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Chapter 6

Influence of Strategic Technology Management on Smart Manufacturing: The Concept of 'Smart Manufacturing Management'

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Additional information is available at the end of the chapter

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Abstract

As technology advances, organisations are moving towards adapting the best options so as to enjoy a competitive edge. The performance of firms, besides other factors, relies on effective management of these technologies. Strategic management of these technologies is of interest to firms, but studies on this have been restricted to studies in the West. A study carried out by the author helped to analyse which of the technology strategy (TS) and technology management (TM) factors are related to performance of firms. Additionally, it was explored if any of these factors are related to nature and size of the firm. The research focused on high-technology manufacturing industries; some of which employed advanced manufacturing. This chapter will introduce the concepts of strategic technology management and smart manufacturing, provide a critical analysis of literature on the work done in these areas, discuss results of a study done on the application of STM in a high-technology manufacturing sector and extend the results of research to smart manufacturing. It is concluded that a good STM can guide smart manufacturing in enhancing firm productivity and achieving a competitive advantage.

Keywords: technology management, strategic, smart manufacturing, performance

1. Introduction

Technology management has come to be accepted as a vital activity and considered by many to be the basis of competition amongst organisations. On the other hand, Pandza et al. (2004) posit that 'Advances in technology have moved manufacturing organisations toward a new competitive landscape. Managers in manufacturing organisations are experiencing the emergence of new manufacturing concepts or even a new paradigm' (p. 402). Smart manufacturing

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is one of these emerging concepts. There has been considerable interest by researchers to peep inside manufacturing firms and explore the elements contributing to their performance. 'Over the last decade there have been many attempts to set out the elements of manufacturing systems and to understand their effects' [1]. Concepts such as virtual organisations, concurrent engineering, advanced manufacturing, flexible manufacturing systems and computer-integrated manufacturing have been applied at the company level. However, Hayes and Jaikumar [2] are of the opinion that 'investment based on these technologies frequently proved disappointing, not because of any fundamental weakness in these technologies, but because the links between these technologies and the needs of business were not well understood'. The repercussion of this has been, according to Womack et al. [3], a move by companies to lay more emphasis on soft issues like operations, quality, financial control, production control, change management and supply chain networks. It would be worthwhile to deduce that advanced manufacturing or smart manufacturing alone might not relate to performance of firms. The application of advanced technologies needs to align with the strategy of the firm, hence the need to consider technology strategy and technology management as the main drivers of smart manufacturing.

It is almost impossible for firms to keep away from technology. Continuous development in various industries has relied heavily on technology. The manufacturing sector has also moved leaps and bounds in technology applications. The concept of smart manufacturing also relies on utilising state-of-the-art technologies to monitor and improve productive effectiveness. 'The primary fact about technology in the twentieth and twenty-first centuries is that it has a momentum of its own. Although the technological stream can to some extent be directed, it is impossible to dam it; the stream flows on endlessly' [4]. The development of the Internet and modern sensor technology has benefited most. These technologies can be 'directed' to able to monitor and control the production processes more effectively than is done by current systems which are a mix of manual and automatic parameters. The trend in the development of fast Internet and control systems has provided unique opportunities to introduce smart manufacturing. However, technology alone cannot provide a competitive advantage. The way these technologies need to be applied (technology strategy) and implemented (technology management) needs to be understood by both the academics and the practitioners. This concept of integrating the areas of engineering and management is a concept which this chapter looks into and is introduced by the author for the first time here as 'smart manufacturing management' and resembles with 'engineering management' and 'technology management'. It provides useful results based on a study undertaken in a high-technology manufacturing sector.

Business strategy can be apprehended through its content or its processes [5]. Content research mainly focuses and investigates strategic typologies. Process research puts more emphasis on how the strategy is formulated and implemented ([6], p. 193). 'Strategic technology management' (STM) encompasses both the 'content' of technology strategy and the 'process' of technology management. Technological advances and the timing of their implementation have a considerable influence on the competitive standing of firms. Technology strategies could thus be regarded as important elements which could provide a competitive edge to organisations and also help in the development of their business strategies. Badawy ([7], p. 359) observed that White and Bruton use a similar definition for the management of technology, that is, 'the linking of engineering, science and management disciplines to plan, develop and implement technological capabilities to shape and accomplish the strategic and operational goals of an organisation'.

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2. Technology management

Technology management, according to Corey [8], is an integration between business and technical disciplines to develop technology capabilities in order to achieve operational objectives. He further elaborates that R&D is also an essential ingredient for incorporating technology into the products and processes of a firm. Jones, Green and Coombs [9] have defined technology management as the 'identification, development and application of relevant technical knowledge and expertise to achieve organisational goals'. This definition goes beyond the usual domain of R&D and is more strategic in nature.

The effect of employing such strategies has resulted in enhanced productivity of many firms where technology was once treated as a relatively low priority [10]. The importance of technological competencies is evident from the fact that NEC outperformed GTE simply because 'it conceived itself in terms of core competencies' [11]. Therefore, it can be concluded that for the advanced manufacturing industry, technological competencies are always going to be significant as effective *management* of technology is dependent on them (on this, see also [12–16]).

2.1. Missing links in technology management

In order to determine the missing links in technology management, Gregory [1] conducted a critical literature review on this subject and concluded that 'all authors identify the need for a set of instruments, for a methodology to facilitate technology oriented decision making and none of the current approaches relates to general management concepts i.e. they do not lend themselves to integration in a unified concept of firm management'. Traditional approaches to technology strategy tend to focus on the identification of critical technologies and the allocation of R&D effort to the most important of these. Manufacturing firms tend to become multinationals, and technologies employed in the parent firm are similar to those employed by other countries, but it is unclear as to whether or not R&D is similar in the home and host countries. The firm exists to create value-added products. Wahab [17] reiterates that the 'performance of firms depends very much on innovation and R&D environment'. However, despite their similarities there are striking differences in the ways that different firms and organisations approach their technology management—the university system in the USA, for example, plays a different role from the one in Southeast Asia. Thus, technology management strategies applied in advanced manufacturing firms in the host country might be different than those applied in the home country—this is a missing link (gap), and this chapter in part has tried to address this gap.

2.2. Overemphasis on technologies in smart manufacturing

If as Gregory [1] maintains that 'a strategy is only of value if mechanisms for its implementation and renewal are in place', it is surprising that no comprehensive framework for technology management has emerged. Many authors, including Hayes and Jaikumar [2], have highlighted that an overemphasis on technology, rather than on products and services, has led some companies to develop or acquire inappropriate technologies. 'There is a need, then, for a "language" which can represent and link the important dimensions of a business, including technology, in the context of customer requirements' [1]. However, if such a language of technology is developed, it should be

common across all functions in the organisation. It should be noted as an example that 'accounting language tends to be the only common language of the firm while technological language fragments at lower operational levels, that is, in production engineering and R&D' [5]. The failure to *measure* technological capabilities is also a missing link in technology management; though the technology contribution factor (TCF) has been applied in research conducted by various researchers, it does not provide the necessary link between the various dimensions of technology management. Therefore, studies which can provide measures to establish this link should contribute to the existing knowledge. The concept of strategic technology management introduced in this chapter—a combination of technology strategy (TS) and technology management(TM)—attempts to address this issue in the sense that it measures the performance of firms in relation to various technology strategy and management dimensions. Acquiring smart manufacturing capability is a moderator in the performance of the firm, and strategic technology management is the driver.

2.3. The strategic content in technology management

The rapid change in technology over the last two decades has raised concern on two major issues. These have been defined by Mitchell [18] as (1) poor linkage between technology and strategy planning and (2) over-reliance on short-term measures, both of which masks the more strategic plans. Strategic importance of technology has been recognised as helping to provide competitive advantage. However, Mitchell [18] states that strategic management of technology has certain practical problems, which are:

1. There is no generally accepted language for defining the critical technologies.

2. There is no way to manage these technologies.

3. There is no appropriate financial framework for allocating resources for strategic positioning.

Hence, there are opportunities to explore how technology strategies are formulated by firms, how they are subsequently implemented and how they contribute towards the firm's growth, especially those which employ advanced manufacturing.

The need to create and use new technology to provide a competitive advantage has been ever increasing and has been a source of growth for many firms. This requires strategic thinking about technology beyond the simple development of new products and services. Hence, 'the task of managing technology is integral to, and essentially synonymous with, strategic management' [19].

Since 1980, the relationship between technology and business strategy has been considered important by companies, but its implementation has not. As highlighted by Chiarmonte [20], 'technology, although very important, was still often not considered in the process of strategy formulation, the essential reason being the trend that technology development takes longer time compared to other functions of the company like marketing'. Thus, more than recognition of this issue is needed to determine what linkage mechanisms need to be established to provide the technology strategy fit.

Contrary to this argument, Thomas and McGee [21] suggest that the strategy literature treats technology as an implementation issue, that is, the technology to be used is defined by strategy.

Thus, technology does not enter into the strategy formulation process, and there is no clear direction on how to manage it. The authors further suggest that technology should be considered as the central part of a company's thinking. Evan et al. [22] go a step further and suggest that 'technology should be recognised as a strategic resource … to ensure new technologies provide sources of strategic advantage. This has tempted cutting-edge firms [to] increasingly integrate technology management with their management processes'. However, this approach on its own is not sufficient; it may confine firms to an inward-looking approach. There is also a need to explore those technology developments occurring outside the firm so that appropriate technologies can be matched to their management strategy. This emphasis by firms on both internal and external inputs—a key aspect of strategic technology management—is explored in this chapter, and both approaches are included as relevant variables in the survey instrument.

Attaran [23] opines that technology in itself does not guarantee success in increased efficiencies and reduced inventory turnover times. He further states that 'management plays a fundamental role in the implementation of such initiatives which could include flexibility, customer service, employee welfare, quality and training'. Thus, allocation of appropriate resources and provision of capital, both for product (development) and services (welfare, training, etc.), are important for the implementation of technologies—a point which has been borne out by one of the results of the bigger research and does not form part of this chapter.

Wilson [24] analyses the strategic management process of Bank of America and concludes that four major thrusts are included in the technology planning of its strategic management process. They are 'emphasis on focusing on technology to meet customer needs; investing in employees to build a diversity of skills and talent; applying technology to build a competitive advantage; and linking business and technology strategies to build a common value'. These values provide a useful set of strategic technology management strategies for researchers. Wilson's understanding of the subject is supported by Sahlman and Haapasalo [25] who regard strategic technology management as the management of those technology activities which interact with a company's socio-economic and technological environment and help to formulate and implement that company's overall strategy.

According to Thomas and McGee [21], 'the evolutionary theory of the firm also provides an important framework for the strategic management of technology because the strategic capabilities evolved through experience reflect the ability of the organisation to adapt to changing technologies which provides profitability'. Although not exclusively naming the approach as strategic technology management, Corey [4] proposes that 'technology management must accept the responsibility for managing its process with the associated strategic perspective otherwise the results could be catastrophic'.

One of the definitions of technology management which integrates the elements of strategic management comes from the NRC Report (cited in [26]): 'Management of technology is a linking block amongst engineering, science and management disciplines to plan, develop and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation'.

One of the key recommendations of the Strategic Management of Technology Conference [27] was that firms needed to create a sustainable competitive position, one which requires strong

linkages between the company's business environment and the way that company develops and maintains its technological base. Despite this, the main focus remains on the way of acquiring new technology and how to improve the existing ones to gain competitive advantage. The underlying task remains how to find an answer to match technology to market. This is relevant in the case of smart manufacturing whereby employing only modern technologies in terms of IoT (Internet of Things), and data analytics might not be able to provide the competitive advantage.

3. Smart manufacturing and strategic technology management

Smart manufacturing is nothing new; terminologies like advanced and flexible manufacturing have also been used in the past which focus on utilising modern technologies to improve manufacturing. Smart manufacturing entails availability of data of the entire manufacturing process so that manufacturing organisations can *strategise* the processes to match the market. In this respect smart manufacturing 'influences' and 'aids' technology management decisions. Smart manufacturing provides data and empowers everyone in the organisation including top management, which should help management in developing appropriate technology strategies to maintain a sustainable competitive advantage. It would not be wrong to say that smart manufacturing is in fact a technology management trend.

Ettlie [28] conducted a study of various successful firms in the USA and found that synchronous innovation of both technology and administration made for the best-performing firms. 'If business strategy can be thought of as defining the preferred field of contest and the tactics used in confronting a competitor, a technology strategy defines how these tactics can be created and employed' [29]. Clark et al. [30] use the phrase 'technology management' to refer to 'organizational issues and processes involved in developing and implementing a strategic approach to technology'. *As such in the context of smart manufacturing, only utilisation of advanced technology is one of the aspects of performance of firms; how to employ and administer these technologies (TS/TM) will remain the major driver of performance enhancement.*

According to Dell ([31], smart manufacturing provides immense opportunities for organisations including predictive maintenance, quality control, automated process management and supply chain visibility. To be able to avail these opportunities, organisations will need a robust technology strategy in order to determine what tactics need to be employed to ensure compliance of these.

Andrew Waycott [32] suggests that smart manufacturing is about collecting and crunching data to make more informed decisions. With greater visibility of the real workings, your shift supervisors and operators can make better, more informed decisions, all day long. Thus, smart manufacturing can help in strategic management of technology.

Chand and Davis in a paper written for Rockwell Automation [33] suggest that smart manufacturing is not merely technology rather an integration of information, technology and human ingenuity. This integration could be achieved by application of technology management strategies at the strategic level in the organisation to ensure it aligns with the business strategy and provides a competitive advantage.

4. Strategic technology management in advanced manufacturing: analysis of a research study

A study was carried out to determine the influence of STM on the performance of firms in technology-intensive advanced manufacturing sector of the economy. This was a mixed-mode study and employed a survey instrument comprising both quantitative and qualitative questions. The respondents were the chief executive officers, technology managers and senior management in 101 high-technology firms who were considered to be part of strategies at the firm level. The responses were analysed using statistical tools. The variables included in the questionnaire were reduced by performing factor analysis. The relationship between the variables of interest was determined using regression analysis. The factors were grouped into TS and TM dimensions. These were then used to determine their influence on performance of firms. Sales revenue growth (SRG) was selected as the performance measure. Two of the factors, namely, *key positioning* and *strategic R&D*, were found to relate with performance, while the other five factors, namely, *technology leadership*, *up-to-date plants and facilities*, *technology consciousness*, *formal planning* and *external technology acquisition*, were not correlated with performance. Multinational corporation and joint venture firms were found to have acquired the factors of key positioning and strategic R&D, whereas foreign and locally owned companies were found less likely to acquire these factors. These results have implications both for management within the firm and the policy planners at the national level.

4.1. Influence of R&D on technology strategies

Investment in R&D contributes to technological innovation, and to manage these innovations requires the development of technology strategies. So, why do firms invest in R&D? Shane [34] highlights five reasons for this:

1. To create new technologies that can serve as the basis for new products and services.
2. To develop products to replace those threatened by substitutes.
3. To differentiate products from those of competitors.
4. To create strong intellectual property positions by making fundamental discoveries on which pioneering patents can be obtained.
5. To create absorptive capacity to recognise and use knowledge from elsewhere.

Competition amongst firms lays the foundations of business strategy and is a driving force in the establishment of R&D strategy. 'R&D strategy' is often used interchangeably with 'technology strategy' in the literature. As such R&D management has dominated in technology-intensive and advanced manufacturing industries. This R&D emphasis is quite common in the US industries; this is in contrast to the European model which stresses acquisition, diffusion and transfer of knowledge [20]. R&D strategy needs to be integrated with the other strategies of the firm. And, indeed in recent times, there has been a 'shift from an R&D management focused attitude, towards a wider perspective of the issues facing innovation management, and, more recently, towards a combination of innovation, technology and strategy' [20].

In this study R&D is considered as an integral part of a firm's strategy and is employed as a background variable to determine its relationship with the performance of firms. Technology helps in the formulation of a company's technology strategy, and its implementation provides the success. This is the rationale to define strategic technology management as a combination of technology strategy and technology management.

'R&D has to live in continuous symbiosis with other functions in the company and should be absorbed into the technology function' [27]. This Strategic Management Conference [27] also recommended that firms need to 'measure the technological assets' so as to decide on how to use technology in making strategic choices.

According to Van der Meer et al. [35], 'Companies which operate in technology intensive environments are compelled to invest heavily in R&D in order to maintain a competitive advantage'. This study, besides exploring the effect of technology strategy factors on success of firms, also explored if R&D investments in terms of the number of people employed in the R&D department related to the performance of the firms.

'The promise that R&D holds is not the reality for many firms as competitors often appropriate and commercialise new technologies more nimbly than the firms that paid to develop them' [36]. Firms need to find a fit between their R&D and their company strategy. Evan et al. [22] suggest that technology strategy improves communication between R&D and the rest of the firm and seeks to answer questions like:

1. What is the fit between technology projects and the company strategy?

2. How do technology efforts compare with those of competitors?

3. Are external sources (universities, laboratories) used effectively?

4.2. Methodology

4.2.1. Sample

The definition of a high-technology industry has not been agreed upon. The Department of Commerce (USA) [36] defines a high-technology industry on the basis of the percentage of its investment in R&D relative to its sales revenue. Although MNCs in the manufacturing sector outnumbered other types, this study chose to include all types of firms within this subsector: multinational corporations (MNCs), joint ventures (JVs), foreign-owned (FO) and locally owned (LO). The further classification of firms was inspired by Thomas and McGee [21] who define firms in terms of modes of innovation: 'mode 1 as small high technology firms, mode 2 as large multi-product, multi-market, and multi-divisional corporations and mode 3 as huge multinational enterprises that usually involve public and private sector collaboration on mission-oriented programs' (p. 266).

There were a total of 380 E&E firms listed in the Federation of Manufacturing Directory. However, about 80 of these were incorporated after the date this research was carried out, so they were excluded, leaving about 300 high-technology manufacturing firms for the survey.

This sample was considered as a probable one, and it was thus possible to 'extrapolate beyond the sample to establish findings for the wider population of interest' ([37], p. 184).

Because of their familiarity with technology management and strategy issues in their firm, the CEO, technology managers or senior management of each firm was expected to complete the questionnaire.

4.2.2. Research design

In order to address the research question, a mixed method design was used to collect data. Zahra [38] has indicated a 'need to refine the conceptual and operational definitions of technology strategy and … that field studies and surveys can help to identify additional components of technology strategy' (p. 214). The data-gathering phase had three objectives:

1. To gather data on key technology strategy and management elements from senior executives of firms in the manufacturing sector.
2. To gather data about the level of technology awareness of the respondents and about their understanding of the role of technology and the competitive environment.
3. To gather data about the performance of the firms.

The research was designed in three phases. The first phase involved the development of a survey instrument. The survey instrument was developed in line with the objectives of the research and so as to maximise information extraction from the respondents ([39], p. 29). Advantage was taken of prior surveys in selecting the variables chosen for the study, especially Herman [40]. The response rate was initially 18%; this increased to 26.5% (useful rate being 20.7%) after two follow-up letters were sent. The second phase involved the pilot testing of the survey instrument. The pilot study involved 10 firms and sought to assess the clarity and usefulness of the questionnaire items. Phase three of the study involved the administration of the survey.

4.2.3. Measures

According to Jones et al. [9], 'Successful technology strategy management must go beyond content, implementation is as important' (p. 158). There are 10 elements of strategic technology management that were selected for this study. Each element is measured through inductively developed items in order to develop a richer description of the element and to triangulate on the element value. A four-point modified Likert scale was chosen due to its inherent advantages over the original odd-numbered Likert scale.

4.2.4. Firm's performance dimensions

In this study firm performance was measured using sales revenue growth (SRG), that is, by considering the annual sales revenue at the start and end of the period of this study. SRG reflects the effects of technology strategy decisions. Although SRG is not a perfect measure, various researchers have found it adequate for performance, especially for developing countries [41].

4.3. Data analysis

4.3.1. Factors underlying strategic technology management

Factor analysis was used to reduce the original number of items (32 items, 16 strategy and 16 management) in the survey. The literature review identified several variables which could be used to measure two dimensions which define strategic technology management. These two dimensions are referred to as technology management (TM) and technology strategy (TS). A thorough analysis of the environment in which the survey was carried out revealed that 32 items could be used to measure these dimensions. According to the respondents to the pilot study, these items were deemed suitable for use in the main questionnaire.

Principal component analysis (PCA) was selected for extracting the factors. In order to determine the appropriateness of the factor analytic framework, a number of methods were employed. These included Bartlett's test of sphericity and Kaiser-Meyer-Olsen's (KMO) test. The 16 strategy items were factor analysed using the PCA method.

Kaiser's criterion with an eigenvalue of greater than 1.0 was used to determine the number of factors to be extracted. The extraction using PCA for the 'technology strategy' variables revealed that three components accounted for 71.3% of the total variance. The extraction using PCA for the 'technology management' variables revealed that four components accounted for 83.2% of the total variance. The rotated factor loadings are presented in Appendix A.

Strategic technology management in this research has been understood in terms of the technology strategies formulated by firms and the processes for implementing or managing these strategies. Seven new factors have been identified by this research, and these all apply at the company level (Appendix A). These seven factors can be seen as falling into two dimensions: the technology strategy (TS) dimension and the technology management (TM) dimension.

The TS dimension, which refers to the *content* of strategies, is in this study and can be conceptualised in terms of three factors:

1. The first is *technology positioning*, in which a firm introduces high-risk or breakthrough technologies in order to build a reputation for technical innovation that it can be used as a competitive advantage. A firm that uses *technology positioning* also emphasises the sophistication of the technology they apply, with an emphasis on state-of-the-art tools and equipment and a focus on hiring highly trained R&D personnel. Such a firm strives to not only increase its range of products but also to reduce product development time. Thus, this factor could be summarised as referring to a firm's utilisation of technology to achieve competitive advantage. It does so by using even more sophisticated technology and by increasing the number and rate of development of new products.
2. The second factor developed from the data is that of *leading in the discovery of new technologies and introducing innovative products*. This factor relates to the efforts a firm puts into the *discovery* of new technologies and to introducing new products before other firms. Thus, it is about the willingness to lead in technology discovery and in the introduction of new products.

3. This third factor relates to the extent to which *technology is embedded in plants and processes*. This construct relates to a firm's exploitation of technology to manufacture unique products, to reduce manufacturing costs and to increase the flexibility of production processes. This measure also reflects the maximisation of the inclusion of technology in a firm's plant and processes in order to gain an advantage in relation to competitors.

The TM dimension, which relates to a firm's handling of the process side of technology, can be conceived in terms of four unique factors:

1. The first is *R&D linked to business*. This refers to the degree to which a firm links its R&D activities with its other business operations, that is, the degree to which it elevates R&D to a strategic level. It also relates to the existence of mechanisms—mechanisms for recognising and rewarding R&D and mechanisms for evaluating the costs and benefits of specific R&D projects.

2. The second factor is called *keeping abreast with emerging technologies*. This is about the processes that firms employ to ensure that they are aware of innovative and competing emerging technologies. This basically refers to the processes it has in place for scanning for new technologies employed by firms.

3. The third factor is *formal process for planning*. This reflects the emphasis that firms place on using formal processes for planning and selecting technologies, as compared to *ad hoc* decision-making.

4. The fourth factor is *in-country external acquisition of technology*. This is about the processes that firms use to acquire technology by conducting R&D in collaboration with universities, research labs and other companies within a country, that is, technology acquisition that does not rely on internal R&D at the firm level.

The seven strategic technology management factors highlighted above were evident in firms investigated. However, not all factors were found to contribute to a firm's success. The next section describes in detail the relationship between these factors and SRG.

4.3.2. Factors influencing performance of firms

For this study, sales revenue growth (SRG) was used as a measure of firm performance and was averaged over a 10-year period.

The results revealed that there was a statistically significant correlation between *strategic R&D* and SRG, as well as between *technology positioning* and SRG. These two factors represent technology management and technology strategy dimensions of strategic technology management; thus, it could be stated that application of strategic technology management factors contributed to the positive performance of the advanced manufacturing firms during the 10-year period under review. The summary of the factors that correlated with success is provided in **Table 1**.

Factors	Correlation with SRG	Result
Strategic R&D (TM)	Yes ($r = 0.34$, $p < 0.01$)	The firms that are extremely focused in placing emphasis on R&D and linking it with other business operations have a positive significant correlation with the growth rate
Key positioning (TS)	Yes ($r = 0.33$, $p < 0.01$)	The firms that are extremely focused in using technology as a key positioning factor in their strategy have a positive significant correlation with the growth rate

Table 1. Strategic technology management factors contributing to success.

5. Implications

This study has contributed to the discipline of STM and SM by investigating the nature of technology strategies applied in advanced manufacturing firms in an Eastern environment.

The study has offered an approach to quantify the cumulative effect of STM application in SM and performance.

The results could be extremely useful to provide an insight to the national technology planners of the influence of STM in smart manufacturing and the performance of firms.

This study indicated that not all factors of strategic technology management applied in smart manufacturing would produce sales revenue growth. This has implications for the managers of firms and especially for those who are responsible for technology management.

6. Conclusion

Smart manufacturing alone will not be able to provide success in the performance of firms. It has been demonstrated based on the literature review, and an exclusive study carried to explore if strategic technology management factors rather technology alone (as is smart manufacturing) influence performance of advanced manufacturing firm. Although several factors were drawn up from this study, but only two factors contributed to the performance of such firms, and they were strategic R&D and key positioning. The strategic R&D factor demonstrates that the innovative use of technologies and new product designs can contribute to performance of firms. The key positioning factor accounts for good decision-making in terms of market positioning. The study also supports the viewpoint of Chand and Davis (in Rockwell Automation Report) [33] that smart manufacturing is not merely technology rather an integration of information, technology and human ingenuity. Since two factors in strategic technology management contributed to the growth of firms, it could be concluded that integration of both

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technology (R&D) and human ingenuity (key positioning/decision-making) can provide success to firms. Thus, smart manufacturing is the engine, and strategic technology management the driver for performance of firms.

A. Appendix A: factor analysis

A.1. Technology strategy

Total variance explained

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings[a]
	Total	Percentage of variance	Cumulative (%)	Total	Percentage of variance	Cumulative (%)	Total
1	8.261	51.632	51.632	8.261	51.632	51.632	7.383
2	1.755	10.968	62.600	1.755	10.968	62.600	3.750
3	1.388	8.677	71.277	1.388	8.677	71.277	4.769
4	.987	6.167	77.444				
5	.784	4.903	82.347				
6	.672	4.203	86.549				
7	.457	2.853	89.403				
8	.428	2.678	92.080				
9	.324	2.025	94.105				
10	.256	1.598	95.703				
11	.192	1.199	96.902				
12	.187	1.167	98.069				
13	.113	.704	98.773				
14	.089	.558	99.332				
15	.071	.446	99.777				
16	.036	.223	100.000				

Extraction method: principal component analysis.

	Component matrix[a]		
	Component		
	1	2	3
Pursuing high technical risk	.757		
Having reputation for technology innovation	.775		
Dominance in key technologies	.774		−.411
Importance of advanced qualifications	.652		
Striving for technology development	.755		
Employing pacing technologies	.795	−.425	
Using state-of-the-art tools	.796	−.420	
Reducing product development time	.769		
Increasing the number of products	.582		
Continuously improving products	.708		
First in discovering technologies	.704	.638	
First in introducing new products	.683	.628	
First in introducing low-cost products	.498	.626	
Unique product manufacturing capabilities	.725		.579
Low manufacturing cost	.661		.606
Improving production flexibility	.790		.478
Extraction method: principal component analysis			

[a]Three components extracted.

A.2. Technology management

Total variance explained							
Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings[a]
	Total	Percentage of variance	Cumulative (%)	Total	Percentage of variance	Cumulative (%)	Total
1	7.804	48.772	48.772	7.804	48.772	48.772	6.961
2	2.927	18.296	67.069	2.927	18.296	67.069	4.941
3	1.387	8.668	75.737	1.387	8.668	75.737	2.117
4	1.190	7.440	83.177	1.190	7.440	83.177	2.548

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Total variance explained							
Component	**Initial eigenvalues**			**Extraction sums of squared loadings**			**Rotation sums of squared loadings[a]**
	Total	**Percentage of variance**	**Cumulative (%)**	**Total**	**Percentage of variance**	**Cumulative (%)**	**Total**
5	.642	4.012	87.189				
6	.505	3.155	90.344				
7	.358	2.237	92.582				
8	.320	1.998	94.580				
9	.259	1.619	96.199				
10	.167	1.046	97.246				
11	.150	.939	98.184				
12	.116	.725	98.909				
13	.060	.374	99.283				
14	.052	.327	99.610				
15	.033	.203	99.814				
16	.030	.186	100.000				

Extraction method: principal component analysis.

Component matrix[a]				
	Component			
	1	**2**	**3**	**4**
Awareness of existing technologies	.665	.658		
Awareness of emerging technologies	.650	.670		
Awareness of innovative technologies	.619	.689		
Awareness of competing technologies	.520	.746		
Technology acquisition within the firm	.786			
Technology acquisition from laboratories & universities	.570			.528
Technology acquisition from outside firms within the country				.738
Market-driven programmes	.692			
Product-driven programmes			.776	
Formal planning processes	.454		.455	
R&D integrated programmes	.867			
R&D researchers empowered	.905			

Component matrix[a]				
	Component			
	1	2	3	4
R&D success rewarded	.895			
High R&D investment	.858			
Ensuring high returns on R&D investment	.894			
External R&D funding	.753			

Extraction method: principal component analysis.
[a]Four components extracted.

B. Appendix B: regression analysis

Variables entered/removed[b]			
Model	Variables entered	Variables removed	Method
1	Capital Investment, employees[a]	.	Enter
2	Strategic R&D[a]	.	Enter
3	Technology positioning[a]	.	Enter

[a]All requested variables entered.
[b]Dependent variable: sales revenue growth.

Model summary				
Model	R	R square	Adjusted R square	Std. error of the estimate
1	.732[a]	.536	.520	342.24750
2	.733[b]	.538	.514	344.47139
3	.740[c]	.547	.516	343.85691

[a]Predictors: (constant), capital investment, employees.
[b]Predictors: (constant), capital investment, employees, strategic R&D.
[c]Predictors: (constant), capital investment, employees, strategic R&D, technology positioning.

ANOVA[d]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	7979285.248	2	3989642.624	34.061	.000[a]
	Residual	6910867.880	59	117133.354		
	Total	1.489E7	61			
2	Regression	8007841.708	3	2669280.569	22.495	.000[b]
	Residual	6882311.420	58	118660.542		
	Total	1.489E7	61			

ANOVA[d]

Model		Sum of squares	df	Mean square	F	Sig.
3	Regression	8150611.362	4	2037652.841	17.234	.000[c]
	Residual	6739541.766	57	118237.575		
	Total	1.489E7	61			

[a]Predictors: (constant), capital investment, employees.
[b]Predictors: (constant), capital investment, employees, strategic R&D.
[c]Predictors: (constant), capital investment, employees, strategic R&D, technology positioning.
[d]Dependent variable: sales revenue growth.

Coefficients[a]

	Model	Unstandardised coefficients		Standardised coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	−440.577	125.548		−3.509	.001
	Employees	40.917	53.711	.094	.762	.449
	Capital investment	342.801	63.427	.664	5.405	.000
2	(Constant)	−416.552	135.523		−3.074	.003
	Employees	47.858	55.881	.109	.856	.395
	Capital investment	350.486	65.733	.679	5.332	.000
	Strategic R&D	−27.306	55.663	−.052	−.491	.626
3	(Constant)	−640.907	244.923		−2.617	.011
	Employees	44.717	55.855	.102	.801	.427
	Capital investment	351.309	65.620	.681	5.354	.000
	Strategic R&D	−79.027	72.820	−.151	−1.085	.282
	Technology positioning	123.035	111.967	.141	1.099	.276

[a]Dependent variable: sales revenue growth.

Excluded variables[c]

	Model	Beta In	t	Sig.	Partial correlation	Collinearity statistics tolerance
1	Strategic R&D	−.052[a]	−.491	.626	−.064	.705
	Technology positioning	.051[a]	.520	.605	.068	.826
2	Technology positioning	.141[b]	1.099	.276	.144	.481

[a]Predictors in the model: (constant), capital investment, employees.
[b]Predictors in the model: (constant), capital investment, employees, strategic R&D.
[c]Dependent variable: sales revenue growth.

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