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*Kari Sahlman*

# ELEMENTS OF STRATEGIC TECHNOLOGY MANAGEMENT

*FACULTY OF TECHNOLOGY,*
*DEPARTMENT OF INDUSTRIAL ENGINEERING AND MANAGEMENT,*
*UNIVERSITY OF OULU*

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# ELEMENTS OF STRATEGIC TECHNOLOGY MANAGEMENT

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Supervised by
Professor Harri Haapasalo

Reviewed by
Professor Dilek Cetindamar
Professor Saku Mäkinen

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Faculty of Technology, Department of Industrial Engineering and Management, University of Oulu, P.O.Box 4610, FI-90014 University of Oulu, Finland
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***Abstract***

In an increasingly complex economic and social environment, high technology companies are facing accelerating technological development and global technology-based competition. Due to the critical role of technology in a competitive environment, strategic technology management is important for enterprises. For the long-term success, companies must develop and sustain their technological capabilities to create internal and external impacts within an ambiguous socio-economic context.

In the absence of commonly agreed frameworks, elements of strategic technology management are discovered in this dissertation. The research is conducted in the context of high technology product companies, to develop a framework based on literature findings, and by obtaining qualitative information on enterprise practices.

For the framework development, integrated management theory is applied to consider technology management in strategic dimension. The framework consists of *structures*, *objectives* and *impacts* categories, each having six main elements which contain several sub-classes.

In the research, perceptions of enterprise practitioners indicated that the entire field of strategic technology management is confusing and diversely practiced. The contribution of this dissertation is benefiting practitioners by providing an outline to assist in defining and developing the practices. For the main theoretical contribution, the framework unites strategic management, organizational management, and technology management concepts in enterprise context.

As a practical implication, it is suggested that companies should consider establishing and integrating strategic technology management as a distinguishing managerial discipline amongst other organizational functions. Enterprises should consider defining and developing the necessary structures and objectives for strategic technology management, to proactively manage impacts of technology for competitiveness of the enterprise, and for sustainable development of its socio-economic environment.

In conclusion, the framework provides for scholars and practitioners a logical structure to elements of strategic technology management.

*Keywords:* strategic management, technology management

*To Bacchus*

# Preface

The motivation for a research has to stem from the needs of the people, companies and institutes involved.

In the autumn 2007, the researcher was assigned responsibility on developing technology and architecture management practices for product technology in Nokia Siemens Networks. The company was established in the spring 2007 as a merger of Nokia Networks and Siemens Communications. The new company had to start consolidation of the businesses and the company's resources in a fiercely competitive business environment. The intent was to leverage the portfolio of the products and technologies as efficiently and effectively as possible. Consequently, the researcher's principal need was to gain comprehensive understanding on what strategic technology management is.

There are several means to acquire knowledge: learning by doing, attending training, reading books and conducting research. For the researcher, it became evident that there is no single solution that would sufficiently serve the need of gaining knowledge on technology management. Therefore conducting studies and research, and making a doctoral thesis on strategic technology management, appeared feasible to increase personal knowledge on the subject.

For publicly funded institutes, like University of Oulu, it is important to interact with the society to create innovations, promote competences of people and improve competitiveness of companies. Performance of universities is measured, among other things, by the number of yearly graduates and the number of publications. In this respect, conducting research provides opportunities for publications, and also a possibility to involve the researcher in technology management related courses to provide study topics and exercises for the students.

The purpose of this dissertation is to serve the above mentioned diverse needs, and to contribute to discussion on strategic technology management.

# Acknowledgements

Actually, it took some 23 years to complete this dissertation, for which the formal PhD studies were remarkably intensive. Continuous learning and involvement in technology management related duties at Nokia and Nokia Siemens Networks since 1987 can in this respect be regarded as practical university education. Therefore I appreciate guidance, support and contribution of all my superiors, colleagues and team mates during this time. For the latest stint, for which I committed myself for three years, I wish to thank Lauri Oksanen, Head of Research at Nokia Siemens Networks, for a challenging task that he assigned to me, and enabled participation in scientific conferences.

For the opportunity and support during my studies at the Department of Industrial Engineering and Management in University of Oulu, I thank Professor Pekka Kess and all the personnel at the department. I thank Pekka also for providing me insights into strategic management.

For conducting the studies, I am indebted to my supervisor Professor Harri Haapasalo. We had all the time a grand plan, extremely focused parallel activities ongoing, and we were able to proceed steadily in a timely manner banishing waste. To this process of becoming wiser – as Harri phrases it – Harri contributed with his respectable devotion, extraordinary conceptual talent and exuberant joy of life. The entire thesis process was really demanding, rewarding and enjoyable. Thank you Harri, very much indeed.

I highly respect Dr Mike Gregory and Dr Robert Phaal from the University of Cambridge, for their ideas and work on technology management process concepts. During my one month study leave, I was able to make a short visit to Cambridge, to work on a joint paper with Rob and his colleagues. The study leave was financially supported by the Finnish Doctoral Program in Industrial Engineering and Management, which I sincerely acknowledge; it was a very motivating and a productive period. I also want to thank Dr Kari Hakkarainen for interesting discussions on technology management. In the summer 2007, when I was enjoying the extra 2 weeks of summer holiday, granted after 20 years of employment at Nokia, I read Kari's dissertation on strategic technology management, which inspired me to consider trying to write one of my own.

For acting as a tutor in my early study phase, and for all the support, I am grateful to Hanna Kropsu-Vehkaperä who made an enormous effort in arrangements of the first company interviews. I also want to thank Marjut Uusitalo for her assistance in arranging the second interviews. All company

representatives who took part in the interviews deserve thanks for providing their time and knowledge. The almost 50 students, taking part in the research assignment during the technology management courses in the autumn 2008 and in the spring 2009, were of invaluable help in carrying out and documenting the interviews. I want to thank warmly all of you for the good work.

For indispensable advice on writing journal papers, I want to thank the Chief Editors Dr Binshan Lin from Lousiana State University, USA; Dr Kongkiti Phusavat from Kasetsart University, Bankok, Thailand; Professor Angappa Gunasekaran from University of Massachussets, USA; and the anonymous reviewers of the papers for their constructive comments.

In many exhaustive but effective reviews Dr Pekka Belt, Dr Janne Härkönen and Dr Matti Möttönen, the three musketeers from University of Oulu, provided their insights into writing a dissertation summary. We reviewed large and small things, we read between the lines, and we even paid attention to the comma after the dot of *et al.*, whether it is written in italics or in regular font. The review practice definitely advanced the thesis summary writing significantly. Pekka, Janne and Matti, your contribution was priceless.

Pre-examiners of the thesis summary, Professor Dilek Cetindamar from Sabanci University, Istanbul, Turkey and Professor Saku Mäkinen from Tampere University of Technology, Finland also deserve many thanks for their valuable feedback to improve the summary.

I would like to thank my wife Jaana and our delightful black belt level skilled daughters Marjo and Marjaana, as well all my relatives and friends for their encouragement and support. Special thanks to my friend Pekka Seppänen and his neighborhood, I always kept in mind one of the first comments to my plan to make a PhD: “If you start it, you will surely finish it”.

With all the good spirit enjoyed, one starts to think that the ancient cultures were right on their assumption that out there exists something taking care of the fun. And this something, undoubtedly, has incarnated in the form of the most faithful companion, from water fetching agile tracking dog, our beloved poodle – Bacchus.

Now it is time to turn the page, and as always in life: move on.

Oulu, May 2010 Kari Sahlman

# List of original publications

This dissertation is based on the following publications:

I Sahlman K & Haapasalo H (2009) Elements of strategic management of technology: a conceptual framework of enterprise practise. International Journal of Management and Enterprise Development 7(3): 319–337.

II Sahlman K & Haapasalo H (2009) Perceptions of Strategic Management of Technology in Small High-Tech Enterprises. PICMET 2009 Proceedings, August 2-6, Portland, Oregon USA: 93–104.

III Sahlman K & Haapasalo H (in press) Objectives of strategic management of technology in a conceptual framework of enterprise practise. International Journal of Business Innovation and Research.

IV Sahlman K & Haapasalo H (in press) Impacts of strategic management of technology in a conceptual framework of enterprise practice. International Journal of Innovation and Learning.

The article I is already published, and the articles III and IV have gone through a double blind review process and have been accepted for Journal publication in the forthcoming issues.

The article II has been published in the Conference Proceedings of Portland International Conference on Management of Engineering and Technology (PICMET) in August 2009.

The author of this dissertation has been the main author of all the original publications. The co-author has been in the role of reviewer and advisor on the structure, the logic and the contents of the papers as the supervisor of the dissertation and research work.

# Table of contents

# 1 Introduction

## 1.1 Context and purpose of the research

During the past century, competitive, economic and social environment has become increasingly complex due to rapid proliferation of information and accelerating technological development. Already one hundred years ago, in 1911, Schumpeter (1961) proposed that technological change induces emergence, evolution, fusion, and disruption of industries over time. Especially, in high technology industries, global technology-based competition forms a significant managerial challenge for enterprises. The fundamental question is how to strategically manage product offering, value system, product technology, competences and capabilities in the rapidly changing business and technological environment.

The operating environment is perceived as turbulent and complex, and technology has a significant role in productivity, innovations and business model development. Companies are constantly struggling in adapting to ambiguous technology changes, and optimizing investments for new opportunities in the marketplace. Therefore, the underlying need for companies is the capability of creating and executing business and technology strategies for value creation and sustained competitiveness.

Enterprises have evolved from single function optimization of production, marketing or research & development (R&D) to a multifunctional strategic orientation. The need to optimize the company's return on investments and the performance as a whole, calls for strategic management capability in enterprises. (Ansoff 1979, Ansoff 1987.) Several schools of thought have emerged to address aspects of market dynamics, competitive positioning and planning in strategy formation (Minztberg 1978, Porter 1980). The right strategy is critical for enterprises because the distinctive competencies and capabilities, which are created and developed through the execution of the strategies, determine the competitive position and success of enterprises in the marketplace (Learned *et al*, 1969). Various approaches to competitive strategies have emerged, for instance, resource based view to strategy (Wernerfeldt 1984), core competences (Prahalad & Hamel, 1990) and dynamic capabilities (Leonard-Barton 1992, Teece *et al.* 1997, Eisenhardt & Martin 2000). They all consider the strategic substance that a company should possess in order to succeed in the changing environment.

Linking strategic business management with technology management leads into managerial challenges in enterprises, due to the complexity of both disciplines. The attribute of 'strategic' was added to technology management during the 80's by several authors (e.g. Bhalla 1987, Ansoff 1987, Betz 1993). Strategic technology management is expected to offer a potential solution for managing ambiguity, complexity and business dynamics that are caused by technology. Consequently, a holistic concept of strategic technology management is needed to provide clarity for practitioners in the field of technology management. Thus, researchers must be able to combine traditional strategic thinking and the demands of modern high technology industries.

In this dissertation, the term 'strategic', in the context of technology management, is used to emphasize the linkage of technology management to strategic management. Strategic management provides the larger context for strategic technology management, which is the focus of this dissertation. Furthermore, the term strategic is used to distinguish strategic technology management as an own discipline separate from, for example, R&D management and innovation management which embed technology management activities. The topic is handled in the strategic dimension of the structure, provided by integrated management theory of Bleicher (2004). Thus, strategic technology management is positioned apart from normative management and operative management.

In companies, technology management is often embedded in R&D management, which is increasingly incorporating strategic management aspects (e.g. Drejer 1997, Edler *et al.,* 2002). Still, the main activity of R&D management is to organize resources and manage operational R&D work. During the past decades, innovation management has become an extensive research discipline of its own. Innovation research has created knowledge on the innovation process itself, but does not provide a comprehensive framework on innovation management practice. The major concern in innovation management is how to recognize the value, and how to assimilate and apply knowledge commercially in products (e.g. von Hippel 1988, Pavitt 1990, Cohen & Levinthal 1990, Tidd *et al.* 2001). Technology management relates to innovation management with the perspective on how to acquire knowledge and transfer technologies into innovative products. However, neither R&D management nor innovation management considers strategic technology management holistically from viewpoints of strategic objectives, organizational structures and effects of technology.

Profound understanding and capabilities on technology management are crucial for the companies, due to the critical role of technology in creation and execution of company strategy (e.g. Burgelman *et al.* 2001, Chiaromonte 2003, Dodgson *et al.* 2008). Scholars in the field of strategic management and technology management have been studying technology management for some 30 years as a discipline of its own. Nevertheless, there are no commonly accepted theoretical and practical frameworks for technology management (e.g. Drejer 1997, Phaal *et al.* 2000, Phaal *et al.* 2004, Brent & Pretorius 2008, Cetindamar *et al.* 2009b). Technology management is typically not organized in enterprises as a distinguishable managerial function, either.

The purpose of this research is to contribute to the discussion on strategic technology management.

Technology management is related to several scientific disciplines (Khalil 2000, Dodgson *et al.* 2008). These relations and the role of technology are exemplified, for example, in research of the following areas:

- social and economic objectives, outcomes and evolution of industries
- organizational structures and strategic management of enterprises
- knowledge, information, innovation and engineering management
- engineering practices, methods and tools

This dissertation on strategic technology management is positioned within the discipline of industrial engineering and management. The context of this research has a specific focus on product technology within high technology enterprises.

## 1.2 Scope and objectives

Competitive environment of enterprises involves increasing complexity due to rapid changes in economic, social and technological circumstances. Therefore, effective capability on strategic technology management is crucial for enterprises. Current state-of-practice within high technology enterprises indicates deficiencies in knowledge and practices of strategic technology management. Moreover, literature on theoretical frameworks is inconsistently covering this complex arena, and it is difficult to find practical and theoretical overviews on these issues. Accordingly, the research problem is formulated as:

> *Practitioners and scholars are lacking a comprehensive frame of reference that describes elements of strategic technology management.*

In the absence of commonly agreed frameworks for strategic technology management, the intent of this research is to create a theoretical model that describes elements of strategic technology management. For the purpose of this research, and to outline the scope of the research, strategic technology management is defined as:

> *"Strategic management of technology is management of technological activities, interacting with company's technology infrastructure and socio-economic environment, to contribute to formulation and execution of the company's strategy." (Sahlman &Haapasalo 2009a)*

Strategic technology management activities have to be linked with the strategy of the company. The purpose is to combine technology and business issues within the scope of strategic management. Ordinary strategic management activities typically focus on business and product aspects of a company, whereas strategic technology management emphasizes the connection and transformation of business aspects to technology subjects. The research objective is to create a theoretical model that distinguishes elements of strategic technology management while enabling integration of the elements within the context of strategic management in an enterprise.

The research results are assumed to be applicable, in general, for high technology enterprises. Thus, the framework is meant to assist practitioners in conscious and systematic development of strategic technology management practices in enterprises. The framework is also intended to provide a theory basis for further amendment by scholars in the field. The generic objective of the research can be summarized as an intention to create a theoretical framework, to provide structure to the topics of strategic technology management for analysis, presentation, communication and discussion among practitioners and scholars.

In order to derive adequate research questions, suitable viewpoints were needed to dismantle the research problem into relevant areas of enterprise management. Obviously, there would have been several alternative starting points for the study, for example, process view, capability view, and corporate strategy view. The integrated management model of Bleicher (2004) was found to provide the necessary viewpoints covering comprehensively enterprise management. The model has been applied by Tschirky (1991) to link technology management conceptually as an integrating function with general management issues, and by Luggen & Tschirky (2003) in the context of small to medium sized enterprises.

The integrated management model contains normative, strategic and operative management viewpoints to structures, objectives and behavior of an organization. Conceptually, it provides vertical integration of normative, strategic and operative dimensions, and horizontal integration of structures, objectives and outcomes of the operational activities. The principles of the integrated management concept are described in more details in Chapter 2.2.2.

This kind of integrated management viewpoint entity exists in organizational theory, but does not exist in technology management to comprehensively describe the issues. Consequently, the integrated management model of Bleicher (2004) was selected as the starting point for the framework development. In the research, the focus is to discover elements of technology management in a strategic management dimension. From a technology management point of view, operative management is assumed to contain management of operative activities to perform the actual tasks of technology management, for example, management of roadmap creation, technology forecasting activity, or creation of a technology strategy. Normative management dimension is assumed to contain the legal, institutional and cultural factors and policies related to technology management, for instance, whether a company has its own R&D, structure for centralization or decentralization, policies towards intellectual property acquisition, protection and licensing, fostering innovative culture, or development and utilization of internal processes. Normative and operative dimensions are excluded from the scope of this research.

Accordingly the research problem was approached through the research questions listed in Table 1.

**Table 1. Research questions and related articles.**

| RQ# | Research question | Article # |
|---|---|---|
| RQ1 | What are the *elements* of strategic technology management and how to categorize them into a framework? | I |
| RQ2 | What are the *structures* of strategic technology management as elements of the framework? | II |
| RQ3 | What are the *objectives* of strategic technology management as elements of the framework? | III |
| RQ4 | What are the *impacts* of strategic technology management as elements of the framework? | IV |

Each of the main research questions is answered in more detail in a research article. The four articles constitute the description of the strategic technology

management framework. Theoretical contributions and managerial implications of these articles are presented in this dissertation summary.

Article I lays the overall foundation for the framework, and describes the key principles and the initial main categories. Articles II, III and IV respectively describe *structures, objectives* and *impacts* categories of the framework. The logic of the framework is adopted from the integrated management theory model of Bleicher (2004). The overview of the framework and the relation of the articles are presented in Figure 1.

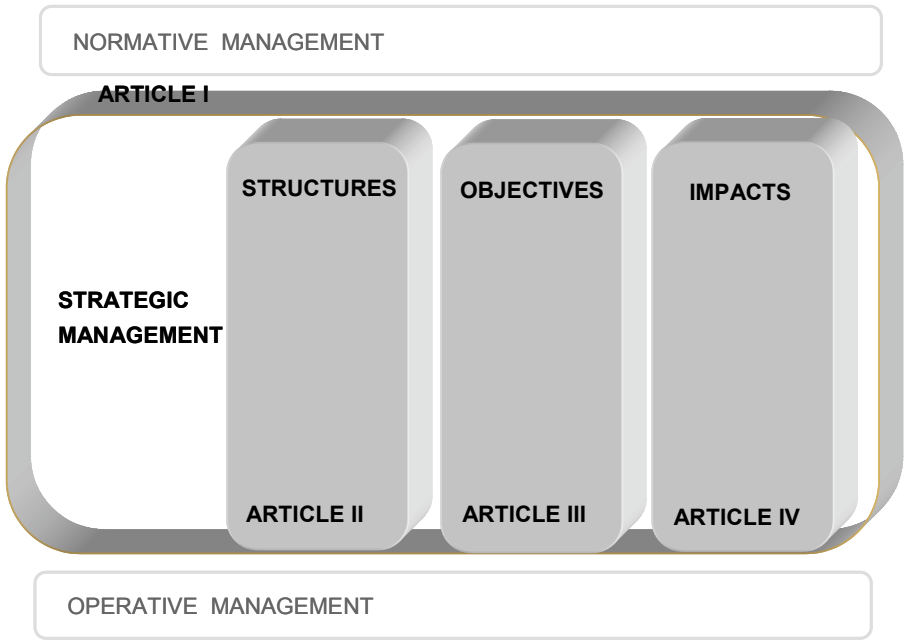


**Fig. 1. Positioning of the articles in the framework as outline of the study.**

## 1.3 Research approach

Particular research approaches adduce specific knowledge that is characterized by its truthfulness and correspondence to reality. The researcher must contemplate aspects relating to philosophy of science, scientific methodology, research process and available resources when attempting to solve his research problem (e.g. Niiniluoto 1980, Arbnor and Bjerke 1997, Lancaster 2005). The desired qualities

of the scientific knowledge influence the selection of the research approach and methodology. Consequently, the research approach affects the definition of research questions. In practice, availability of time, money, research personnel, materials, people's knowledge and interest in the research affect the research approach.

The following rationale explains the research approach used in this dissertation. The main considerations are presented in Table 2.

**Table 2. Key considerations of the research approach.**

| Topic | Approach | Explanation |
|---|---|---|
| Ontology | Pragmatism | Knowledge has representation in objectivistic-rationalistic reality. Knowledge created is subjective and conceptual in the form of a framework for strategic technology management. |
| Logic of reasoning | Mainly abductive | Inference to find best possible explanation for the theory. |
| Type of research | Explorative & Descriptive | Clarifying understanding, seeking insights to the subject. |
| Type of data | Qualitative | Using qualitative data to describe the subject. |
| Method to obtain data | Questionnaire<br>Literature<br>Documents | Obtaining qualitative data on the subject through interviews, literature study and documents of an enterprise. |

Ontological perspective to the objective or subjective reality under research determines the research paradigm and the choice of theoretical concepts (Saunders *et al.* 2007). In this research, ontology is pragmatic: the research provides subjective knowledge which has a representation in objective-realistic reality. It is assumed that explicit and tangible objects represent objectivistic-rationalist reality, whereas intangible objects represent information about the reality. These objects can be, for example, products, documents containing information on organizational structures and objectives, information on socio-economic circumstances or technological phenomena, or un-codified knowledge.

The research problem and objectives of the research have to be considered when selecting the research approach and making the research design (Saunders *et al.* 2007). The objective of this research is to create a theoretical framework for strategic technology management to solve the research problem. The research objective could be achieved by studying the objective reality and information about the reality, and by using inductive reasoning to discover the framework. The objective could also be achieved by creating a hypothetical framework and testing it in reality using deductive reasoning. Due to practical constraints of

resources and availability of information, and due to restricted access into enterprises to make observations, these approaches were abandoned. In addition, the entire subject was considered to be extremely vague for building a hypothetical framework for deductive testing of the hypothesis. Instead, an abductive approach was selected to gather understanding on conceptual knowledge that represents the objective reality, in the form of scholarly literature and perceptions of industry practitioners.

Abductive reasoning is a suitable approach in qualitative research because it enables theory building through simultaneous data collection and theory development (Dubois & Gadde 2002). The objective of abductive reasoning is to gain understanding on the subject or phenomenon under study for theory development (Arlbjörn & Halldorsson 2002). The development of a theory to correspond empirical observations is called *theory matching* or *systematic combining*. Thus, there is interaction during the theory development and the empirical study. The iterative process contains creative elements and continuous learning aiming to increase understanding of the subject (Taylor *et al.* 2002, Dubois & Gadde 2002, Kovács & Spens 2005). In this process the researcher can creatively contribute on theory building by allowing the framework to evolve despite the preconceptions (Dubois & Gadde 2002). To allow evolvement of the framework during abductive reasoning, inference is explored from the interrelated information for possible explanation to the object under study (Dubois & Gadde 2002).

According to Saunders *et al.* (2007) exploratory and descriptive studies are well suited to clarify understanding and to seek for new insights into the topics under study. In this research, literature and perceptions of enterprise practitioners is explored to describe elements of strategic technology management in a theoretical framework. In the abductive approach, the researcher is strongly involved in the research process in theory building and seeking for inference. Due to the nature of the data on conceptual knowledge to be collected, and due to the researcher's role in the process, the knowledge created in this research is subjective. As theoretical frameworks and concepts of technology management are still vague, quantitative research was not considered reasonable.

In this research, qualitative research methodology was pursued. The purpose of qualitative research is to create understanding on the subject under research and to theoretically describe the subject (Yin 2003). Research methodology must comply with the boundary conditions of the research problem, objectives, resources and approach, and with the nature of the knowledge to be created (e.g.

Yin 2003). Accordingly, structured interviews in high technology product companies were selected as the main method for collecting data.

It was also known that certain materials concerning the topics under research were available and accessible in the company where the researcher is working. The materials were considered to be suitable to allow the use of the grounded theory method, for theory building of one part of the framework. In grounded theory, the theory emerges from the process of data collection and analysis (Glaser & Strauss 1967, Strauss & Gorbin 1990). In the method, theory is explored without a predetermined framework, although preconception is required in order to estimate what kind of data has to be available and what aspects to look for from the data. These aspects are the interests of the research subject and make the research findings meaningful for the research purpose. The approach presented by Strauss & Gorbin (1990) allows the use of preliminary data, and the process of finding the best explanation to the phenomenon is mainly abductive. It also acknowledges the subjective nature of the research and involvement of the researcher during note taking, coding, memoing and sorting. Use of grounded theory as qualitative method for one part of the research is appropriate to the chosen research approach.

During the research design, the methodology for collecting and analyzing the data needs to be carefully considered to ensure reliability and validity of the results (e.g. Yin 2003, Saunders *et al.* 2007). According to Bryman & Bell (2007), in qualitative research reliability and objectivity is about dependability and conformability of the results. The researcher has to consider, are the results applicable at other times, and has the researcher's own subjective values influenced the results. Credibility relates to the internal validity, and transferability is concerned with external validity of the results, that is, how credible the results are and whether they are transferable to another environment.

The entire field of technology management is extensive, and on specific topics there exists profound knowledge, methods and practices separately. Therefore, the scope of this research covers the viewpoints that are needed to describe and define in the framework the elements that are relevant for a product company. This research approach was elaborated and realized during the proceeding of the research.

## 1.4 Research process

The research was conducted in four major phases involving industry practitioners, and university personnel and students as research assistants. As the result of each study phase, a journal article was created about the entire framework or a part of it. The overview of the proceeding of the research is presented in Figure 2.

Starting from the original research problem, the first phase literature was studied to gain understanding on the key concepts and existing theoretical frameworks on technology management. Based on literature analysis, the integrated management theory approach was considered and a *draft entire framework* was outlined. In order to obtain practical views on the topics, two workshops were arranged to elicit conceptions of industry practitioners. The workshop findings confirmed that the entire field was confusing, and that there is need for a conceptual model. Also, logical consistency of the draft framework was confirmed, and accordingly, the *initial entire framework* was formulated.

After the completion of the first research phase, the research approach and the research questions were refined for the subsequent study phases. The *structures* and the *impacts* categories of the framework were decided to be studied through qualitative questionnaires in high technology enterprises. The *objectives* category was decided to be derived from the available company materials using grounded theory method.

The initial framework model was used to derive a structured questionnaire for the company interviews in the second study phase. The interviews were conducted in small to medium-sized enterprises. This class of companies was selected as the target group to enhance the interviewee base, because the initial framework was reflecting conceptions of large company representatives. The interview materials were analyzed and a study report was written on the interview findings. Consequently, the *structures* category of the initial framework was refined and validated in this study phase.

The third study phase was conducted using the materials of the company in which the researcher works. The materials were memorandums on particular technology management related decisions in the company over a two year period. Thus, the materials were not specifically collected for this research purpose. Grounded theory was used to derive the *objectives* category of the framework.

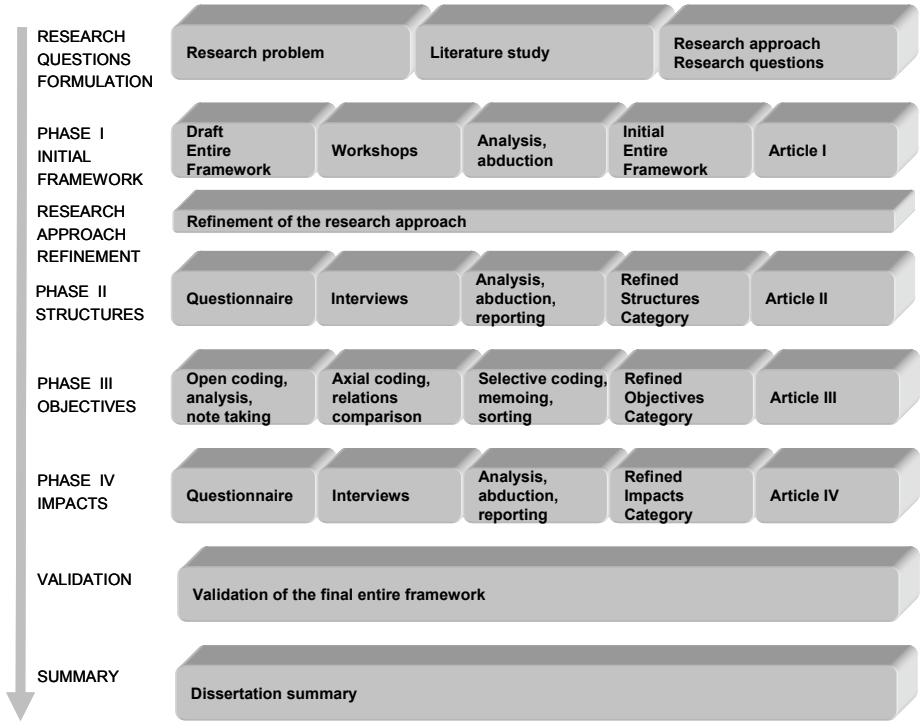


**Fig. 2. Proceeding of the research according to phase of each article entity.**

The fourth major study phase was similar to the second phase. The scope of the interviewed companies was targeted to be of all sizes in order to obtain diverse perceptions. The only requirement was that the company should be a high technology product company. In this phase, the *impacts* category of the initial framework was refined and validated.

In each of the articles, the research process of the related study phase and conclusions of the results are presented and discussed in more detail.

After completion of the research phases and creation of the articles for each category of the framework, validation of the *entire framework* was conducted. For the validation, five experienced industry practitioners were interviewed to evaluate relevance and current state of practice for each element of the framework. The persons have 24-30 years of experience in global high technology companies as company founders, owners, and chairmen of the board, chief-executives and

R&D directors. The companies in which the interviewees have been involved are consumer and industrial electronics, telecommunications equipments, R&D sub-contracting services and SW products for mobile communications, all having customers and competitors globally. In the interviews, the framework concept was briefly presented, and for the evaluation, the category descriptions of Tables 6, 7 and 8 were used. The interviews were held in Finnish language, recorded and lettered. In the evaluation, scale from 'not relevant' (1) to 'extremely relevant' (10), and 'not practiced' (1) to 'well established' (10) was used. The evaluation results and their averages are shown in Appendix 1. The results of the validation phase are discussed in the summary chapter of research contribution (Chapter 3.5), and validity of the framework is discussed in Chapter 4.3.

Finally, the summary of the dissertation was created. Table 3 summarizes industrial involvement and the materials used in the research phases. In phase I, there were 24 experienced industry representatives from 7 companies involved in two workshops. In phases II and IV, interviews were carried out in a total of 32 companies and involved 41 people. In phase III, materials from a case company were used covering 55 meeting minutes and 125 decision items on technology matters. In the validation phase, 5 people were interviewed.

**Table 3. Industrial involvement and the materials used in research phases.**

| Phase | Part of the framework | Nr. of companies | Nr. of persons | Nr. of workshops | Nr. of interviews | Nr. of memos | Nr. of topics |
|---|---|---|---|---|---|---|---|
| I | *Initial framework* | 7 | 24 | 2 | - | - | - |
| II | *Structures* | 18 | 25 | - | 18 | - | - |
| III | *Objectives* | 1 | - | - | - | 55 | 125 |
| IV | *Impacts* | 14 | 16 | - | 14 | - | - |
| Validation | *Entire framework* | 5 | 5 | | 5 | | |

# 2 Theoretical background

Strategic technology management is related to several theoretical concepts and management disciplines. The body of knowledge in strategic technology management is intertwined with abundant aspects of strategic management, organizational management, knowledge management, innovation management and R&D management (e.g. Steele 1989, Khalil 2000, Burgelman *et al.* 2001, Tidd *et al.* 2001, Schilling 2008, Dodgson *et al.* 2008). Each of the areas has a large amount of detailed knowledge and diversely consistent empirical findings, practices, concepts and theories. The entire field of technology management is divergent, the boundaries of the concepts are blurred, and the knowledge and research interests differ remarkably in different parts of the world (Pilkington & Teichert 2006, Cetindamar *et al.* 2009a). The theoretical foundation of this dissertation builds on the relevant concepts of strategic management, organizational management and technology management that provide an adequate theoretical basis for the framework development. Therefore, knowledge management, innovation management, and R&D management have been excluded from the study scope. The focus of this dissertation is to create contributions for a strategic technology management school (see Drejer 1997), to integrate business, technology and organizational aspects. The context of the framework, as presented in Figure 3, is outlined essentially with respect to strategic management, organizational management, and existing concepts on technology management.

In the large context, people as actors in environment, society and enterprises, form various stakeholder groups, for example, scientists, engineers, entrepreneurs, managers, consumers and individuals that engender knowledge, artifacts and wealth through their activities. In this context, an enterprise exists for wealth creation on the basis of a legal agreement with the government representing the society. In enterprises, managed activities of people utilize tangible resources that are derived from a physical environment to produce artifacts into the environment and society. To close the loop, knowledge of nature and society is utilized by enterprises. The strategic technology management framework, in the scope of this dissertation, is considered within this context with a focus on product technology in an enterprise.

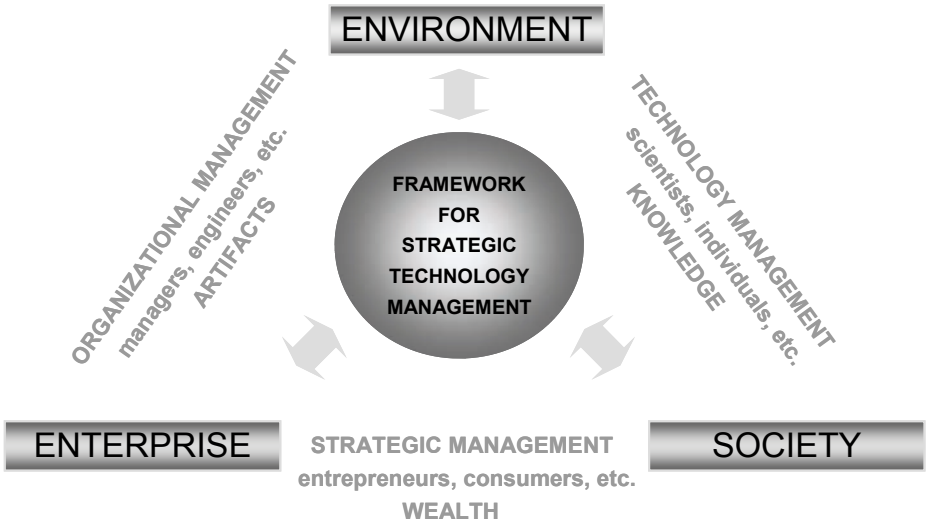


**Fig. 3. Context for creating strategic technology management framework.**

## 2.1 Strategic management

Classically, company's strategy is defined by Chandler (1962: 7) as *"determination of the basic, long-term goals and objectives of an enterprise and the adoption of courses of action and the allocation of resources necessary for those goals"*. Strategic management is concerned with the company's initiatives taken by the management, to create, enhance and sustain its capabilities regarding its environment, and to reach the company's objectives (Ansoff 1979). Conceptions on what is strategy and strategic management have evolved and fragmented over the years (Whittington 2001, Drejer 2004, Bigler 2009). According to Nag *et al.* (2007), amongst strategic management scholars, the implicit consensus definition for strategic management is: *"The field of strategic management deals with the major intended and emergent initiatives taken by general managers, on behalf of owners involving utilization of resources, to enhance the performance of firms in their external environments"*. The definition covers explicitly aspects of environment, society, enterprise; organization,

management, people; knowledge, outcomes, and value creation, which all have reflection to the context of the framework for strategic technology management.

Strategic technology management attempts to address technology related matters contained in the field of strategic management. In the scope of strategic management, Pilkington & Teichert (2006) identify seven research themes and core disciplines for technology management: strategy and technology; national technology management systems; sources of competitive strategy; manufacturing, operations and new product development; knowledge management; inventions and patents management; life-cycles and discontinuities. In this dissertation, the interest point is in linking strategy and technology by means of strategic technology management within strategic management of an enterprise. In the following, strategic management themes of value creation and business models, strategy formation and execution, competitive strategies and technology strategy, are discussed to form the theoretical foundation from a strategic management literature perspective, for the strategic technology management framework development.

### *2.1.1 Value creation and business model*

The purpose of an enterprise is to create value throughout the value chain for customers, owners, personnel and society (Ansoff 1979). In macro-economic scope technology and innovations within the value creation systems, are a major source for productivity, economic growth and increasing wealth in socio-economic environment (Solow 1957, Denison 1962, Nelson & Winter 1982, NRC Council 1987). Furthermore, companies are affected by continuous technological developments and innovations that are changing the value creation systems and lead to the evolution of entire industries.

For value creation, a company has to define and execute the strategy, in order to develop the required capabilities regarding to customer, financial, business processes and learning perspectives (Kaplan & Norton 2004). Through creation and execution of a certain strategy, the company is actually structuring its position in the market and in the value chain (Porter 1985). This position is fundamentally defined by the business models that a company pursues for achieving its mission (e.g. Chesbrough 2006). In simple terms, a business model consists of offering, value creation system and revenue model, although contemporary conceptualization of business models is often inadequate when applied in practice (Suikki *et al.* 2006, Mäkinen & Seppänen 2007).

The composition and involvement of technology in each of the business model elements determine the objects and aspects that strategic technology management is concerned with in the enterprise context. Within micro- and macro-economic scope, the paramount interest in strategic technology management is to proactively manage technology of an enterprise for sustained value creation, and survival amongst business model changes and industry evolution that are enabled by advancements in technology.

### *2.1.2 Strategy formation and execution*

Strategy is crucial for value creation, long term success and survival of the company. Nevertheless, there is no common agreement on what a corporate strategy is and how to establish a successful strategy (e.g. Mintzberg 1978, Porter 1996, Markides 1998, Grant 2003). The main perspectives to strategy formation are the distinctive characteristics regarding to the strategy creation process, rationale and focus of the strategy. The defined meta schools of strategy are rational, evolutionary, processual and systemic (Whittington 2001). Minztberg *et al.* (2005) have defined and described three prescriptive schools of strategy: design, planning and positioning, and seven descriptive schools of strategy: entrepreneurial, cognitive, learning, power, cultural, environmental, and configuration. There is no clear empirical evidence which strategy formation style provides the best outcomes and how companies actually create their strategies (Grant 2003). The main debate is about whether a successful strategy can be planned or should it be emergent.

During strategy formation, technology aspects must be considered properly as technology is involved in all activities that constitute the company's value system (Porter 1985). Therefore, business and product strategy has to embed technology matters, for instance, business and technology strategies have to be aligned to ensure company's performance and competitiveness, or alternatively, technology strategy has to be derived from the business strategy (e.g. Burgelman *et al.* 2001, Momaya & Ajitabh 2005, Mei & Nie 2008, Dodgson *et al.* 2008). Construction of a business strategy is a challenging managerial task of its own. Adding the more abstract dimension of technology in strategy formation increases the complexity and uncertainty even further. Dynamics and uncertainty of technological developments are the main concerns in strategy formation of enterprises with respect to technology (Paap & Katz 2004).

In the fast changing and unreliably predictable business and technology environment, another challenge for the companies is management control of the firm's technological evolution (Ansoff 1987). Proliferation of technologies and innovations in the market place, as well management of product life-cycles and product substitution, enabled by technology, has to be mastered in companies (e.g. Dewar & Dutton 1986, Foster 1986, Anderson & Tushman 1990, Moore 1991, Christensen 1997, Scott 2000). Therefore, due to the critical role of technology in strategies of a company, the conduct of strategic technology management is inevitable. These constituents of the business environment increase managerial complexity of strategy making and strategy execution (e.g. Bossidy & Charan 2002, Mankins & Steele 2005, Sull 2007, Kaplan & Norton 2008).

### *2.1.3 Competitive strategies*

For achieving its mission, long term goals and objectives in the market, a company executes a strategy, which may be prescribed or emergent. The classical approach to a company's strategy, as formed by Chandler (1962) and Ansoff (1965), is based on rational analysis, separation of strategy making from execution, and profit maximization as the main goal of strategy. Contemporary thinking is that companies have to consider also social, political, environmental, risks, security, sustainability and business continuation related aspects in their strategies and technology management (Thomsen & Pedersen 2000; Brent & Pretorius 2008). The strategy determines the distinctive competences and capabilities that are critical for the company's success in execution of the strategy and achieving the company's mission amongst competition (Learned *et al.* 1969).

The main school of thought about competitive strategy is Porter's positioning approach, which is about attempting to achieve a sustainable competitive advantage for the company by preserving what is distinctive about the company within the industry (Porter 1996). This means performing different things from rivals, or doing things differently compared to rivals. Fundamentally, the competitive scope and source of competitive advantage determines the type of competitive strategy, which can be either generic or focused cost leadership, or differentiation (Porter 1980). The concept of core competency (Prahalad & Hamel 1990) suggests that strategy is an integrated and coordinated set of actions to exploit competencies, in order to gain a competitive advantage in the business that a company pursues.

It has been argued that a competitive advantage cannot be sustained in the changing environment, and that it is the dynamic capabilities that determine the company's success (Leonard-Barton 1992, Teece *et al.* 1997, Eisenhardt & Martin 2000). Dynamic capabilities are the organizational and strategic routines by which management develops, integrates and reconfigures the resource base that the company has (Grant 1996). The resources are the physical, human and organizational assets that a company utilizes for its value creation strategies (Wernerfelt 1984). Strategies that are not resource based will not be successful in a turbulent industry environment. Eisenhardt & Martin (2000) have the opinion that resource based strategy collapses in unpredictable high-velocity markets. In technology-based industries, knowledge is the major source for competitive advantage and success, and knowledge as a strategic resource constitutes a new management paradigm for enterprises (e.g. Grant 1996, Hitt 2000, Kess *et al.* 2008).

### *2.1.4 Technology strategy*

Technology has to be connected with the firm's business strategy by considering importance and relation of technologies to the company's generic competitive strategy. Also, technology must be connected to the firm's strategy on products, services and processes throughout its value chain activities (e.g. Porter 1985, Meyer & Lehnerd 1997, Cooper *et al.* 1998, Burgelman *et al.* 2001, Schilling 2008, Dodgson *et al.* 2008).

In order to effectively react into technological changes, a company must be capable of assessing dynamics of the life-cycle of the technologies it uses or intends to use, and recognize events that may lead into disruption (e.g. Anderson & Tushman 1990, Henderson & Clark 1990, Christensen 1997). Capabilities and characteristics of technology have to be evaluated, developed and leveraged across the company, according to its technology, product and business strategy.

Technology strategy is one of the key elements in strategic technology management. Technology strategy serves as the basis for business strategy and competitive advantage. It helps answer the questions such as, which technologies, competences and capabilities are needed for competitive advantage, which technologies are to be used, what should be the investment level on technology development, what is the make or buy strategy, how to introduce technology to the market as embedded in products, and how to organize technology development and technology management (Burgelman *et al.* 2001). The scope

and importance of a technology strategy is often recognized in companies, but the existence of an explicit technology strategy varies even in high technology companies (Kropsu-Vehkaperä *et al.* 2009).

The definition and purpose of technology strategy is quite unified in literature, although every author has their own flavor in the definition. The actual content varies enormously depending on industry, enterprise business context, size and life-stage (Pavitt 1990). According to definition by Burgelman *et al.* (2001), technology strategy is concerned with linking technology with the firm's competitive strategies, and this can be the basis of the overall strategy. It is fundamental to integrate all areas of management of technological innovation into a coherent whole. Technology strategy comprises of the definition, development and use of those technological competencies that constitute the company's competitive advantage (Dodgson *et al.* 2008).

Strategic approach for developing and leveraging technology depends on the competitive strategy that the company is pursuing. Depending on the company's strategic intent, competitive position, resources and capabilities, it has a variety of strategic choices on how to direct its investments in technology, and how to align technology with business strategy. Competence and capability view to technology strategy requires a company to take a position in its value chain activities. Accordingly, this leads into a need to balance investments in resources and capabilities, and into decisions to consolidate, differentiate or diversify those (Dodgson *et al.* 2008.).

Factors shaping the technology strategy comprise of internal and external integrative and generative forces. These forces are in interaction with organizational and industry context, strategic actions and technology evolution (Burgelman *et al.* 2001). Determinants of technology strategy are presented in the Figure 4.

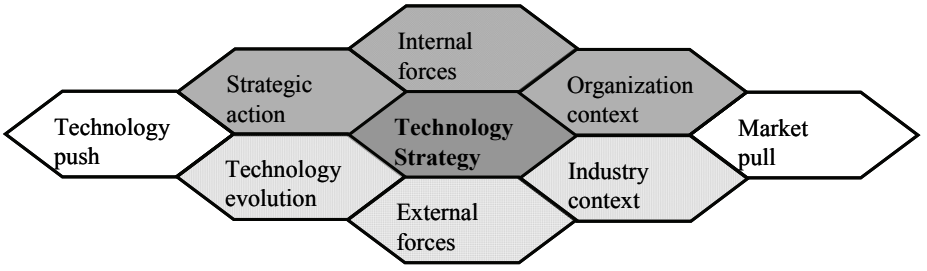


**Fig. 4. Determinants of technology strategy.**

Technical capabilities and competitive advantage of a company are affected by technology evolution, maturity, life-cycles, and competence building or destroying technological disruptions (e.g. Rothaermel & Hill 2005). Also, industry structures, dominant designs (Utterback & Abernathy 1975) and complementary assets' availability, standards, intellectual property rights and their protection have an essential impact to the pursued technology strategy and business attractiveness.

In internal environment, strategic actions must overcome the internal inertia and to react on external signals about technology evolution and business opportunities. Organizational context deals with management challenges, to address exploitation of opportunities within existing strategy or emerging opportunities that require strategy changes. The ability to balance between the two is characterized by organizational agility and the culture of the firm (Doz & Kosonen 2008).

## 2.2 Organizational management

### *2.2.1 Key concepts of organizational management*

Company management needs to define and conduct initiatives to achieve the objectives and long term goals to fulfill the mission of the company. The initiatives are completed in organizations through people who are being managed through the management process. The generic functions of management process are planning, organizing, leading and controlling (Robbins & Coulter 1996: 8). Galbraith (1977: 3) defines organization as *"Organizations are composed of people and groups of people in order to achieve some shared purpose through a division of labor, integrated by information-based decision processes continuously through time"*. Since the start of industrial revolution, theories and models of management and organizations have been developed, for example, about division of work, decision-making, organizational structures and dynamics, and people's behavior and motivation in organization (e.g. March & Simon 1993, Galbraith 1973, Mintzberg 1979).

The structure of an organization can be a source of competitive advantage (Galbraith 2002), and it has been realized that managers need to understand the principles of designing organizations in order to capture the potential advantage. In organizational design, the fundamental opposing decisions are the division of

tasks and integration or coordination. The division of tasks can be based on function, process, and knowledge (Mintzberg 1983). The general forms of organizing are functional, divisional, matrix, and networks (Daft 2004). Integration or coordination is about management of activities that take place in various parts of an organization and co-ordination is needed to accomplish the organization's overall task (Mintzberg 1983).

Organizational structures and functional specialization have led into difficulties to work across the functional barriers. Consequently, finding the optimal degree of functional de-centralization versus integration or co-ordination is a challenge in organizational design (Sherman 2004, Turkulainen 2008). In addition to organizational design challenges, managers are also challenged by the need to possess a variety of competences, for conducting the managerial tasks. Managers in organizations need technical, human and conceptual skills and competences, and the relative importance of the skills varies according to manager's level in organization (Katz 1974), which means that at the lower level of organization technical skills are emphasized.

Over the decades of the last century, companies have evolved from single function orientation to multi-functional strategic orientation (Ansoff 1987). This movement is induced by increasingly accelerating industry evolution, emergence of new business opportunities, and disruptions in the competitive landscape, driven by complex and indefinite technological development. Instead of optimization of a single function, companies need to strategically integrate and align goals and actions of functional units across the company (e.g. Tushman & O'Reilly 1996, Swink *et al.* 2007). This involves the company's management to consider comprehensively, not only manufacturing, marketing, purchasing, research or engineering functions, but also attitudes, skills, decision-making, information systems, organizational structures and planning practices to accommodate the changes in business environment (Ansoff 1987). Transformation to multifunctional strategic orientation implies capability to strategically manage technology, for instance, anticipate technological change, evaluate business potential and risks of technologies, control proliferation of technology in products, and manage technology substitution (Twiss & Goodridge 1989). Effectively, creation of such capability in an enterprise means establishment of a technology management function, which can be organized as embedded within existing functions or as a distinctive function of its own.

### 2.2.2 Integrated management concept

Ambiguous business environment sets high standards for enterprise management to cope with complexity and to adapt to changes. In demanding business situations, management needs to make the right assessment and correct decisions, which may have a long-term impact to company operations. However, time to react is short due to dynamics in environment, decisions have to be made with limited information available, and final outcomes of the decisions are hard to predict (March & Simon 1993). The amount of information increases continuously, and information proliferates globally, causing rapid advances in technology and business processes. In the global perspective, competition, social, demographical, political and environmental aspects have to be considered in company endeavors. These changes necessitate a comprehensive approach to enterprise management.

Integrated management concept of Bleicher (2004) attempts to provide a systematic method into management thinking and decision-making. In the integrated approach to enterprise management, the main objectives are to secure survival and development capabilities for an enterprise, to avoid partial solutions to the problems, and to see dependencies of an organizational entity. The concept is non-prescriptive as the actual contents depend on the context that it is applied in. The integrated management model is presented in Figure 5.

In this conceptual model, the networked interactions of the system elements form the entity. The model is composed of the dimensions of normative, strategic and operative management. Normative and strategic dimensions deal mainly with outlines and plans. Operative management is about directing the actual execution of the activities according to the plans. The managerial dimensions are logically separated, based on differences in the problem areas that company management has to deal with. Conceptually, there is interaction between the dimensions, including feedback between the plans and execution. Normative management covers general goals of a company in the form of legal structure, principles, policies, norms and governance rules that intend to secure the company's viability and development capability. Strategic management focuses on building, and exploiting the competitive potential of an enterprise, for which resources need to be assigned. Normative and strategic management dimensions are transformed into operative execution of the activities, according to the goals and objectives of a company. The function of the operative management is to direct the execution that impacts on the capabilities and resources of the company. (Bleicher 2004.)

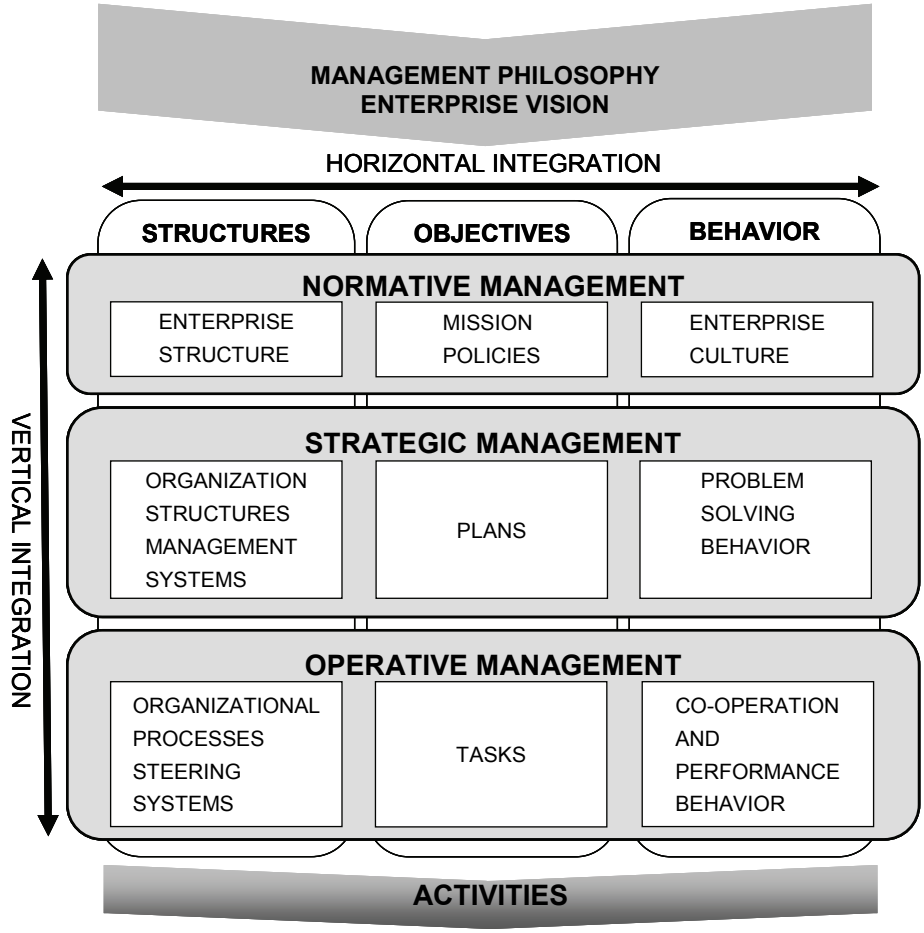


**Fig. 5. Conceptual integrated management model.**

Each of the management dimensions has horizontally integrated aspects of activities, structures and behavior, which all need to be aligned and integrated also vertically. The activities are derived from operative tasks, strategic programs, and normative mission. Objectives of the tasks, programs and missions constitute the objectives of a company at the respective management dimension. The objectives get integrated and aligned when realized as activities.

Similarly, vertical integration between the management dimensions for management structures takes place in the form of a normative constitutional

governance structure of a company in the normative dimension, organizational structure and management systems in the strategic dimension, and operative steering structures in the operative dimension. The path dependent behavior, represented as the company culture at a normative dimension, defines the future behavior of people in a company when strategic and operative managerial tasks are handled. This is manifested in roles and problem-solving behavior of people.

The task of the strategic management dimension is to influence the behavior in the operative management dimension. At the operative dimension, behavior is represented as work performance and co-operation capability of people when activities are performed. Through these mechanisms, horizontal and vertical integration of normative, strategic and operative dimensions, and the aspects of structures, objectives and behavior, are realized. (Bleicher 2004.)

As a summary, the integrated management concept provides a framework for analysis of the managerial problem fields, and it establishes a logical order to analyze managerial dimensions and the aspects of each of these dimensions. It also offers a progression model for conception of the solutions to the problems in the context of enterprise development, and assists in self-reflection and dialog in positioning the situations and intentions. In this research the integrated management model is adopted to provide viewpoints regarding to *structures, objectives* and *impacts* categories of strategic management dimension.

## 2.3 Technology management

### *2.3.1 Key definitions*

The definition and understanding of the term *technology* is somewhat problematic. In general, every term has its formal expression and intention that relates the semantic associated to the term, and extension that relates the references associated to the term (Niiniluoto 1980: 118). Every author and user of the term *technology* has their own intention and knowledge about the possible extensions of the term. Consequently, definitions used in literature have different flavors, for example, technology for products, manufacturing, information, capabilities, value chain processes, competitive advantage, and technology as an outcome of research or innovation (e.g. Porter 1985, Steele 1989, Khalil 2000, Dodgson *et al.* 2008). Considering etymology of the word technology as ‘techne’ and ‘logos’ from the Greek language, the term *technology* can be translated into the definition of skill to apply proper techniques (Hakkarainen 2006) or practical application of

knowledge (Webster 2010). Burgelman *et al.* (2001: 4) defines technology as *"technology refers to theoretical and practical knowledge, skills and artifacts that can be used to develop products and services as well their production and delivery systems. Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment, and tools"*. The definition of Burgelman *et al.* (2001) is applied in this dissertation.

Technology management is defined by several authors and institutes like National Research Council of U.S.A. (1987) and European Institute of Technology and Innovation Management (2010). Gregory (1995) has proposed a definition based on a generic process view to technology management. The generic processes of identification, selection, acquisition, exploitation and protection are also included in the definition of European Institute of Technology and Innovation Management. Cetindamar *et al.* (2009b) have summarized the definitions of several authors (e.g. Roberts 1988, Gregory 1995, Rush *et al.* 2007, Dodgson *et al.* 2008, Levin & Barnard 2008). Cetindamar *et al.* (2009b) concludes that there might be a consensus about the core process activities of technology management. On the other hand, the scope of technology management is diversely enhanced by, for example, strategy, knowledge, learning, planning, resource, competence, capability, innovations, product development, and commercialization views.

There exists several definitions and differing understandings on what is *knowledge management*. In simple terms, knowledge management is about managing what we know (Wilson 2002). In this dissertation, knowledge management is understood as identification, creation, codifying, storing and sharing of knowledge to make it available for business purposes of an enterprise. To avoid confusion, it is necessary to differentiate technology management from knowledge management: technology management is concerned with skills to apply and utilize knowledge for business needs and purposes.

### *2.3.2 Schools of technology management*

Development paths of management of technology and R&D management can be traced back to the end of 19th century to corporate R&D laboratories. Since then technology management has evolved along 2nd, 3rd and 4th generation R&D until end of 20th century (e.g. Talonen 2008).

Drejer (1997) summarizes four schools of technology management: *R&D management, innovation management, technology planning* and *strategic*

*technology management*. The philosophy of the so called 4th generation *R&D management* regards research, development and technology as strategic instruments for long-term competitiveness and innovations (e.g. Edler *et al.* 2002). It emphasizes formulation of explicit technology strategy, and integration of technology with corporate and business strategy. Current R&D management themes are concerned on knowledge acquisition and diffusion, networked R&D and open innovation (Chiaromonte 2003, Chesbrough 2006, Lichtenthaler 2008).

The scope of the *innovation management* school is about managing innovation in the entire company, from ideas to commercialization. In the innovation management school of technology management, environment is seen as changing but predictable, to justify the use of tools and methods, for example, technology forecasting. This is to anticipate technological changes for opportunities to create innovations by a managed innovation process of a company. Discontinuous, radical, really new, incremental and imitative types of process, product and service innovations (Garcia & Galantone 2002) have been categorized, and sources of innovation are known (von Hippel 1988, Pavitt 1990). The effect of technological and market contingencies to innovation management would still need better characterization (Tidd 2001). The scope of the *technology planning* school is to manage technology across the company in a changing environment using, for instance, forecasting, portfolio analysis and management method, and road mapping to plan and react to technological developments in a business environment (e.g. Andreasen & Hein 1987, Cooper *et al.* 1998).

The *strategic technology management* school can be divided into technology-based, organization and technology-based, and integrated strategic technology management schools that intend to combine technology with aspects of business and strategy (Drejer 1997). In technology-based strategic technology management school, technology is seen as a starting point for strategic management. In organization and technology-based school, the emphasis is on the integration of human resources and organizational performance measures with technology. In integrated strategic technology management school, the intent is to consider, combine and decide technology and business issues in the scope of strategic management, but without considering organizational issues. However, boundaries between the strategic technology management schools are vague. Current approaches of strategic technology management in an enterprise context aims to integrate technology with business strategy through management of technology activities (e.g. Brockhoff 1998, Burgelmann *et al.* 2001, Drejer 2004, Phaal *et al.* 2004, Lichtentaler 2008).

### 2.3.3 Technology management frameworks

Frameworks are generally used to present and communicate ideas or concepts in a structured way to support understanding of the topic under study. For considering the applicable viewpoints that a framework should provide, Phaal *et al.* (2004) refers to a meta-framework of Shehabuddeen (2001) that represents conceptual, applied, dynamic and static dimensions to the topics to be presented in a framework. Necessary abstraction, practicality, position of the elements, and interaction of the elements can be presented in a framework through these dimensions. A variety of theoretical, commercial and practical frameworks for presenting ideas related to technology management have been depicted (e.g. Phaal *et al.* 2000, Talonen 2008). The main types of existing technology management frameworks and their key characteristics are presented in Table 4.

Each of the framework types represents a partial solution to the problem of 'what are the elements of strategic technology management'. Pilkington & Teichert (2006) and Brockhoff (2003) give an explanation that the reason for the ambiguity of the field of technology management can be traced back to its early roots to management of R&D laboratories, and that the positioning of the field, amongst other disciplines, has been difficult due to its intertwined nature.

The underlying skeleton of the framework types indicate an approach where attempts are made to define the key processes, functions, routines, methods and tools for specific technology management activities. Secondly, technology management activities are presented as a discipline that needs to be integrated with the core business processes, and with market and business strategies of an enterprise.

A third approach is to manage knowledge flows of a company as embedded in other processes to link technology as a resource for reaching business objectives, or to manage technology specifically as part of innovation or new product development processes. An integrated management approach divides fields of technology management in normative, strategic and operative dimensions of organizational management from perspectives of objectives, structures and behavior, and outcomes of managed activities.

**Table 4. Main types of technology management frameworks.**

| Type | Characteristics | Reference |
|---|---|---|
| Generic process model | Generic five process models: identification, selection, acquisition, exploitation and protection. | Gregory (1995) |
| | Generic five processes and learning seen as dynamic capability. | Cetindamar *et al.* (2009b) |
| Technology management functions | Key functions related to technology management: technology strategy, road mapping, development, information and knowledge management, acquisition, transfer, forecasting, product development, life-cycle management, commercialization. | Kropsu-Vehkaperä *et al.* (2009) |
| Technology management routines | Key routines: producing scientific and technological knowledge, transforming knowledge into working artifacts, matching artifacts with user requirements, providing organizational support. | Levin & Barnard (2008) |
| Integration of technology management activity to business processes | Five best practices to integrate technology planning with business planning: planning, involvement, commitment, buy-in, accountability. | Metz (1996) |
| | Generic framework integrating technology management core processes to processes of strategy, innovation and operations. | Phaal *et al.* (2000, 2004) |
| Technology strategy approach | Technology strategy creation and implementation regarding to definition of core and complementary technologies, competencies, make/buy decisions, environment analysis, planning. | Burgelman *et al.* (2001), Porter (1995), Dodgson *et al.* (2008) |
| Integrated management concept | Technology management as a task of general management: normative (vision, know-how acquisition, decision-making, policies, innovation culture creation); strategic (planning, organizational design, make/buy, alliances creation), operative (R&D goals, motivation, tasks fulfillment) | Tschirky (1991) Luggen & Tschirky (2003) |
| Innovation funnel | Integrating New Product Development from concepts to commercialization, through knowledge flows and decision-making within commercial/market and networked technology/resource/R&D perspectives. | Wheelwright & Clark (1992), Chesbrough (2006) |
| Knowledge management | Integration and management of knowledge dimensions (what, why, how, when, who, where) by processes, methods, tools and people. | Nonaka (1995), Chai *et al.* (2003) |
| Methods and tools approach | Road mapping, blue-box analysis, portfolio analysis, forecasting, decision tree, performance indicators. | See e.g. Phaal *et al.* (2006) |

Due to complexity of the field, and dependency on industry context, the framework types are quite generic. There exists profound knowledge on generalized theories on phenomena about technological development, technology diffusion, dominant designs, innovations, and about role of core competences and dynamic capabilities in enterprises (e.g. Utterback & Abernathy 1975, Dosi 1982, Anderson & Tushman 1990, Rogers 2003, von Hippel 1988, Prahalad & Hamel 1990, Teece *et al.* 1997). On the other hand, specific practices have been developed, for example, on technology forecasting, road mapping, portfolio management, evaluation, benchmarking, selection, patenting, licensing, decision grids and strategy making (see e.g. Phaal *et al.* 2006). Nevertheless, none of the frameworks present a comprehensive view to the entire field.

## 2.4 Theoretical synthesis

Technology imposes managerial challenges due to the high level of abstraction, dynamics and profound effects on company strategy, business model, competitiveness, capabilities, and execution of strategy for sustained business success. Table 5 presents the essential concepts from *strategic management, organizational management* and *technology management* theories for creating the strategic technology management framework.

Key findings from *strategic management* theories that are used in the framework development include: the scope of strategic management in enterprise, value creation for its stakeholders, role of technology in value creation, business models, and as a source for productivity increase. In addition, technological capabilities are important for formulating and executing competitive strategy. In socio-economic context, the need for strategic technology management capability in enterprises is justified by the major impact of technology for sustainable development and wealth creation. From *organizational management* theories, the integrated management concept is adopted for the framework development.

*Structures, objectives* and *impacts* categories in strategic management dimension are considered to provide the necessary viewpoints for the framework development. Normative and operative dimensions are excluded from the scope of this research.

**Table 5. Key theoretical concepts for strategic technology management framework.**

| Theoretical topic | Key concepts for creation of strategic technology management framework | Main reference |
|---|---|---|
| Strategic management | Definition of strategy. | Chandler (1962: 7) |
| | Scope of strategic management. | Nag *et al.* (2007) |
| | Technology as a major source for economic growth and productivity. | Nelson & Winter (1982) |
| | Consideration of technology with respect to sustainability aspects in company's socio-economic environment. | Thomsen & Pedersen (2000) |
| | Critical role of technology in the business model creation. | Suikki *et al.* (2006), Chesbrough (2006) |
| | Management control over firm's technology evolution, complexity of technology dimension in strategy execution. | Ansoff (1987) |
| | Resource based strategy view on enterprise. | Wernerfeldt (2006) |
| | Technology strategy has to be connected with firm's business and product strategy. | Burgelmann *et al.* (2001) |
| Organizational management | Functions of management: planning, organizing, leading and control. | Robbins & Coulter (1996: 8) |
| | Multifunctional strategic orientation of an enterprise. | Ansoff (1987) |
| | Integrated management concept. | Bleicher (2004) |
| Technology management | Definition of technology. | Burgelmann *et al.* (2001) |
| | Definition of technology management and key processes. | Gregory (1995) |
| | Strategic technology management school. | Burgelmann *et al.* (2001), Phaal *et al.* (2004), Drejer (1997) |
| | Underlying knowledge on phenomena, methods, tools and role of technological development, forecasting, diffusion, innovations, dominant designs, core competences and dynamic capabilities in strategic technology management and business success of enterprises. | Utterback & Abernathy (1975), Anderson & Tushman (1990), von Hippel (1988), Prahalad & Hamel (1990), Teece *et al.* (1997), Phaal *et al.* (2006) |

Technology management is regarded as an own managerial discipline amongst other disciplines in a multifunctional organization. In this respect, an approach based on integrated management concept is expected to be beneficial for integrating strategic technology management with the other functional management disciplines. Finally, the framework is founded on the key definitions and concepts of technology management, with a specific focus on product technology in an enterprise context.

# 3 Research contribution

In this chapter, the research contributions of the individual research papers are presented. The entire research subject is outlined in the first article that presents the overall framework. The following three articles discuss and elaborate the framework in more detail, focusing on the categories identified in the first article. Each category is further divided into six elements. In each article, the overall framework model and the respective framework category is described in detail. Also, each article discusses theoretical contribution and managerial implications respectively. Due to practical reasons, in the scope of this dissertation, the technology management related matters are covered to identify elements of strategic technology management without deeply diving into each of the element topics, specifically.

## 3.1 Framework for strategic technology management

In the first article, the foundation for the framework development is created, and the article therefore answers the research question 1. Based on the integrated management model of Bleicher (2004), and by amending previous work of Tschirky (1991) and Luggen & Tschirky (2003), elements of strategic management of technology are divided into three categories: *structures, objectives* and *impacts*. In addition, the article discusses how the framework relates to company strategy, and defines strategic technology management as:

> *"Strategic management of technology is planning, organizing, leading and controlling of technological activities, interacting with company's skills to apply knowledge, structures, resources and socio-economic environment, to contribute to formulation and execution of the company's basic, long-term goals and objectives, and adoption of courses of action and the allocation of resources necessary for those goals."*

The categories of the initial framework are presented in Figure 6. In the paper, the principle of the framework as a systemic model is explained. Categories, their initial main elements, and example contents of the elements are described. The framework provides internally and externally related viewpoints on strategic technology management. Each of the categories are studied in the sub-sequent research phases and described in more detail in the following chapters, to form the description of the entire framework.

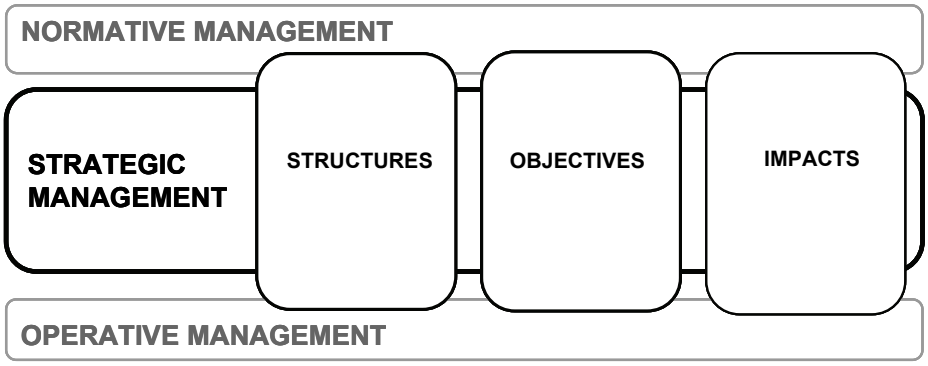


**Fig. 6. Initial framework for strategic technology management.**

The *structures* category contains a logical process view over an enterprise. The starting point to consider is the artifacts needed for the strategic technology management. The respective processes, methods and tools for creating the artifacts are described. Governance structures are needed to define authorization for decision-making and for managing the use of processes and practices to create these artifacts. Organizational structures are needed for planning and conduction of strategic management activities. The form of organization depends on the company's business context, size and principles for centralization or de-centralization of the businesses and functions. Technology management is seldom organized as a distinguishing function. In addition to internal resources, companies also utilize various types of collaboration networks which form the fifth main element of the structures category.

The *objectives* category contains objectives that conform to the company's business strategy. The strategic objectives are reflecting basic competitive strategies which require different types of objectives to technology (Porter 1985). The company's product offering requires diverse qualitative and quantitative objectives with respect to the needed qualities of the entire technology portfolio. Economic and time bound objectives determine the life-cycle costs of technology portfolio. They balance and determine the timing of investments for competitive positioning and introduction of technologies in products.

The *impacts* category contains tangible and intangible outcomes. Tangible outcomes in the form of products and services create economic, social and

environmental impacts. Intangible outcomes accumulate as un-codified or codified knowledge which form the company's technological capabilities.

## 3.2 Structures category of the framework

In the second article, the *structures* category is elaborated to answer the second research question. The categorization of the framework elements is expanded and validated based on perceptions of practitioners in small to medium-sized enterprises. The summary of the elements in the *structures* category of the framework is presented in Table 6.

**Table 6. Structures category of the framework (Sahlman & Haapasalo 2009b, published by permission of Inderscience).**

| Main element | Definition |
|---|---|
| Artifacts | Information, documents, reports, plans, prescriptions as the outcomes of the performed processes of technology management. |
| Processes | Procedures and practices performed to transform inputs into artifacts of technology management. |
| Methods, tools, IT systems | Techniques and tools to perform tasks of the procedures and practices of technology management. Information systems for processing and storing artifacts generated in the processes of technology management. |
| Governance | Management structure, definition of authorization and policies for decision-making of technology management topics. |
| Organizational functions | Managerial disciplines of an organization for planning, organizing, leading and monitoring technology management functions. |
| Collaboration networks | Stakeholder organizations involved in the company's processes of technology management. |

In the elaborated framework, the main class of methods, tools and information technology systems was separated from processes to better reflect practical and logical categorization. Logically, the processes of technology management utilize methods and tools to produce artifacts in the form of documents and information on plans, portfolios, repositories and guidelines. Information technology and knowledge management systems are then essential for processing the information of the artifacts. In the processes area, technology planning, technology development and disposal were introduced to complement Gregory's (1995) generic five process model. This was to highlight strategic planning and life-cycle management process areas of technology management. Fine grained division of organizational functions and governance for the purpose of decision-making, and

managing the activities that utilize the processes, were also defined. Collaboration networks include various stakeholders that are involved in the scope of technology management and constitute a collaborative part of the technology infrastructure of a company. For most of the elements that are presented in the *structures* category of the framework, there exists separately, more deep studies and body of knowledge, which have been excluded from the scope of this dissertation.

## 3.3 Objectives category of the framework

The third article presents the *objectives* category of the framework, and answers the third research question. The elements in the category are derived from technology management related decisions of a large telecommunications equipment manufacturing company. The summary of the *objectives* category is presented in Table 7.

The elements discovered in the article consist of product offering and value chain related objectives, objectives for technology assets and productivity imposed by technology and objectives related to internal and external policies. Qualitative and quantitative properties of technology must satisfy company product offering objectives, which are enabled by technologies embodied in products. The products and technologies must enable competitive life-cycle costs for the company and its customers. This is to meet social and environmental expectations, for example, energy efficiency, and the fundamental market and end user needs must be satisfied. These all cause many-sided objectives for technology. Business model aspects determine the technology related objectives for value chain positioning, supplier dependency, and scope and scale of the used technologies. Objectives for the properties of technology assets reflect product offering related targets. Additionally, scope, scale and technology life-cycle aspects must be considered in the objectives setting for technological items. Furthermore, uniqueness and standards compliancy has to be defined.

Consequently, technology asset base determines also productiveness of a company, and life-time costs of the entire technology asset portfolio in terms of investments needs, maintenance costs and competence requirements. Objectives for internal policies, standards, processes, and for practices development and deployment are also needed.

These are the means to direct divergence or convergence of technology creation methods, use of technologies, and management of technology itself.

Finally, objectives related to industry relations are concerned with regulations, standardization, licensing, intellectual property, supplier and collaboration strategies and policies.

**Table 7. Objectives category of the framework (Sahlman & Haapasalo in press a, published by permission of Inderscience).**

| Main element | Definition |
|---|---|
| Product offering | Objectives for product offering enabled by technology e.g. cost, performance, capacity, quality, reliability, availability, maintainability, and commonality. |
| Value chain | Value chain related objectives for technology supply e.g. business scope and scale of technology use, position in value chain, revenue logic, supplier lock-in, technology change cost. |
| Technology assets | Objectives for technology assets e.g. scope, scale of deployment, lead time for products, life-cycle state, performance, and compliancy to internal and external standards. |
| Productivity | Objectives for productivity enabled by technology e.g. technology portfolio scope and scale, life-cycle position, operating expenses, capital expenses, scope and scale of competence and resources to develop and maintain the technology base. |
| Internal policies | Objectives for internal policies, standards, processes and practices e.g. policies and internal standards definition and deployment, best practices dissemination, harmonization of practices, agility and adaptability of technology creation. |
| Industry relations | Objectives for industry relations e.g. compliancy to regulations, standards, de-facto standards, standardization strategy and policy, IPR, licensing, supplier strategy, extend of supplier base, publications, collaboration with institutes, creation and support of technology ecosystems. |

In general, the discovered elements conform to the purpose and goals of strategic management, in terms of objectives setting for value creation, business model, development of technological capabilities, and competitive positioning enabled by technology.

## 3.4 Impacts category of the framework

The fourth article presents the *impacts* category of the framework. The elements of the initial framework are elaborated and validated based on perceptions of high technology enterprise practitioners, and the fourth research question is answered. The summary of the *impacts* category of the framework is presented in Table 8.

The elements consist of tangible, business model, knowledge based, transitional and dynamic, social and environmental impacts. Tangible impacts are

created by technologies manifested in products and services that a company delivers.

**Table 8. Impacts category of the framework (Sahlman & Haapasalo in press b, published by permission of Inderscience).**

| Main element | Definition |
|---|---|
| Tangible outcomes | Impacts of technology management by technology manifested in delivered products and services. |
| Business model impacts | Impacts of technology management to the company's offering, value creation system, industry clusters, revenue logic, value creation and productivity. |
| Knowledge based impacts | Impacts of technology management on skills, competence, data, information, knowledge and wisdom embodied in people and enterprise capabilities. |
| Transitional and dynamic impacts | Impacts of technology management that can be observed as phenomena in the market and environment. |
| Socio-economic impacts | Impacts of technology management on social welfare and people's behavior. |
| Environmental impacts | Impacts of technology management to natural resources consumption, materials exploitation and waste. |

Impacts to business model related matters are realized by the company offering, in terms of added value and customer needs fulfillment. Also company competitive positioning and created business benefits are affected by efficiency and productivity enabled by technology. R&D investment decisions affect internal technology creation efforts, utilization of value chain collaborators, and on creation of the technology eco-systems and clusters. Investments and company activities within the value chain influence on the evolution of industries, business models and value chains. Thus, competitiveness, levels of integration and fragmentation of value chains change over time. Through the activities, un-codified and codified knowledge is accumulated within value chain actors, which ultimately determine capabilities of companies and value chains within the competitive environment. Finally, it is the value chains that compete, not the companies alone. Tangible products and services, on the other hand, create dynamic impacts in the market place in the form of innovations, technology leadership, technology life-cycles, and other attributes of technology that can be observed, for example technology diffusion and trajectories. Furthermore, tangible outcomes cause social impacts through utility of technology in value and social welfare creation, and through use of technology chancing people's behavior. Finally, technology management has environmental impacts due to required materials and resources to produce the services and products.

## 3.5 Elements of strategic technology management

After completion of each of the categories, the *entire* framework was validated by interviewing experienced industry practitioners evaluating relevance and current state of each element of the framework. Evaluation results are presented in Appendix 1.

Evaluation of the elements mostly scored on average from 8.0 to 9.4. Methods, tools and IT systems were evaluated least relevant, on average at 7.0, due to one respondent not seeing them as relevant in his company context, although he stated that the bigger the company is, the more relevant they are, but knowledge of substance is more relevant than tools. Relevance of socio-economic and environmental impacts was also evaluated low at 7.2 and 6.0 respectively, nevertheless, the topics were understood, and their importance was seen to increase. Relevance of value chain related objectives was seen not very valid by one interviewee because his company's value chain position is stable, and there is no intent to change the position. For the same company, the industry relations were not seen relevant either, due to the focused scope of the company.

The perceived current state of practice of the elements was evaluated mostly from 6.2 to 7.6 indicating that the interviewees were not quite satisfied how the matters are implemented in practice. The lowest score was on artifacts at 5.2, which may indicate that practices are not systematic or outcomes are not well documented. The highest score was on collaboration networks at 8.0, indicating that the networked operational model for globally operating companies is a necessity.

The interviewees were able to associate the elements to business activities. The linkage of business needs and enterprise strategy to technology management was acknowledged. On average, all of the elements were seen relevant and their substance was understood. It was stated that strategic technology management and R&D management are typically practiced in own silos in enterprises, or technology management is embedded in R&D, which effectively prohibits gaining the whole picture. It was also stated that it is important to see what the different matters logically are, and how they are interlinked. For this purpose, the presented framework was seen relevant and the topics were seen to be the right ones. Also the positioning of technology management within strategic dimension was seen correct, and its difference from operative R&D management was highlighted. Strategic technology management as a distinguishing function was seen to provide potential to improve visibility to technologies and decision-

making, improve follow-up on technology strategy execution, and to increase productivity by some 20%, e.g., from 60% to 80% of optimal level.

The strategic importance of technology in creation and execution of the company strategy was brought up. Technology should be seen as an enabler to satisfy the market needs. It was emphasized that marketing and product development are too often technology driven, and the real user needs are not considered. The utilization of the framework was understood as assisting in consideration of the desired impacts for setting the strategic objectives that are realized by the structures. Thus, the framework was seen as making sense and providing necessary viewpoints on the relevant issues.

Key questions on benefits of strategic technology management were raised on whether there is evidence on what is its impact to competitiveness, which are the best practices for formal organization of technology management in large companies, and whether strategic technology management is the key success factor for a technology-based company. It was stated that management is not becoming easier, product lifecycles are shortening, and there is a need to anticipate technological development. Therefore, market driven strategic technology management was seen as important.

In conclusion, the four articles of this dissertation form the framework for strategic technology management. Article I presented the outline of the framework, and the three categories of *structures, objectives* and *impacts* were studied in articles II, III and IV. The articles answer the research questions 1, 2, 3 and 4 respectively. During the research, some 250 classes and sub-classes were identified for the eighteen main elements. Elements of the *structures* category follow mainly a process and organizational view over an enterprise. The *objectives* category elements conform to strategic management objectives for value creation, business models and competitiveness. The *impacts* category elements represent internal and external, tangible and intangible outcomes within the company, and in its socio-economic environment. In the validation, the framework was recognized to contain relevant elements, and it provoked considerations, interest and discussion on the topics. As a summary, the framework provides many-sided viewpoints to strategic technology management in strategic dimension of enterprise management. It combines technology management matters with strategic and organizational management. The resulting elements of strategic technology management are presented in Figure 7.

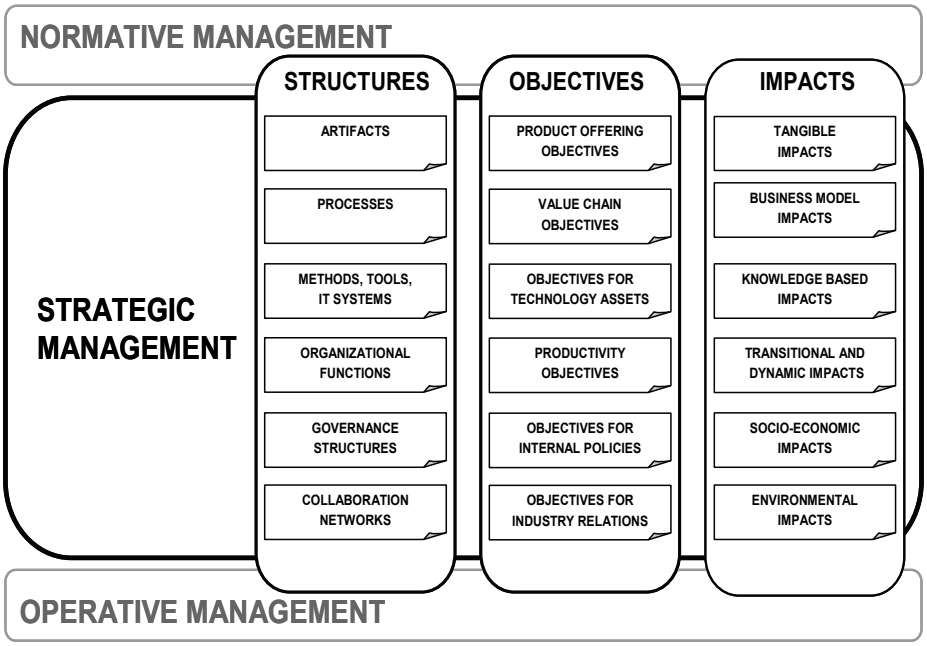


**Fig. 7. Elements of strategic technology management.**

# 4 Discussion

## 4.1 Theoretical implications

In this dissertation, the research problem is approached by developing a framework that describes elements of strategic technology management. The developed theoretical framework describes the elements as categories of *structures, objectives* and *impacts* in strategic dimension. The new theoretical contribution of this dissertation includes the framework model applying organizational theory on strategic technology management, and combines aspects of technology management. Table 9 summarizes the theoretical contributions and implications of the research phases that constitute the *entire* framework.

The framework builds on the integrated management theory of Bleicher (2004), and enhances previous models developed by Tschirky (1991) and Luggen & Tschirky (2003). Other types of existing strategic technology management models are typically focused on certain aspects of technology management (see Table 4), for instance, process, function, routines, activity, methods or tool views, or they are focused on constituents of technology strategies. In existing literature and theoretical models, technology related phenomena, impacts to socio-economic environment, as well as impacts of technology to company business model and competitiveness are covered as separate but intertwined aspects (e.g. Khalil 2000, Dodgson *et al.* 2008). Also, an extension to Gregory's (1995) five-process model is suggested by proposing process areas of strategy planning, technology development, and technology disposal. Moreover, contemporary solutions to the challenges in strategy execution emphasize setting objectives for organizations and management of strategic initiatives' portfolio (e.g. Mankins & Steele 2005, Mankins & Steele 2006, Kaplan & Norton 2005), instead of attempts to transform strategic business objectives into strategic objectives for technology. In this respect, the developed framework complements the existing theory, by providing an integrated approach with the standpoints to *structures, objectives* and *impacts* as element categories of the framework for strategic technology management.

In this research the extensive field of strategic technology management was qualitatively studied to discover the framework elements. The framework builds a logical structure in strategic dimension. The model provides viewpoints for

considerations of horizontal and vertical integration of the related individual elements.

**Table 9. Summary of theoretical contributions and implications.**

| Phase # | Theoretical contributions | Theoretical implications |
|---|---|---|
| I | Defining of strategic technology management in enterprise context.<br>Outlining a conceptual framework for strategic technology management. | Combines definitions of management, technology and strategy.<br>Framework for strategic technology management created. Enhances previous models. |
| II | Defining the *structures* category of the framework. | *Structures* for strategic technology management in enterprises context categorized.<br>Enhancement of Gregory's (1995) 5-process model (*identification, selection, acquisition, exploitation, protection*) by *strategic planning, development* and *disposal* process areas is suggested. |
| III | Defining the *objectives* category of the framework. | *Objectives* for strategic technology management in enterprise context categorized.<br>Introduces the need of transformation of strategic business objectives into strategic objectives for technology. |
| IV | Defining the *impacts* category of the framework. | *Impacts* of strategic technology management in enterprise context categorized.<br>Connects in the form of a framework company internal and external influence of strategic technology management with socio-economic environment. |
| Validation, Dissertation Summary | Concluding the entire framework for strategic technology management. | Unites concepts of strategic management, organizational management and technology management into a framework for strategic technology management.<br>Builds a basis for a logical structure on strategic technology management for further theoretical enhancement. |

Along the integrated management concept, linkage of the structures, objectives and the desired impacts need to be established, although the theoretical framework is not intended to provide an exact system model, which would provide an in-depth description and inter-relations of each of the elements. Nevertheless, in the framework, logical relations can be seen between the elements. For example, between artifacts, processes and methods; product

offering objectives and tangible impacts; value chain objectives and business model impacts. As another example, collaboration networks and objectives for industry relations, as well as socio-economic and environmental impacts are interrelated. Organizational functions, governance structures, productivity objectives and internal policies form also an example cluster of elements. Examples of these element clusters are presented in Figure 8. As a conclusion, the framework provides a theoretical frame for presentation, communication and discussion of strategic technology management topics. It also provides a logical structure for further research and elaboration of the individual framework elements and their interrelations as an integrated entity.

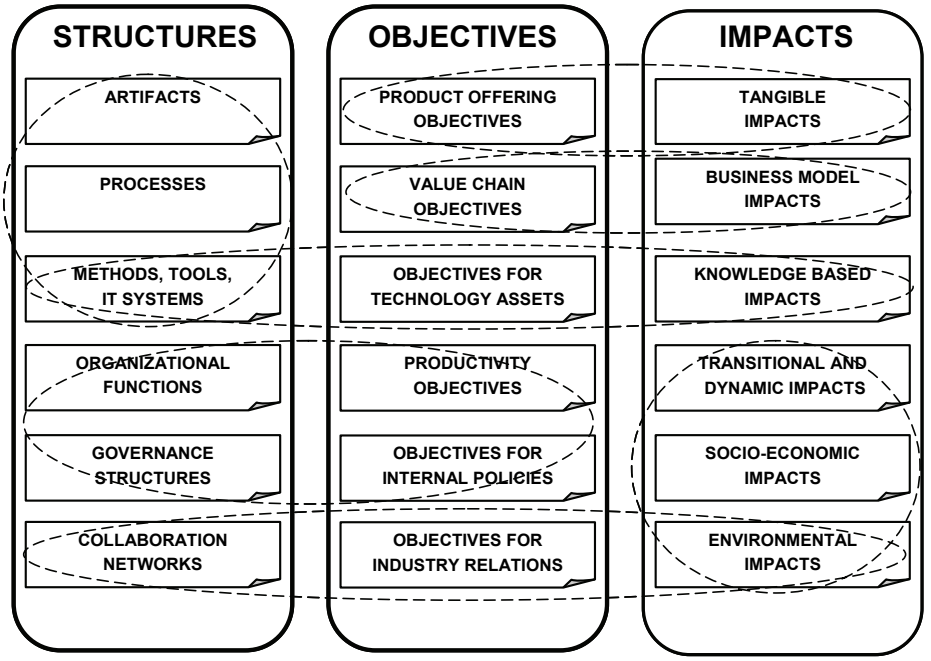


**Fig. 8. Examples of element clusters in the framework.**

The studies brought up perceptions of enterprise practitioners on technology management, asserting that the entire field is complex, confusing and contingently practiced. The viewpoints of the framework open up models for conceptualization of solutions to organizational development problems with regards to strategic technology management. Utilization of an organizational theory model as the theoretical basis for the framework brings strategic

technology management aspects closer to organizational management theories. This is useful for theoretical consideration of technology management as a managerial discipline of its own within other disciplines of a multifunctional organization.

Finally, the derived definition of strategic technology management in this dissertation unites concepts of strategy, management and technology within socio-economic environmental context of an enterprise. As a whole, knowledge of strategic technology management school is enhanced.

## 4.2 Managerial implications

The objective of this research was to create a theoretical framework for strategic technology management to assist in establishing and enhancing practices in high technology enterprises. In the following, the proposed managerial implications are presented based on research findings of the articles.

The developed framework, as presented in article I, describes elements of strategic technology management to provide structure and clarity. The substance of the framework elements was shaped by and reflected against the conceptions of practitioners and scholars in the field. The study revealed that enterprise practitioners encounter problems in distinguishing and categorizing the elements that are relevant to strategic technology management. Linkage of the elements to enterprise strategy, decision-making and resource balancing was highlighted, and complexity in conducting such management tasks was recognized. Thus the need for the framework development was justified.

The framework helps in positioning the elements in strategic dimension for presentation, communication and discussion of the matter. It brings up the essential issues, viewpoints and interrelations of the subjects to assist enterprise practitioners in defining the scope and priority areas of development initiatives for strategic technology management practices within a company. Similar considerations in a larger socio-economic context can also be contemplated based on the framework outline and the substance. The described elements assist in analysis and definition of structures for technology management and objectives for technology. The framework also increases awareness of the impacts that can be gained through strategic technology management.

Article II suggests that enterprises should consider strategic technology management as an explicitly managed function. The study confirmed that technology management in general is perceived confusing among practitioners,

and that the definitions and implementation of the practices are contingent. Technology management is seen as an implicit activity to fulfill customer needs and business opportunities. Nevertheless, the practices are not systematically established within business processes of enterprises.

The developed framework assists in defining and integrating strategic technology management as its own managerial function amongst other organizational functions. Technology intensive companies should consider establishing technology management as a strategic management activity, similar to business strategy, business and product portfolio management. The framework provides a frame of reference for defining and creating the needed structures in terms on artifacts, processes, methods, organizational functions, as well as governance and collaboration networks.

Article III discusses the utility of the framework in the objectives setting for technology and technology management. Strategic business objectives are typically aimed at organizations, market positioning and business measures, whereas strategic technology management objectives are targeted on properties of technologies. Moreover, the objectives for technological properties are different than objectives for customer requirements and product features. This indicates the need for a transformation of business objectives to strategic objectives for technology, and a need for strategic technology management. Technology should also be managed over product life-cycles, due to the long term effects of technology investments. When applying the framework, practitioners should analyze what technology gaps there exist, with respect to the company's strategic business objectives. Depending on the improvement needs, the objectives should be formulated for building, deploying and maintaining the capabilities that are enabled by technology. Therefore setting of strategic objectives for technology is clearly an important managerial task.

For objectives setting the framework presents the viewpoints on objectives related to product offering, value chain, technology assets, productivity, internal policies and industry relations. Application of the framework in an enterprise context is presented in Figure 9.

According to the logic of the framework model, the objectives are implemented through operational activities which in turn influence the technology infrastructure of the company and create internal and external impacts. Consequently, the resulting technology infrastructure and impacts influence on formulation and execution of the company strategy.

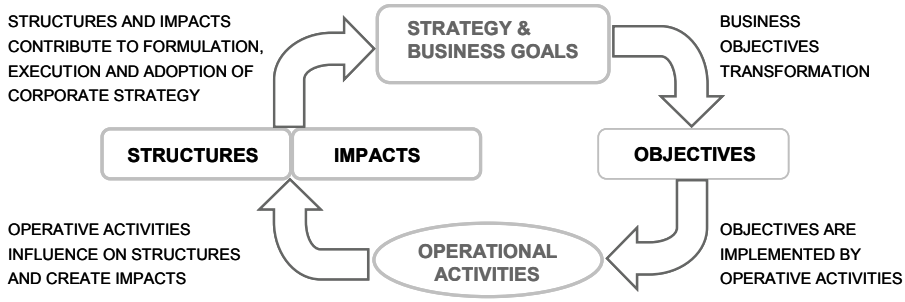


**Fig. 9. Utilization of the framework model in enterprise context (Sahlman & Haapasalo in press a, published by permission of Inderscience).**

Article IV presents a perspective to utilization of the framework model for considering the attributed capabilities inside an enterprise and socio-economic influences outside. This research proposes that the framework model can be utilized to determine the needed structures and objectives for strategic technology management, in order to create technology-based capabilities. The attributed capabilities in turn cause impacts on company environment leading into technology and industry evolution, and creating wealth and social change through innovations and value created.

As a summary, the developed theoretical framework is proposed to assist companies in establishing and enhancing strategic technology management practices. The framework helps in positioning the elements in strategic dimension for presentation, communication and discussion. Evidence on the viability of the framework was experimented in the interviews of experienced company representatives in the framework validation phase. The interviewees were able to link the framework to strategic business aspects of enterprise management, and the positioning of the elements in strategic dimension was acknowledged. Quotes from the interviews are examples of the diverse viewpoints that the evaluation of the elements' validity generated. Thus the framework appeared to function as a mean for presenting, positioning and discussing topics of strategic technology management.

> *"All these topics were right. ... Technology management is part of strategy process; R&D management is another business process. We have been considering these topics with people from MIT (Massachusetts Institute of Technology), and we came into a conclusion that the fields of R&D*

*management and technology management are in silos, but no-one has formed a comprehensive picture on what the topics are and how they are related."*

*"Technology development has internal objectives to bring testing processes to a remarkably higher level. From this entirety, we'll go back to efficiency, and we will get the whole chain significantly shorter. In this way we will create impacts to the whole value chain."*

*"Does this make sense? Yes, you need to start from impacts, and structures are useless unless there have been objectives set. After building this framework, it would be beneficial to find evidence on formal structures, whether it is worth building the structures, and does it make difference in competitiveness."*

*"Socio-economic impacts have a definitive role in globalization. The way globalization is currently understood in companies, will not work. Young people networking drives into novel globalization."*

*"Environment part is the most familiar, focus is shifting there. ... Every company should think about its fundamental purpose, because it should be connected to soft values and well-being considering society."*

## 4.3 Reliability, validity and limitations of the research

Quality of the research is determined through reliability and validity of the research results. They are obtained through proper research design and suitable methodology used in research (e.g. Saunders *et al.* 2007). Ultimately, other researchers should obtain similar results by using the same procedures applied in the research (Yin 2003). Reliability is a pre-condition to validity by ensuring that the same results can be obtained repeatedly at other times and conformably without a researcher's subjective influence (Hirsjärvi *et al.* 2008, Bryman & Bell 2007*)*. In qualitative research, errors and biases in obtaining and processing the research data influence on reliability (Saunders *et al.* 2007).

In this research, situational errors affecting the reliability of the results were reduced by interviewing and inviting into workshops, people who knew the subject based on their experience and had interest on the topics. The materials analyzed for the *objectives* category development were related to technology management decisions in the case company. Opinion biases were diminished in the workshops and interviews by not requiring any preparation. Exposure of the

interviewees in advance to researcher's opinions was avoided by not sending the questionnaire beforehand. Also, the topic was expected to be emotionally neutral. Errors in elicitation of the information were reduced by using structured interviews with open questions along with a numeric evaluation of statements of importance and current state of the matter. Workshop findings were summarized by the workshop participants, and interviews were recorded and lettered. Interpretation errors were reduced by making the conclusions abductively, and by analyzing data from various sources.

According to Yin (2003) validation of qualitative research is evaluated on construct, internal and external validity point of views. Construct validity is concerned with the suitability of the used methods for the research, and it can be increased by designing the research to use distinct means to collect information. In this research, literature, expert workshops and interviews, meeting memorandums, structured questionnaires and evaluation statements, were used as sources for information.

Internal validity is about correspondence of the models to the subject under research. In this research internal validity is gained through the abductive theory matching of the preliminary framework and sub-sequent research findings, and through evolvement of the framework along the research process.

Additionally, the developed framework elements were validated by interviewing five persons that have 24-30 years of experience in large global high technology companies. Based on the evaluation results (see Appendix 1), it can be stated that all the framework elements were seen relevant for the context of strategic technology management. In the conducted interviews, the framework appeared to make sense for the experienced company representatives. The framework provided many-sided viewpoints on strategic technology management, and it provoked discussion and opinions, reflected by business context and values of the interviewees, on all of the elements.

External validity considers potential generalization of the results. Due to the specific focus on product technology in high technology enterprise context, generalization of the results was not the main objective in this research. The results should not be generalized to be applicable in, for instance, services companies or public enterprises. Nevertheless, involvement of adequate numbers and different sizes of enterprises, that represent various types of product businesses and industries, gives reasons for consideration on possible applicability for generalization of the framework, providing relevant substance for product companies in different types of industries.

Subjective nature of qualitative research, due to subjective interpretation of the qualitative data by the researcher, has to be acknowledged as a limitation of qualitative research (e.g. Yin 2003, Tuomi & Sarajärvi 2006, Eskola & Suoranta 2008). People participating in the interviews have subjective relation to topics under research. Their perceptions and conceptions are determined based on their experience, existing knowledge and the context of the enterprise they are working in. Thus, the results of this research should be considered, to a certain degree, as unique, due to specific time the research was conducted, specific people participating in the research, specific companies represented, and the specific researcher conducting the research. The number of the companies and their geographical location was limited mainly to Oulu region in northern Finland. Should the number of companies be higher, and their geographical scope more diverse, the reliability of the results would potentially have been increased. Also, making a study among service companies would probably have led into different results and conclusions. Thus final confidence on what the elements of strategic technology management are can be found only when larger amount of companies in different industries are studied.

The research scope turned out to be quite vast; therefore the framework categorization cannot be asserted to be all-inclusive. Nevertheless, the selected research approach and methodology enabled broad coverage of the topics related to technology management, although deep dives into specific issues were not conducted. Companies and people participating were technically oriented and served well for the purpose of the research.

The material obtained in this research and the used methodology provided a synthesis on elements of strategic technology management, in the form of a conceptual framework. Final categorization could have been made differently by another researcher, and certainly the framework could also be further elaborated. Depending on the industry context, evolution and technological developments, the substance of the framework may evolve accordingly.

## 4.4 Recommendations for further research

In this dissertation, large amount of topics have been studied qualitatively for the purpose of outlining elements of strategic technology management in a conceptual framework. Due to practical limitations of a single dissertation, profound and detailed study of each element had to be left out from the scope of this dissertation. Thus, there are many possibilities for in depth study of each of

the elements in separation. The developed framework can be utilized for identifying and positioning practical problems and research topics in the field of strategic technology management.

In general, further research can be conducted on how the elements are configured in enterprises, what the practical challenges are, and how the elements can be horizontally and vertically integrated to gain an optimum outcome. Also, the entire framework can be elaborated, and potentially new element groups can be found.

In the *structures* category of the framework, an interesting research topic would be to study how companies have implemented various elements: how the processes for technology management have been implemented or how the functions of technology management are exemplified within other functions like inside R&D management. Another study area would be how strategic technology management practices are linked with key business processes. That is to investigate how to link technology management with business development, new product development and order-delivery processes.

In the *objectives* category, research can be conducted on what are the most effective objectives for technology to be prioritized for reaching company's strategic goals. Potentially, research could also be conducted on how the objectives change over the life-time of an enterprise, and how the objective classes and priorities depend on company size and business context.

For the *impacts* category, the most important question would be from the company perspective, to know what kind of arrangements of structures and sets of objectives produce the desired impacts most effectively. As the entire field is extremely complex, potentially all cause and effect relationships cannot be defined, therefore it would be interesting to understand which of the impacts can really be managed, how to manage them, and which impacts just emerge in spite of management attempts.

The framework in this dissertation was developed based on enterprise practices in the context of high technology product companies. Further research could be conducted to study how the framework can be generalized and applied for services companies and for different types of industries.

# 5 Summary

In an increasingly complex economic and social environment, high technology industries are facing accelerating technological development and global technology-based competition. In these circumstances, fierce rivalry forms a challenge for enterprises on how to strategically manage the company's technology, to ensure competitive business models, value creation systems, product offering, competences and capabilities. Therefore capability of strategic technology management is crucial for execution of the company business and technology strategy for long-term business success.

Over the decades, companies have evolved from single function optimization to multifunctional strategic orientation, in which strategic technology management has an increasingly important role. In the absence of commonly agreed theoretical and practical frameworks for strategic technology management, the research problem of this dissertation is formulated as:

> *Practitioners and scholars are lacking a comprehensive frame of reference that describes elements of strategic technology management.*

In order to address the research problem, a theoretical framework is created to describe elements of strategic technology management. The research is conducted within high technology product companies. The framework is abductively developed based on literature findings, and using questionnaires and documents to obtain qualitative data for analysis. The development of the framework is approached by four research questions, handled in individual articles respectively. The first article presents the concept and the outline of the framework, and the framework elements are studied in more details in three sub-sequent research articles. The four articles together describe a possible explanation to the research problem in the form of a theoretical framework.

Integrated management theory, that considers enterprise management in normative, strategic and operative dimensions, is applied for the framework development. The developed framework consists of *structures, objectives* and *impacts* categories in strategic dimension. Each category has six main elements which contain several sub-classes.

The main theoretical contribution of this dissertation is the developed framework, applying viewpoints of organizational theory to strategic technology management. In the studies, perceptions of enterprise practitioners proved that the entire field of strategic technology management is confusing and diversely

practiced. The framework provides a logical structure to elements of strategic technology management for conceptualization, discussion and elaboration of the topics among scholars and practitioners.

As managerial implications, it is proposed that companies should consider establishing and integrating strategic technology management as a managerial function amongst other organizational functions. It is also proposed that enterprises should consider defining the needed structures and objectives for strategic technology management, in order to develop and sustain technology-based capabilities, and to create internal and external impacts within socio-economic context.

As a conclusion, the developed framework unites strategic management, organizational management and technology management concepts in an enterprise context, enhancing knowledge in strategic technology management. The contributions of this dissertation are benefiting practitioners by providing an outline for organizational development concerning strategic technology management.

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# Appendix 1 Framework validation results

**Table 1. Evaluation results of the framework validation: relevance of the element. Scale for evaluation: Not relevant 1, extremely relevant 10.**

| Element | Evaluation results | | | | | Average |
|---|---|---|---|---|---|---|
| Structures | | | | | | |
| Artifacts | 9 | 6 | 8 | 10 | 8 | 8.2 |
| Processes | 8 | 7 | 10 | 9 | 9 | 8.6 |
| Methods, tools, IT systems | 3 | 8 | 8 | 8 | 8 | 7.0 |
| Governance | 8 | 9 | 9 | 10 | 8 | 8.8 |
| Organizational functions | 8 | 8 | 10 | 10 | 9 | 9.0 |
| Collaboration networks | 9 | 10 | 10 | 10 | 8 | 9.4 |
| Objectives | | | | | | |
| Product offering | 9 | 10 | 9 | 10 | 9 | 9.4 |
| Value chain | 9 | 10 | 2 | 10 | 9 | 8.0 |
| Technology assets | 9 | 9 | 9 | 9 | 9 | 9.0 |
| Productivity | 8 | 9 | 5 | 10 | 8 | 8.0 |
| Internal policies | 7 | 7 | 9 | 9 | 8 | 8.0 |
| Industry relations | 10 | 8 | 4 | 10 | 9 | 8.2 |
| Impacts | | | | | | |
| Tangible outcomes | 5 | 10 | 10 | 8 | 10 | 8.6 |
| Business model impacts | 9 | 8 | 9 | 10 | 8 | 8.8 |
| Knowledge based impacts | 9 | 7 | 9 | 10 | 8 | 8.6 |
| Transitional and dynamic impacts | 9 | 9 | 6 | 10 | 8 | 8.4 |
| Socio-economic impacts | 3 | 10 | 7 | 10 | 6 | 7.2 |
| Environmental impacts | 2 | 10 | 1 | 10 | 7 | 6.0 |

**Table 2. Evaluation results of the framework validation: current state of practice. Scale for evaluation: Not established 1 - Well established 10.**

| Element | Evaluation results | | | | | Average |
|---|---|---|---|---|---|---|
| Structures | | | | | | |
| Artifacts | 5 | 6 | 3 | 7 | 6 | 5.4 |
| Processes | 5 | 7 | 7 | 5 | 7 | 6.2 |
| Methods, tools, IT systems | 9 | 8 | 8 | 6 | 5 | 7.2 |
| Governance | 8 | 7 | 10 | 7 | 6 | 7.6 |
| Organizational functions | 8 | 8 | 8 | 6 | 8 | 7.6 |
| Collaboration networks | 8 | 9 | 10 | 6 | 7 | 8.0 |
| Objectives | | | | | | |
| Product offering | 6 | 8 | 8 | 7 | 8 | 7.4 |
| Value chain | 9 | 8 | 1 | 7 | 7 | 6.4 |
| Technology assets | 7 | 8 | 8 | 7 | 6 | 7.2 |
| Productivity | 6 | 8 | 5 | 8 | 7 | 6.8 |
| Internal policies | 4 | 7 | 8 | 7 | 6 | 6.4 |
| Industry relations | 8 | 8 | 5 | 8 | 8 | 7.4 |
| Impacts | | | | | | |
| Tangible outcomes | 8 | 7 | 8 | 8 | 7 | 7.6 |
| Business model impacts | 9 | 8 | 9 | 6 | 6 | 7.6 |
| Knowledge based impacts | 7 | 7 | 7 | 8 | 6 | 7.0 |
| Transitional and dynamic impacts | 5 | 7 | 6 | 7 | 6 | 6.2 |
| Socio-economic impacts | 5 | 8 | 7 | 6 | 6 | 6.4 |
| Environmental impacts | 9 | 8 | 2 | 8 | 7 | 6.8 |

# Original publications

This dissertation is based on the following publications:

I Sahlman K & Haapasalo H (2009) Elements of strategic management of technology: a conceptual framework of enterprise practise. International Journal of Management and Enterprise Development, 7(3): 319–337.

II Sahlman K & Haapasalo H (2009) Perceptions of Strategic Management of Technology in Small High-Tech Enterprises. PICMET 2009 Proceedings, August 2-6, Portland, Oregon USA: 93–104.

III Sahlman K & Haapasalo H (in press) Objectives of strategic management of technology in a conceptual framework of enterprise practise. International Journal of Business Innovation and Research.

IV Sahlman K & Haapasalo H (in press) Impacts of strategic management of technology in a conceptual framework of enterprise practice. International Journal of Innovation and Learning.



Original publications are not included in the electronic version of the dissertation.

345. Väisänen, Tero (2009) Sedimentin kemikalointikäsittely. Tutkimus rehevän ja sisäkuormitteisen järven kunnostusmenetelmän mitoituksesta sekä sen tulokselli-suuden mittaamisesta

346. Mustonen, Tero (2009) Inkjet printing of carbon nanotubes for electronic applications

347. Bennis, Mehdi (2009) Spectrum sharing for future mobile cellular systems

348. Leiviskä, Tiina (2009) Coagulation and size fractionation studies on pulp and paper mill process and wastewater streams

349. Casteleijn, Marinus G. (2009) Towards new enzymes: protein engineering versus Bioinformatic studies

350. Haapola, Jussi (2010) Evaluating medium access control protocols for wireless sensor networks

351. Haverinen, Hanna (2010) Inkjet-printed quantum dot hybrid light-emitting devices—towards display applications

352. Bykov, Alexander (2010) Experimental investigation and numerical simulation of laser light propagation in strongly scattering media with structural and dynamic inhomogeneities

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