the technological ones and have to be accounted for as such. Secondly, any organisation could be considered to be technology-based to some or other degree, implying that technologies have the ability to affect the bottom line of the organisation in some way. It is thus required to assess the business impact of such technologies, typically through a technology or innovation audit.

Having assessed specific technological threats and opportunities facing the organisation, an innovation strategy needs to be developed in response to the identified threats and opportunities. Various possible offensive and/or defensive responses should be considered, culminating in the selection and implementation of an optimal strategy. © 1999 Elsevier Science Inc.

Introduction

Achieving market success through technological innovation requires that technology must be managed. The problem is not a static one, however, since technology is a dynamic entity, i.e., it changes with time, sometimes at a very fast rate. Technological change is the primary driver of technological innovation—it is, as mentioned by Ashton and Klavang, both the creator and destroyer of entire markets, companies and industries [1]. One of the major challenges in the management of innovation thus becomes one of managing the technological future.

Although the future cannot be predicted with certainty, the ability to anticipate future technological developments and trends can be a significant competitive advantage,

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Technological Forecasting and Social Change 61, 215–234 (1999)

0040-1625/99/$–see front matter
655 Avenue of the Americas, New York, NY 10010
PII S0040-1625(99)00037-2

both from a company and a national viewpoint. Similarly, the lack of doing so may be very costly. Emerging technologies bring not only new opportunities to grasp, but also threaten to replace old ones. New technologies have often given rise to entire new industries, which more often than not, then lead to the demise of old ones. In an age where technology itself is becoming an increasingly important component of the ability of companies to compete and even survive, the capability of a company, industry or country to identify emerging technologies and take appropriate action is a vitally important issue. There is a growing awareness that the ability to identify emerging technologies as well as the ability to assess the sustainability and demise of mature technologies are important elements in the process of managing technology.

This need to anticipate technological change has been articulated by various authors. Bright, for example, attributes this necessity to the fact that the degree of advance in the capabilities of new entities vis-à-vis their predecessors is often so great that the means, effects, time and costs of doing things are abruptly and drastically altered [2].

Furthermore, the rapidity of the introduction of technical successors seems to be increasing in many fields, leading to shorter marketplace lives. As an example, the average life of a product from Hewlett-Packard's printer division in 1998 was one year and shrinking [3].

Similarly, taking a national perspective, Bloom considers Japan's achievement of a pre-eminent position in world trade involving highly sophisticated manufactured products and its growth to an economic superpower to be largely due to its success in anticipating the technological future by acquiring information from other countries [4].

Technologies such as the internet and other information and communication technologies have lead to a "global village"–causing organisations to face increased competition in the global marketplace. These increased levels of competition reiterate the need to anticipate technological change. In summary, it can thus be said that it is no longer sufficient to be technically competent—organisations need to be able to anticipate technological change in order to take advantage of it [5].

The fact that a need to anticipate technological change exists does not, of course, imply that it is necessarily possible to do so. One perspective could be that technological change is a completely random process, and that any effort to anticipate possible change is thus futile.

However, there is sufficient evidence to prove this perspective erroneous. Firstly, if a specific technological parameter, such as the efficiency of the internal combustion engine or the accuracy of global positioning systems (GPS), is plotted against time, a regular S-shaped curve is often found. This is because the development of a new technology is usually retarded at first until bottlenecks are removed. Due to learning effects, it then grows exponentially. Every technological entity has a ceiling in performance, however, and this is usually approached with reverse exponential curve. The combination of these phenomena produces an S-curve [6]. In this context, technological change can thus be seen as an evolutionary process.

Secondly, when reviewing the history of technological change, it can be seen that when a technology reaches the ceiling mentioned in the previous paragraph, it is often succeeded by a new technology with a higher ceiling. Examples include mechanical typewriters being succeeded by electronic ones, carburetors being replaced by fuel injection systems in car engines and the analogue basis of recording music (LPs, tapes) being succeeded by digitally-based means (CDs). Hence, a more accurate description of technological change would thus be as an evolutionary process, but one that is punctuated by discontinuous change.

Also, technological change can be seen as a response to various forces that drive technological trends or global demands that cause technological change. It is important to note that these driving forces or global demands may be political, social, economic, or technological in nature. For example, new anti-pollution regulations, which are a political response to a global social demand for environmental sustainability, will have far-reaching effects on technology in the manufacturing industry. The assessment of these driving forces and global demands may thus enable technological change to be anticipated (see for example [7]).

Therefore, it has been established that it is not only necessary, but also that it is possible to anticipate technological change. The next logical question therefore becomes how this might be done.

In the next two sections the concept of the anticipation of the technological future is elaborated on and the subsequent notions of technological threats and opportunities are put into perspective.

A structured framework for analyzing technological threats and opportunities is then proposed in section 4. Finally, in section 5 the conclusions and recommendations are presented.

2. Anticipating the Technological Future

The recognition of the need to anticipate technological change is not a recent phenomenon. In the 1900s a technique such as expert opinion forecasting was already being employed with distinguished scientists and inventors such as Edison and Tesla expressing their views on scientific and technical developments in the popular press as well as in books [8].

The development of the discipline of technology forecasting can be seen as a response to this need to anticipate the technological future. Naturally, the field of technology forecasting has developed and evolved over the decades with many new techniques and methodologies being introduced. The 1960s, for example, was a period of significant growth as proven by the launch of several journals on the subject, such as *Futures* (1968), *The Journal of Technology Forecasting and Social Change* (1969), and *Long Range Planning* (1969). A professional society, the *World Future Society*, publishing *The Futurist,* was established in 1966. Hence, during this period technological forecasting was a fashionable approach to anticipating the technological future, particularly with regard to the application of quantitative models.

Even though some skepticism has since then arisen with respect to a strict and dogmatic approach to quantitative trend extrapolation, there is a growing consensus in the management of technology community that it is essential to deploy a structured system to anticipate the technological future. The discipline of technology forecasting has subsequently developed into a much more mature and pragmatic field in which a variety of techniques are used to assess the growth of emerging technologies as well as the mature technologies together with the impacts that these technologies may have on the economy, environment, societal structures and a host of other areas. The objective has thus been to provide a means whereby a systematic approach can be applied to obtain a better view of the technological future, specifically one that is sufficiently sound to provide an adequate foundation for managerial decision support.

Even though no technique can eliminate the unavoidable uncertainties inherent in any consideration of the future, a structured approach to the anticipation of the technological future and the assessment of emerging technologies can be an invaluable aid to technical decision-making.

In order to accomplish this, it is required, however, to go beyond forecasting. There must be a value-added process that transforms the forecast into an actionable decision support system. In order to support decision making in the innovation process, it is necessary to assess not only the technological component, but also the market applications and specifically the technology-market interaction. The notion of *technological threat and opportunity assessment* is therefore proposed as a useful framework to anticipate the technological future in this regard. Howard and Guile [9] corroborate this to some degree when they state that "the essence of a prepared technological manager is the ability to recognise and distinguish among the various ways in which technical change provides opportunities and pitfalls for business."

3. Notion of Technological Threat and Opportunity Assessment

Any organisation continuously experiences a multitude of forces acting upon it, including political, economic, social and technological forces. Although the emphasis is on *technological* threats and opportunities, it has been found that social, economic and political issues tend to affect technology diffusion acutely [10]. For example, the social trend of urbanisation may have significant impacts on, amongst others, the transportation industry as the need for efficient public transportation systems will most probably increase. Likewise, political trends such as new or modified competition policies have been shown to have notable effects on technological innovation [11]. Thus, while the interest is not in social, political or economic trends and developments per se, there is a need for a methodology that could translate these trends and developments into technological impacts.

Furthermore, any organisation could be considered to be *technology-based* to one degree or another. Some organisations are merely users of technology whilst others actually develop and "manufacture" technology as well. Therefore, since any organisation is technology-based to some degree, it implies that technology has the ability to affect the bottom line of any organisation in one way or another. In light of the fact that technologies continuously change, whether incrementally or radically, technological changes will therefore affect the bottom line of organisations—and these changes are often driven by political, social, economic and related issues. In this sense technology related decisions are business decisions and have to be managed as such.

From a technology management point of view it is therefore necessary to develop and deploy management tools that can account for the effect that the dynamics of technological changes can have on the organisation's bottom line. Decision-makers are less interested in the future performance of a specific technology per se, and more interested in the impact that a given technology or trend will have on its business in the future. The key question thus becomes what threats or opportunities do technological changes present for the organisation?

Combining the notion of a rapidly changing global technological landscape with that of a technology-based organisation leads to a proposed two-pronged approach to assess technological threats and opportunities, which is illustrated in Figure 1.

It is evident from Figure 1 that it is firstly necessary to keep track of global developments, utilising a technique known as monitoring and scanning. It should be kept in mind that the concern here is with innovation, which has both an invention component and a commercial exploitation component. The criterion for the success of an innovation is thus also of a dual nature: technical success (invention component) as well as market success (commercial exploitation component). For this reason, it is important not to limit the monitoring and scanning effort to technology, but also to

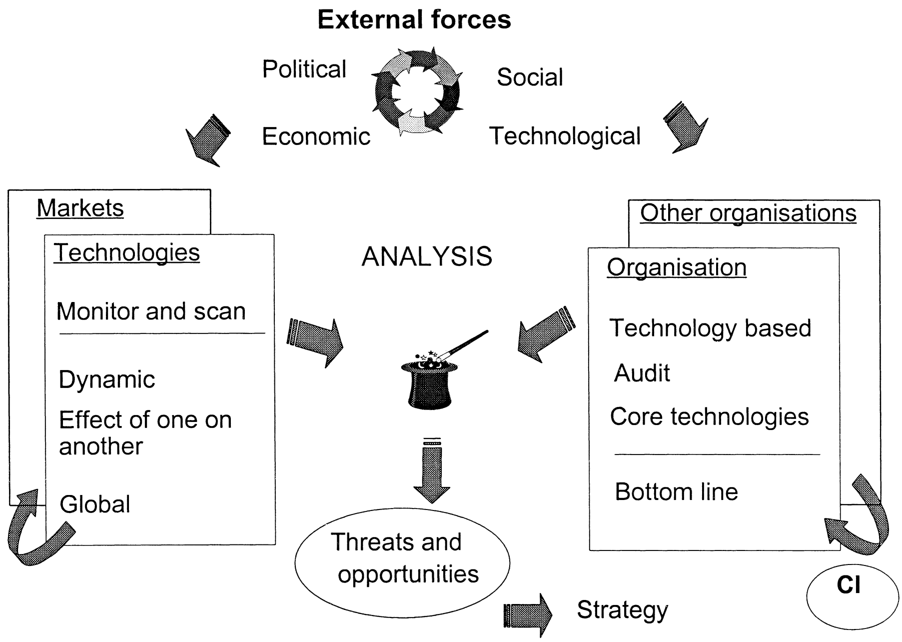

Fig. 1. Technological threat and opportunity assessment.

include technology-market interactions. Technology and market trends should hence be tied together in a two-dimensional domain. This also necessitates monitoring and scanning the political, economic and social landscapes. Although the interest is not in trends in these landscapes per se, these trends could possibly influence technology diffusion as previously mentioned, and hence affect the market component of the success of an innovation.

It is essential to scan broadly, because it is well known that industry-shattering and paradigm-shifting innovations very often come from an entirely different industry than the one on which they eventually have an impact [12]. As an example, the biggest threat to bookstore A may not necessarily be the opening of bookstore B but rather the offering of internet-based services which offer significantly lower prices and a wider range of products. There should hence be a focused effort to determine the impact that a technological innovation in one area, discipline or sector may have on an entirely different or unrelated area.

The second element of the approach to assess technological threats and opportunities comprises an analysis of the core technologies on which the organisation depends, as indicated in Figure 1. From the viewpoint of a technology-based organisation, it is necessary to identify those technologies that may possibly affect an organisation's bottom line. Appropriate technology audit mechanisms need to be developed for this purpose. If a company has a certain strength in steel technology, for example, and steel will in the future be replaced by composite materials for some applications, it will probably affect the company's bottom line. No organisation operates in a vacuum, and hence it is also important to identify other role players that interact with the organisation in question, be they allies or competitors, in the Porter framework [13], substitutes or suppliers, for example. It is thus necessary to gain knowledge about other role players.

Some competitive intelligence practices may therefore be highly applicable in the technological threat and opportunity assessment effort.

Once the situation has been cast into a framework of technological threats and opportunities, the challenge lies in developing a strategy to deal with the threats and opportunities that have been identified. The specific manner in which this is done will differ from organisation to organisation. The identification of threats and opportunities may, for example, be part of a larger process in which organisational strengths and weaknesses are assessed as well (SWOT analysis). Alternatively, the identified threats and opportunities may serve as inputs to a greater scenario building process during which technological issues are considered concurrently with other business decisions or problems. In a generic way it can thus be said that possible offensive and/or defensive responses need to be developed whereupon the most optimal strategy should be selected and implemented.

There are generally considered to be four dimensions of strategy related to technology. The first dimension is the deployment of technology in the organisation's product-market strategy to position itself in terms of differentiation and cost, and thus to gain technology-based competitive advantage. The use of technology in a broader sense in the various organisational activities constitutes the second dimension. The third dimension is the organisation's resource commitment to various areas of technology. Finally, the organisation's use of organization design and management techniques to manage the technology function is the fourth dimension [14].

Having introduced the notion of technological threat and opportunity assessment as well as the generic components of and requirements for such a methodology, the rest of this article will focus on a specific methodology for the assessment of technological threats and opportunities that has been developed at the Institute for Technological Innovation (ITI) at the University of Pretoria in South Africa.

4. Structured Framework for Assessing Technological Threats and Opportunities

Since January 1998, the ITI has been acting as the hub of a research consortium of academic and industrial organisations that have an interest in building and utilising a capacity to assess technological threats and opportunities. The first step in this process was to identify the generic components of and requirements for such a methodology, which were described in the previous sections. The next logical step was the development of a specific methodology, which is presented here. It should be stressed, however, that this methodology represents the first output of an iterative and ongoing research process and should by no means be regarded as fully comprehensive or conclusive. Various aspects of the methodology could indeed be improved and augmented. Thus, whilst the methodology presented here is certainly not a panacea for the problem of anticipating the technological future, it is regarded as a step in the right direction and is meant to serve as one possible conceptualisation of how to assess technological threats and opportunities.

The methodology proposed is illustrated schematically in Figure 2 . Although they are not shown graphically in Figure 2 for the sake of clarity, a multitude of feedback loops exist among the activities indicated. As an example, the objective of the effort will, at first, be largely exploratory with personnel having little or idea of what they are looking for. However, as the process progresses (e.g. during the analysis activity) several factors that could provide warning that a specific development or trend is evolving in a certain direction might be encountered. In this regard, Twiss [15] proposes the compila-

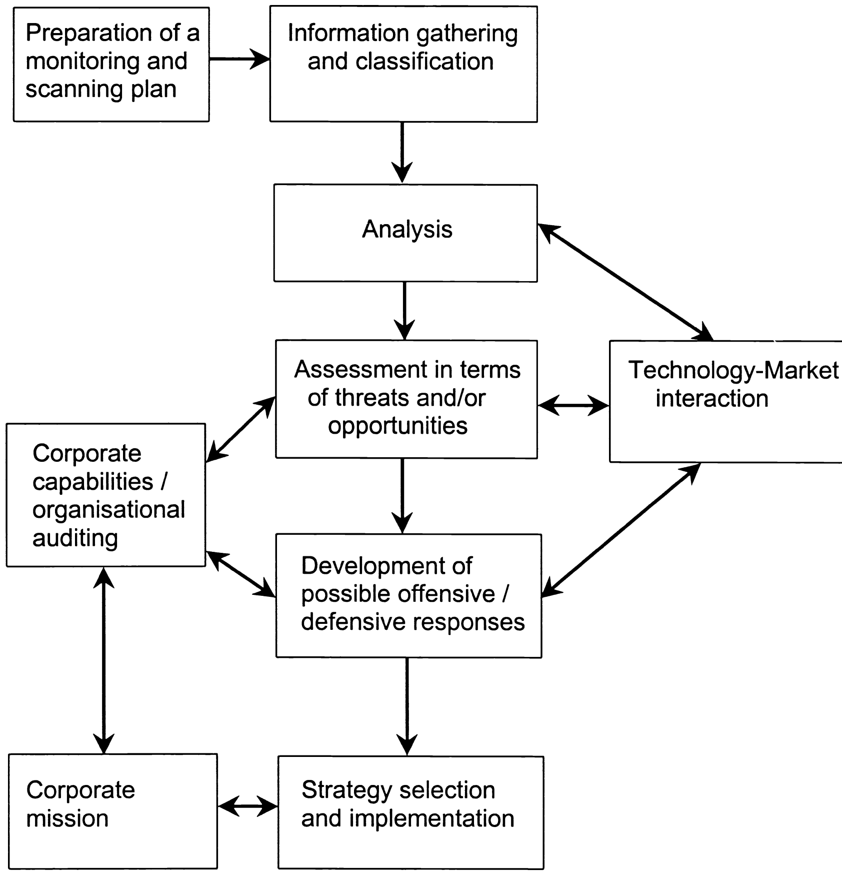

Fig. 2. A structured framework for assessing technological threats and oppotunties.

tion of specific "Factors to Watch" which should be looked out for by personnel in future (p. 127). Hence, as information is gathered, these factors or warning signs are fed back to the earlier activities in the process and the effort becomes more focussed.

In the subsections that follow, some of the activities indicated in Figure 2 will be discussed in more detail. The first three activities, viz. the preparation of a monitoring and scanning plan, information gathering and classification as well as the analysis activity, are typical of the monitoring and scanning technique that is utilised to keep abreast of developments on a global scale. The discussion will be commenced with an examination of the preparation of a monitoring and scanning plan.

4.1 THE PREPARATION OF A MONITORING AND SCANNING PLAN

This planning activity is essential for the management of the overall monitoring and scanning process. Specific aims and objectives for the effort should thus firstly be determined. Resources required should then be established and appropriated. A variety of aspects are of significance and should be considered during this activity. Three issues have been chosen to serve as examples of these aspects to be considered, namely the sources of information, the organisation of monitoring and scanning staff and the storage of gathered information.

TABLE 1
Examples of the Sources of Information

Published sources
Annual company reports
Articles in the business press/technical journals
Electronic databases
Company brochures and internal newsletters
Announcements of new equipment, facilities, or other resource commitments
Patent awards
Advertising literature
Symposium or conference proceedings
Reports of governments agencies
Professional society reports
Internet homepages of organisations
Other internet resources
Unpublished sources
Speeches by management or other role players
Expert opinions
Reverse engineering and benchmarking
Industry contacts and friends
Trade shows, exhibitions, tours, or conferences
Court appearances, testimony, lawsuits, and antitrust information
Customers
Suppliers
Unions
Subcontractors

Sources of information about competitors, technological entities and the industry in general could be classified into published and unpublished sources. Table 1 provides some examples for both of these categories.

In terms of organising monitoring and scanning staff, a first issue that springs to mind is their backgrounds. On the one hand, personnel with expertise in a specific area could be advantageous, as they might be able to provide the most comprehensive picture of developments or trends in a specific field. However, it has been mentioned that the innovations that have the greatest impact, causes a paradigm shift or restructures an industry very often originate from an entirely different industry than the one that they eventually have an impact on. In this regard, generalists as opposed to specialists might have more insight as to the "big picture." A situation of "can't see the forest–too many trees" is one to be avoided. Perhaps a less specific criterion for the selection of monitoring and scanning personnel, namely whether they would be able to contribute to a comprehensive yet selective picture of the nature and extent of technological change, is the most fitting [16].

Another issue related to monitoring and scanning personnel is their location. The most viable option might be to locate the effort in the corporate planning office and to involve functional specialists from the various departments, thereby aiming to consider all relevant issues in the technological, social, political, and economic environments. The final example of aspects to be considered during the preparation of monitoring and scanning plan is the storage of information, which in turn encompasses such issues as the mode and the period of storage.

In terms of the physical mode of storage, a strong case is to be made for an electronic database. While a manual mode of storage, i.e., files and cabinets, may seem adequate at first, the volume of information generated by the monitoring and scanning

TABLE 2
Four Different Modes of Information Gathering

Modes of information gathering	Procedures	Scope	Purpose
Undirected viewing	Informal	Panoramic	The purpose of the viewer is exploratory and the procedure is unstructured and informal
Conditioned viewing	Formal	Panoramic	The purpose is still exploratory but the procedures more structured—the scanner is conditioned and on the lookout for particular features
Informal search	Informal	Finely focussed	The purpose is to learn more about a specific area but without following a highly structured investigatory procedure
Formal search	Formal	Finely focussed	The purpose is to find detailed information through active and directed probing

process is likely to be such that this will soon prove to be inadequate. Advantages of the electronic database includes intelligent search facilities and the more efficient determination of links between items and cross-impacts between developments. For example, specific fields in the database files might be "Warning signals" or "Possible impacts" and any new information gathered and scanned into the database could then automatically be checked against this data.

Living in an age of information overload and change at ever-increasing rates, the length of time that items should be stored for should be reflected on. This ties in with the reasoning in the previous paragraph where a case was made for an electronic database. The database could assist greatly in the management of information by automatically deleting items after a specific period of time. Alternatively, the number or date of links and cross-references could be checked and used as a criterion for the deletion of items.

It is reiterated that the aspects discussed above were merely meant to serve as examples of issues to be contemplated during the preparation of a monitoring and scanning plan and should not be regarded as exhaustive. The issues that need to be considered will obviously differ according to the requirements of a specific organisation. In the subsection that follows, the second activity of the methodology shown in Figure 2, namely information gathering and classification, will be deliberated on.

4.2 INFORMATION GATHERING AND CLASSIFICATION

As previously mentioned, the initial objective of the monitoring and scanning effort will be mostly exploratory with personnel having little or no idea of what they are looking for. However, as the effort progresses and information is gathered and analysed, specific issues will be identified and further examined. Hence, the mode of information gathering changes as the whole process becomes more focussed. Aguilar [17] mentions four different modes of information gathering which Van Wyk [18] classifies in terms of their procedures and the scope of the effort. These four modes of scanning are illustrated in Table 2.

Each of the successive modes represents a higher level of attention and requires more resources. Different areas of attention will of course be examined through different specific modes, and a particular area of attention may move up or down these modes according to such factors as the budget and other resources available, the urgency in gathering data and the envisioned impact of a development or area of attention on the firm.

It was stated during the discussion on the various sources of information that the volume of information likely to be generated by the monitoring and scanning effort is immense. A very important objective for the information gathering activity is therefore to target *relevant* pieces of information so that analysts need not wade through mountains of materials in subsequent steps in the technological threat and opportunity assessment process.

A very important step in a comprehensive monitoring and scanning effort is to construct a suitable framework for the classification of technologies. A valid question at this point might be why we would want to classify technologies or any other entities for that matter. Firstly, entities are classified to enhance our comprehension of them and to provide a means of differentiating between groups of entities. Secondly, it is interesting to note that a strong phenomena in technological evolution is the notion of technological fusion, where various technologies come together to produce a new technological system far more advanced than any of its predecessors [19]. Hence, classification assists us in studying patterns of interaction between various technologies.

The mere grouping or classification of technology is a relatively new approach to technology monitoring and scanning and therefore standard classifications have not emerged yet. Although attempts have been made to classify technology by scholars in this field, no conclusive workable classification has yet emanated [16].

In the establishment of a suitable classification framework, several programs on a national level, such as the foresight studies in South Africa and abroad, were considered, as well as some examples from the management of technology and strategic management literature. The national foresight studies were examined since they tend to utilise extensive, comprehensive and all-embracing classifications. Nevertheless, it should be kept in mind that these classifications were mostly compiled with the purpose of being easily interpretable and unambiguous.

It is important to recognize that the classifications used in foresight studies mostly concentrate on those technology fields deemed to be of most importance to the specific country that performed the foresight study. However, they do provide a good indication of how technologies could be grouped or classified under aggregate headings. It is also important in that the classifications in themselves give an indication of technological trends and major thrusts.

The objective was to keep the focus in the early stages of the monitoring and scanning process as generic as possible, without adding any country, company or industry specific biases. Hence, the combination of elements from several of the frameworks examined resulted in the classification shown in Table 3.

At first glance, the framework shown in Figure 3 might seem simplistic. However, it should be evident that a clear distinction can be made between the different technology groupings without overlooking any specific technological. Furthermore, the idea of the classification is to determine the succinct technology groupings rather than go into detail on specific technological entities. The level of detail in the classification is limited to that of the main technology categories. From these main categories, the levels of detail can be extended to two or more lower-level categories.

TABLE 3
The Classification Framework Utilised

General Classes	Technology Categories
Innovative Technologies	Information and Electronics
	Materials
	Life Sciences
Industry Supporting Technologies	Energy
	Automation and Manufacturing
Social Infrastructure Technologies	Communication
	Transportation
Environmental Quality technologies	Environment

Having examined several classification frameworks, the discussion in the following subsection focuses on the analysis of information that has been gathered and classified.

4.3 ANALYSIS

This is one of the most important activities in the process of assessing technological threats and opportunities. The objective in the analysis stage is to process the information that has been gathered and classified. Possible trends and future events that may be of significance need to be identified. The analyst will thus form certain hypotheses of what the various signals may mean and what impacts they may have. In this regard, it is of paramount importance to identify factors that may serve as either confirming or denying evidence for a particular signal or trend.

These factors that should specifically be watched for are then fed back to the earlier stages of the process, and the mode of scanning will thus be *conditioned viewing* in terms of the framework discussed in the subsection dealing with information gathering. To recapitulate: the scanning process will still be exploratory but the procedures will be more structured as the scanner is conditioned and on the lookout for particular features. As an example, an article describing the significant lowering of ISDN rates by a telecommunications company may serve as confirming evidence or an enabling factor for a hypotheses that videoconferencing may soon increase in importance and could be a threat to airline companies as business travel is reduced.

It is important to note that the analyst will, at this position, have access to a myriad of information. The challenge is to separate the wheat from the chaff. The most significant items should therefore be identified and the trends or impacts they foreshadow deciphered.

It was felt that it is not optimal to have a threat and opportunity assessment effort that is based on a generic approach and which is applied to all industries or companies. Not all methods are equally effective in every sector or industry. The electronics industry, for example, is characterised by a significant degree of patenting activity. In this industry, patent analysis techniques (one of the correlation methods to be described shortly) will be very effective. In some other industries, with other or no forms of intellectual property, patent analysis would not be an optimal analysis technique.

Similar arguments could be made for each of the various techniques. It has been noted that "If the only tool one has is a hammer, every problem seems to look like a nail." This is certainly a scenario to avoid. What has thus been proposed is that several possible techniques be grouped into specific models or families of techniques. From this toolkit of methods, those deemed most appropriate for a specific organisation, situation and industry sector can be selected and applied. With such an approach, the methodology can be customised to every specific situation and an optimal solution can be obtained for each individual problem.

The six families or groups of analysis techniques are causal models, correlation methods, competitor analysis, an analysis of technological artifacts, industry analysis as well quantitative technology forecasting and trend extrapolation. Although in-depth discussions of each of these groups are not possible here, each will be briefly commented on.

Thompson [20] states that various sources of uncertainty affect technical progress. One of these is generalised uncertainty, which stems from a lack of understanding of cause-effect relationships in the organisation's environment. *Causal models* specifically endeavor to improve that understanding. The aim here is thus to relate technological change to the factors that produce it. Instead of starting out by examining technological change or specific trends, we look at the forces that produce the change or are driving the trends. This is a much more reliable way of examining the dynamics of technological change, as the factors that cause change are themselves not volatile over the shorter term. Having identified the generic issues that are most likely to shape future technological trends in the various sectors, industry responses and technological issues that can provide solutions to the problem of meeting demands can then be evaluated. The Institute for Prospective Technological Studies (IPTS) has utilised this principle in some of its efforts [7].

Correlation methods refer to any situation where some relationship between an instance of technological change and some other factor may exist. This other factor may, for example, be an experimental employment of the technology, counts of publications or patents, or an economic factor. Specific techniques within this group include lead-lag correlation or precursors and bibliometrics.

Porter states that a country, company, or research group needs to understand its position in relation to its competitors to exploit potential opportunities and to avoid damaging head-to-head competition [21]. Hence, utilising a group of techniques labelled *competitor analysis*, current and potential competitors need to be identified and aspects such as their activities, products, and R&D expenditure should be analysed.

The objective of the *analysis of technological artifacts* is to try to anticipate possible changes in technological artifacts (product, processes, services, etc.) that may occur. Hence, the aim is to find answers to questions such as how an artefact could be improved, how the next-generation of artifacts may look and what changes (such as operating principles or applications) may take place. Specific techniques such as morphological analysis are utilised and issues examined include the possible merging of technologies, possible attribute substitution ([15], p.94), and new applications of existing technologies.

Industry analysis considers indicators that might provide a warning of possible change in the industry and which could lead to disruptions or paradigm shifts. One set of indicators is specific types of activity within an industry, such as the formation of alliances or joint ventures. Other issues examined include the maturity of technologies within an industry.

In the *quantitative technology forecasting and trend extrapolation* group of techniques, different growth curves for the analysis of single or compound parameters, as well as envelope curves, can be determined. These include, amongst others, Pearl, Gompertz, and S-curves. Aspects such as mortality indicators (oscillatory behaviour in the S-curves of mature technologies) can be utilised to forecast technological discontinuities [22]. When considering trend extrapolation, a very useful technique is qualitative trend extrapolation that is mentioned by Martino [23].

4.4 ASSESSMENT IN TERMS OF THREATS AND/OR OPPORTUNITIES

The output of the previous stage, analysis, is intelligence on a range of signals that may be indicators of potential technological change. The purpose of this stage is to further process those signals and to cast them in a framework of technological threats and opportunities.

The first step in this stage is to consider the effects or impacts of developments in one area on those in another and to examine which developments or trends may be related in some way or another. The analyst should then attempt to map out what different sets of interrelated developments or events may mean. Hypotheses about possible implications are thus formed. This is significant for the reason that future events or enabling factors required to make a hypothesized innovation a reality could be determined as well. These events or enabling factors can then be fed back to the earlier information gathering stages where personnel will specifically look out for confirming or denying evidence that might be found. The feedback to earlier stages after hypotheses have been formed is quite important, as confirmed by the following statement of Utterback and Brown [24], namely that ". . . . the essence of the (monitoring and scanning) method . . . is the power of having prior hypotheses" (p. 7).

Having analysed the effects of developments in different areas on another, the focus now shifts to sets of major related issues that are envisioned to have a potential impact on a specific organisation. The organisation is bound to be faced, at this stage in the process, by quite a large number of issues. This step can thus be seen as a filtering one, where the most important issues are retained for further processing. Hence, an attempt is firstly made to determine which of the interrelated signals or issues may have an impact on a particular organisation. Secondly, those developments or issues should be reduced to a list of most critical developments or issues—those that are regarded to be most important or as having the greatest possible impact on the organisation.

In order to determine which developments or trends may have impacts on a specific organisation, corporate capabilities need to be investigated and formulated. Since the idea is to select those related signals or developments that can affect an organisation's bottom line, core competencies and complimentary capabilities could be investigated as proposed by Prahalad and Hamel [25]. Organisational audits need to be performed to determine which areas represent the organisation's strengths and weaknesses, as well as the current technological base of the organisation. Techniques such as those proposed by Chiesa et al. [26] as well as Burgelman et al. [27] might be very useful in this regard. The goal is hence to establish which sets of related developments or signals are important for the organisation, both at the present time and in the future.

In the third step, a range of scenarios is developed. In the previous two steps, interrelated sets of events or developments were determined and then reduced to those deemed to be of highest significance to the specific organisation. The objective now is to combine these sets of interrelated events and developments in different ways in order to determine how they represent threats or opportunities to the organisation. The use of the scenarios is thus to depict different organisational futures.

Having developed a number of alternative scenario worlds that collectively represent the range of technological threats and opportunities the organisation is compelled to face, analyses will be performed on several issues implied by the different worlds to discover possible impacts on the organisation. One of the most important areas to investigate is the future markets and hence future customer requirements implied by each of the scenario worlds. Thomas [28] offers several suggestions in this regard, which is shortly discussed.

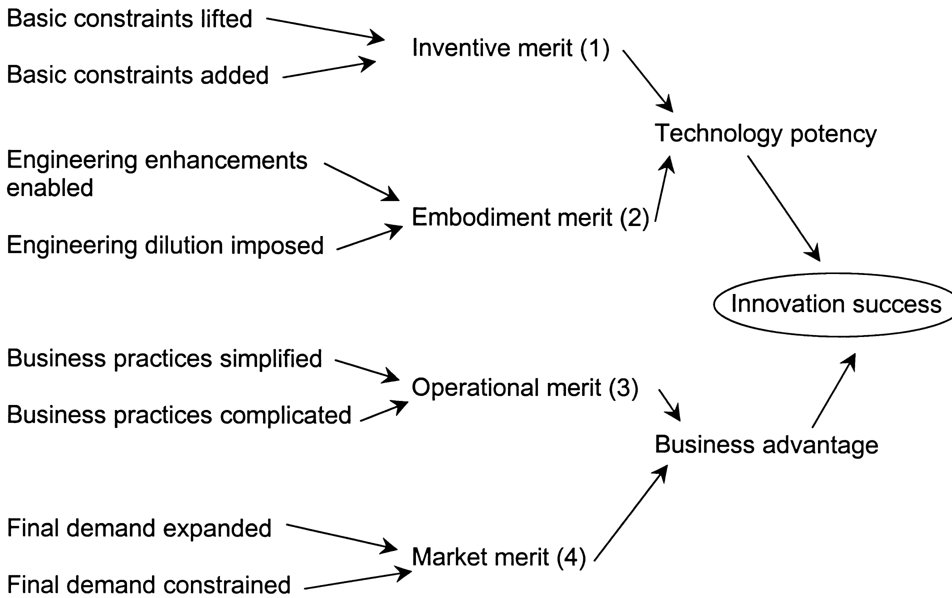

Fig. 3. A framework for evaluating scenario-derived entities.

Future market conditions are firstly examined and from these market conditions a segmentation analysis could be performed. For every scenario world and every target segment, it is then attempted to formulate what the requirements of customers in that segment may be and thus what their potential purchasing behaviour may be. Hence, the challenge is to arrive at possible future technological entities that will satisfy the requirements of potential customers in each segment.

This process should result in an extensive list of scenario-derived future entities. This list should then be reduced to a core set of plausible future entities that are viable across a range of business environments. Thomas offers the following criteria to be used when reducing the list of scenario-derived future entities:

- Evaluating possible entities in terms of corporate resources (compatibility with the current technological base)
- Entities that are robust across multiple environments
- Entities that offer a competitive advantage in a few of the worlds

Other criteria for reducing the list of scenario-derived entities could, of course, be employed. A framework proposed by White and Graham [29], which evaluates possible success in terms of technology and business (market) contexts is most useful for this purpose. This framework is shown in Figure 3.

At this point, a reduced set of future technological entities, envisioned to satisfy customer requirements across a range of alternative future environments will have been determined. What remains to be done is to investiage which technologies should be invested in, in order to realise those entities. A classic technology forecasting method, namely the relevance tree approach [30], is suggesting to assist in this process. The purpose of this method is to determine and evaluate the alternative paths by which an objective or mission could be achieved. Hence, the objective is broken down into alternative solution concepts, which are further broken down into systems necessary

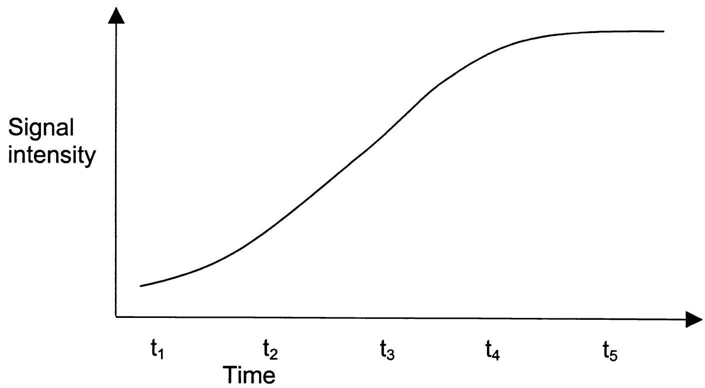

Fig. 4. The relation between signal intensity and time before introduction.

for each of the solution concepts. In this way, the aim is to arrive at specific technologies that will be required to realise future technological entities in order to satisfy customers' demands in future market segments.

4.5 THE DEVELOPMENT OF POSSIBLE RESPONSES

The previous subsection described how identified signals and developments were further processed and cast into a framework of technological threats and opportunities. In the present and the following subsection (on strategy selection and implementation), the focus is on what stands to be done given that certain threats or opportunities have been identified. Since a number of threats or opportunities might exist for a particular organisation at any given time, it may decide to form contingency plans or take certain offensive or defensive actions.

However, it should be appreciated that both processes, namely the development of possible responses as well as strategy selection and implementation, are highly specific and related to the particular decision-making and strategy-forming processes that will differ from organisation to organisation. The discussions in these two sections are thus of a more conceptual nature with certain generic tools offered that may assist the organisation in the processes of developing possible responses and selecting and implementing strategies.

Possible organisational responses will firstly depend on the strength of the signal that has been detected. Signal strength will increase over time, reaching a maximum at the point in time when an entity is commercially introduced. This is indicated in Figure 4 [34] as time t_5. One possible measure of signal strength could be the frequency of appearance in literature. The source of a signal could be a criterion as well. For example, signals at time t_1 may include informal discussions at conferences or symposia or networking with industry contacts—these signals could be considered to be relatively weak or tentative in nature. Stronger signals such as those at time t_2 might be found in company R&D reports or scientific papers. Signal intensity will further increase, as shown at times t_3 (where the sources of signals could be patent applications or the formation of alliances) and t_4 (sources such as the public announcement of product or process developments).

By gauging the signal strength, the organisation could thus approximately determine how much time it has to respond. In the case of a high signal intensity (little time to respond), an organisational response may, for example, be to buy or license a particular

TABLE 4
The Selection of an Optimal Response

		Alternative responses		
Criterion	Weight	Internal R&D	Joint venture	License
Least cost	0.3	0.3	0.5	0.2
Least risk	0.4	0.2	0.2	0.6
Highest payoff	0.1	0.4	0.3	0.3
Least time	0.2	0.1	0.3	0.6

technology, whereas the response might have been to develop the technology through internal R&D if the signal strength had been lower (more time to respond).

Secondly, the extent to which a signal or development has been identified to represent a threat or opportunity to the specific organisation in the previous activity (assessment in terms of threats and opportunities) will also influence the response of the organisation. Even though the signal strength may be high, the development or event it depicts may represent only a small degree of threat to the organisation, in which case the response may, for example, be a slight modification to the organisation's range of products or services. On the other hand, if a signal is picked up about a development that has the potential to obliterate an organisation's business, consequential action might be taken even though the signal intensity is weak.

The output of this activity is a set of contingency plans for dealing with identified threats or opportunities. Alternative strategies for offensive or defensive action have thus been formulated to deal with the possible future environments that the organisation may face. In the following subsection, the topic of discussion moves to the selection and implementation of an optimal strategy.

4.6 STRATEGY SELECTION AND IMPLEMENTATION

When selecting among alternative organisational responses, the whole spectrum of consequences that a particular response may have for the organisation should be kept in mind. One simplistic method that could be utilised in this regard is the impact wheel technique that is often advocated by subject matter on Quality Function Deployment (see for example [32] for more information). The usefulness of this technique lies in the fact that the advantages and disadvantages of all aspects of a decision or response are easily represented in a graphical form.

A further possible problem that may be encountered is that some aspects of a decision, and thus some advantages or disadvantages, are of greater consequence for an organisation than others. Hence, where several alternative responses have been formulated in response to a signal and each of these responses involves an intricate interaction of complex advantages and disadvantages, some quantitative decision analysis techniques may be more useful than relying on subjective judgment or "gut feel" alone. A most basic but effective approach would be to list the criteria on which a decision is to be based, assign weights to the criteria and then quantify the advantages and disadvantages of each alternative response in terms of these weighted criteria. An example is shown in Table 4. If scores were calculated for this example, it would seem that licensing the technology would the present optimal strategy.

Having selected an optimal strategy or strategies, these need to be implemented in practice through integration with the general business strategy. Major strategic decisions may include some of the following:

- Partnership or co-operation decisions, such as entering into a joint venture with another company.
- Intellectual property decisions, such as whether to obtain protection through patenting or whether to license technology to/from others.
- Technology-based guidelines for other strategy decisions, such as human resources, facilities, or capital planning decisions.
- Technology development choices. This incorporates decisions such as the method of procurement (purchasing/contracted-out R&D, internal R&D).
- Decisions regarding the management of the development of new entities (products, processes, services), such as which projects to pursue or terminate.

As stated in the introduction, market issues and technology-market interaction are of significance to the process of assessing technological threats and opportunities. This is elaborated on in the final subsection that follows.

4.7 TECHNOLOGY-MARKET INTERACTION

As mentioned before, the emphasis during the technological threat and opportunity assessment effort is on innovation and not merely invention. The process of innovation is typically envisioned to consist of both invention (the creation of new entities) and commercial exploitation (the acceptance and adoption of new entities in the marketplace). Whereas the criterion for the success of an invention is a technical one (whether the entity works or not), for an innovation it involves a commercial component as well (success in the marketplace). For this reason, it is thus of primary importance that market factors and the technology-market interaction should be considered during the process of technological threat and opportunity assessment.

Examples of issues considered to be of importance in the study of technology-market interaction includes the classification of an innovation process in terms of technology push compared to market pull, the estimation of potential market size, an evaluation of the entity life cycle, and market segmentation. Differences in the psychographic and behavioural characteristics of buyers in these segments are of significance as well.

An in-depth discussion of all of these issues is not possible in this article. However, in order to provide an overview of why these issues are seen as important in the technological threat and opportunity assessment process and how they are considered, one such issue, namely the classification of an innovation process in terms of technology push compared to market pull, will be briefly discussed.

One approach to the problem of examining market opportunity and customer preferences is to analyse the situation in terms of market pull and technology push. Market pull refers to a situation where certain customer requirements exist and technical entities are developed to satisfy those requirements. Hence, an entity is created in response to a particular demand. On the other hand, in a technology push situation, an entity had already been developed because it was possible to do so ("the engineers thought it would be neat") and market demand for the entity needs to be created or developed.

It is beneficial to perform a technology push/market pull analysis for a number of reasons. For example, the likelihood of success for an innovation is greater in a market pull-environment than in a technology push one. As stated above, the criterion for the success of an innovation is a commercial one (success in the marketplace). This criterion is obviously more likely to be satisfied where the demand for an entity already exists than in a situation where it has to be created.

TABLE 5
The Match Between Market Pull and Technology Push

	Market pull			Technology push	
Entity attributes	Segment 1	Segment 2	Segment 3	Entity 1	Entity 2
Robustness	C	C	B	A	B
Compatibility	A	B	B	B	A
Size	C	A	B	B	C
Efficiency	B	A	C	C	B
Price	B	B	B	C	A

Abbreviations: A = significant, B = important, C = less important, D = little importance.

Also, authors such as Groth [33] advocate that in a push situation, proponents need to sell the technology and garner support from those that control resources. Not only is this hard to accomplish, it also causes considerable burdens, such as the following:

- Expenditures of time and resources to promote the technology;
- Extended and sometimes interrupted research efforts stemming from a lack of adequate resources;
- Convincing those controlling resources that the expected benefits are attractive, given a perceived or actual high risk environment;
- Eventual success normally requires that one converts indifferent, non-believers or even hostile forces, into neutral or supportive factors, which is not always possible.

Thus, in general, a pull situation is characterised by a lower total cost of development, shorter development time (since decision-makers don't need to be convinced of feasibility), greater flesibility, and lower risks.

In a study on a technological discontinuities and dominant designs, Anderson and Tushman [34] state that ". . . new designs must win market share from an entrenched standard that is well understood in the marketplace, whose costs have been driven down an experience curve, and which benefits from centrality in a network of supporting technologies." Again, this is much easier to accomplish in a pull situation where demand for an entity already exists.

It has thus been shown that it is necessary to characterise a particular situation in terms of technology push or market pull, and to determine both what factors might change the current situation (from push to pull or vice versa) and the probability of such changes.

Related to the issue of market pull and technology push is an analysis of how closely current and planned entities of the organisation are matched to customers' requirements. Thus, for each target market segment, the emphasis that buyers in that segment place on specific attributes of an entity are determined (market pull). This is compared with the emphasis placed on different attributes during development (technology push). The objective is thus to examine how closely different entities satisfy user needs. An example is shown in Table 5, which is based on a technique proposed by Wheelwright and Clark [35] in the product development process. The table can be extended to include entities of major competitors. A comparison between the organisation's entities and those of competitors is thus facilitated.

5. Conclusions

This article has proposed that it is essential that a structured system be deployed to anticipate the technological future. Specifically, the notion of technological threat and opportunity assessment has been presented as a useful framework for anticipating technological change. This notion is based on a dual approach.

First, the modern-day organisation is facing a global and dynamic technological landscape, necessitating keeping track of technological developments. A technique known as monitoring and scanning could be utilised in this regard. It was shown to be essential to scan broadly, since industry-shattering and paradigm-shifting innovations very often come from an entirely different industry than the one that they eventually have an impact on.

Second, any organisation could be considered to be technology-based to some degree. This implies that technologies have the ability to affect the bottom line of the organisation in some way. It is therefore required to identify the technologies that may possibly do so. The development of audit mechanisms was shown to be necessary in this regard. Furthermore, it is important to gain knowledge of possible other role players in an industry, and some competitive intelligence practices could therefore be very useful in the technological threat and opportunity assessment effort.

It was shown that once specific technological threats and opportunities have been identified, an appropriate strategy needs to be devised in response to these threats and opportunities. While this process is unique to every organisation, it was generically stated that possible offensive and/or defensive responses should be developed whereupon an optimal strategy should be selected and implemented.

Having introduced the notion of technological threat and opportunity assessment as well as the generic components of and requirements for such a methodology, the rest of the article focused on a specific methodology that has been developed. It was stressed that this methodology represents the first output of an iterative and ongoing research process and is by no means fully comprehensive or conclusive. It is presented as an example or one possible conceptualisation of how to assess technological threats and opportunities.

Future research will focus on the improvement and elaboration of the specific methodology that has been developed. A practical implementation of the methodology will most probably point out several problems to be solved and areas that could be refined.

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Received 18 January 1999; accepted 8 March 1999