Managing R&D Processes

– Focusing on Technology Development, Product Development, and their Interplay

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Thesis for the Degree of Doctor of Philosophy

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To my wife Jennie and daughter Lina

Dissertation

Paper I [Nobelius, D., and Trygg, L.]

Stop Chasing THE Front End Process
– management of the early phases in product development projects
International Journal of Project Management, 2002, Vol. 20, No. 5.

Paper II [Nobelius, D., and Sundgren, N.]

Managerial Issues in Parts Sharing among Product Development Projects
Journal of Engineering and Technology Management, 2002, Vol. 19, No. 1.

Paper III [Nobelius, D.]

Evaluating Virtual Reality in an Advanced Engineering Setting
Research Technology Management, 2001, Vol. 5, No. 4.

Paper IV [Nobelius, D.]

Dedicated versus Dispersed Advanced Engineering Structure
– implications for internal technology development and transfer
Forthcoming in International Journal of Technology Transfer and Commercialisation, 2002.

Paper V [Nobelius, D.]

Empowering Project Scope Decisions – introducing R&D content graphs
Journal of R&D Management, 2001, Vol. 31, No. 3.

Paper VI [Nobelius, D.]

An Ambidextrous Organization in Practice
– strategic actions in Ericsson's management of 'Bluetooth'
Forthcoming in International Journal of Mobile Communication, 2002.

Paper VII [Nobelius, D.]

Linking Applied Research to Product Development
– transfer experiences from an automotive company
Forthcoming in Technovation.

Preface

This thesis is the main outcome of a doctoral process, yet it is only one of many results of this process. Other results relate to industrial interactions and reports, academic presentations and discussions, attendance of doctoral courses, supervision of master's theses, and participation in University as well as executive management programs. Managing the process has been far from easy, involving difficult prioritizations, challenges, and a lot of hard work. Even though the main responsibilities lie with me, I have received great support throughout the process from the surrounding network – assistance that I would not have managed without.

I would like to express my greatest gratitude to my advisor Lars Trygg. You have certainly been open-minded and guided me with a large portion of patience and assistance. Without your knowledge of product development practices, admirable logical and rhetorical strengths, and perspective of quality in life, this process would not have been the same. I look forward to continuing the discussion of R&D management with you!

Further, I would like to thank bearers of our research paradigm, Ulf Karlsson, Jan Lindér, and Sten-Olof Gustavsson, for their refreshing view of industrial research and methodology as well as for contributing to the overall working atmosphere and research values.

Niklas Sundgren, also being my co-advisor, has freely offered his insightful advice on most of the research ideas, papers, and company reports. I have especially appreciated your constructive comments, joy of being a researcher, and the fun of co-authoring. I look forward working with you again in the future!

The Department of Operations Management and Work Organization provided a solid foundation for my research, functioning as the base for intellectual stimuli and elaboration of research ideas. I would especially like to thank the senior doctoral candidate team of Peter F. and Fredrik for their constant support, impressive peer review capabilities, and for just being friends. Other dear members of the department, i.e. the former and future colleague Henrik, administrative assistant Anita, and the junior doctoral candidate team of Martin K. (teammate in the Ericsson pre-study), Ola, Magnus, Tobias, Dan, and Klas have also provided me with a challenging and inspiring environment.

During the latter part of the research process, the research committee members Sven-Åke Hörte and Mats Magnusson have guided me thoughtfully and aided me in clarifying my contributions and ideas. This has been most helpful and I enjoyed working with you. Thank you Sven-Åke and Mats!

Robert Cole enabled a great learning experience related to management of technology as my sponsor and mentor during a stay as a visiting scholar at the Haas School of Business in the University of California, Berkeley. Your assistance and experience were of instrumental value.

I would also like to thank Mats Lundqvist, Bo Bergman, Tom Allen, Jim Utterback, and Fredrik Hörstedt for commenting on my research as well as for interesting dialogues.

I have been fortunate to work in several different industrial contexts, e.g. UBI Printer, Volvo Truck Corporation, Volvo Car Corporation, and Ericsson Mobile Communications.

At Volvo I would like to thank my initial steering group consisting of Håkan Sernros and Wilio Rosenquist for their willingness to share their network and for their support; Hans Folkesson, Ragnar Fast, and Håkan Junger for sharing plans and exchanging ideas; Thomas Nyvall for a never-ending interest in commonality issues; and finally, Olof Hägglund and his team for bringing me into his project, tolerating my experiments and challenging my ideas.

At Ericsson Mobile Communications, Björn Ekelund, Jan Gunnarsson, and Torbjörn Gärdenfors were vital in getting access to the company. I highly appreciated your collected competence and your insights into a rapidly evolving organization and market. Örjan Johansson, former director of the Bluetooth organization, was also a key to studying the evolution and overall strategy of the unit.

At UBI Printer, the skilled R&D manager Bernt Holländer and the project leader Eilert Johansson freely shared their platform thinking and philosophy on product development, insights from a medium-sized company that were really valuable.

Throughout the doctoral process, I have had the chance to interact with the industry in a more professional situation via Chalmers Advanced Management Programs, a foundation also providing me with an enriching scholarship. This opportunity has given me possibilities to improve my presentation and project management skills. Thank you, Sören, Martin E., Mikael, Matti, Annika, and the rest of the CHAMPS team.

Concerning my time as Managing Director for an IT start-up, I would like to express my gratitude to my colleagues and friends for understanding my dual role – thank you, Tobias (our complementarities form a great team and I always enjoy working with you), Peter N., Jonas, Anders, Patrik, Carljohan, and the investing team of Eureka Ventures.

This research was conducted within the frames of the Swedish Engineering Design Research and Education Agenda, with Leif Larsson as head of the effort during the majority of my time. Without the initiation of this national school and its clear industrial focus, I would most likely not have pursued a Ph.D. – a route that I now highly appreciate.

The thesis was corrected with respect to use of language and grammar by Jon van Leuven, and the research studies were administrated by Birgitta and Bengt at the Institute for Management of Innovation and Technology – an institute managed by Christer and which also encouraged me with a scholarship as well as by sharing an extensive research network.

Finally, I would like to thank my parents Bengt and Laila for always being there, constantly curious, and heavily supportive in all respects and more. My two brothers Magnus and Anders have also proved one hundred percent reliable; it is good to know you are close. My daughter Lina made the last research phase a bit more complicated, introducing a (healthy) nursery element to my mind and always welcoming me with a big smile and jiggle. The one facing most dilemmas a young researcher meets is my wife Jennie: thanks for your constantly encouraging standpoints, fresh views, and endless support. You are amazing – I love you! The next journey, be it intellectual or physical, will be with you and Lina!

Thank you all for invaluable backing!

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Abstract

This thesis concerns management of research and development (R&D) processes, with an emphasis on technology development and product development and their interplay. The aim is to assist companies in leveraging their R&D efforts and to improve the understanding of R&D management. Organizations' capability to develop and integrate new technologies into commercialized products by using effective and repeatable processes plays a key role for competitiveness.

Recent research has noted that the contracted term 'R&D' might, without care, beguile us into disregarding the inherent differences between aspects such as technology development and product development. While similar in some ways to the management of product development, technology development differs in its prerequisites, technical maturity, time horizon, need for competence, process repeatability, and completion point. These differences, entailing specific managerial issues and approaches, are taken account of in this thesis. Further, particular attention is given to the interplay of the two processes, an interplay that can either hinder R&D efforts or spur them to new heights.

The chosen research path has been characterized by a practice-centered abductive design, building on studies related to knowledge transfer and technology integration, project management approaches, and organizational forms of R&D. A variety of methods has been used, ranging from company-wide surveys and in-depth case studies to development of hands-on project management techniques and tools. The research has been managerially oriented, conducted longitudinally and in close contact with foremost three companies (Ericsson Mobile Communications, Volvo Truck Corporation, and United Barcode Industries).

The research findings belong mainly to two areas. One is the management of internal organizational interfaces, a crucial issue when commercializing new technology. Here, barriers and integration mechanisms have been analyzed, illustrated and explored. The other is management of technology development and product development scope, an issue of long-term strategic importance as well as vital for achieving timely deliveries. Within this area, a visual R&D content tool has been developed and tested, targeting R&D managers who work actively with the scope of projects and the related strategic implications throughout R&D execution.

Keywords: Research and development, technology development, product development, management issues, integration, organizational interfaces, project scope

Contents

A. RESEARCH AND DEVELOPMENT

This thesis deals with management of research and development, with focus on technology development and product development as well as the interplay between them (the research focus is visualized in Exhibit 1). It is argued that the interrelated activities of technology development and product development differ with regard to prerequisites, technical maturity, time horizon, competence needs, process repeatability, and completion point. Further, these differences entail different managerial problems of integration and differentiation, issues that need to be addressed in order to ensure efficient and effective utilization of R&D.

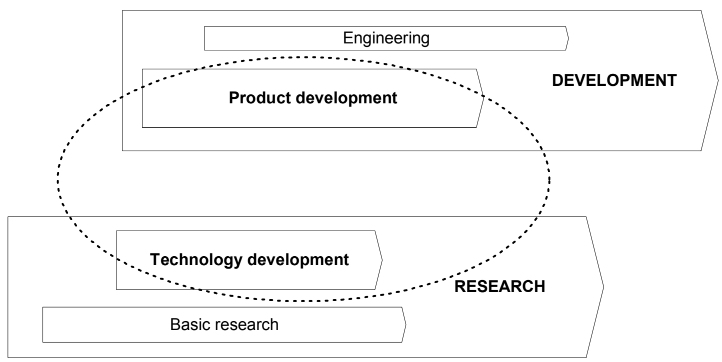

Exhibit 1: Visualization of R&D-related work and surroundings (the ellipse represents the scope of this thesis).

Managerial issues related to technology development, product development and their interplay have been studied in close relationship with UBI Printer, Volvo Truck Corporation, and Ericsson Mobile Communications. Methodological approaches have varied from broad surveys (e.g. the Volvo Truck Corporation study of technology transfer), to in-depth case studies (e.g. the Bluetooth study of Ericsson in Paper VI), and to more action-oriented approaches developing new tools and methods (e.g. the R&D content graphs in Paper V for managing project scope).

This chapter states the overall purpose, presents and elaborates previous research[1], and concludes with the framing of approached research issues.

[1] All books referred to in this thesis will be noted with authors, year of publication (followed by a…z), and referenced page number, and articles will be referenced by authors and publication year.

A.1. INTRODUCTION AND PURPOSE

Many companies perceive research and development (R&D) as somewhat fuzzy, involving high uncertainty, with unclear rate of return, and troublesome to manage. On the other hand, companies that succeed at commercializing new technology in a rapid and precise manner achieve possibilities of attaining a greater market share, premium prices and dominant designs, leading to a much sharper competitive edge. The difference between success and failure is frequently found in the underlying management processes, more specifically in the interfaces between different development phases. Roberts (1979), for example, has long studied the movement of R&D results through organizations, declaring that most large companies are unsatisfied with the R&D outcome in terms of profitable products on the market. In line with this reasoning, Katz and Allen (1985, p. 391) state that an effective organization needs to cause the results of R&D to be appropriately transferred downstream. The capability to develop and integrate new technologies into commercialized products by using a rapid, repeatable, and effective process is at the foundation of competitiveness for industrial firms (Iansiti and West, 1997).

This thesis deals with the management of R&D processes. This is done not only by focusing on technology development and product development, but also by aiming at understanding the interface between those processes. It is all in line with the reasoning of Iansiti (1993) who states: "*a significant body of research has been completed on the management of research as well as on management of development, [while] there is less established understanding of their complex interaction*". Properly managing R&D processes has long been a matter of debate and considered a troublesome area with no simple answers; ranging from an Achilles' heel in some firms to the sole basis of competition for others, many of the differences have contributed to R&D management issues (Clark and Fujimoto, 1991, p. 1; Smith and Reinertsen, 1991, p. 170). By properly managing R&D processes, companies can reach an increase in lead-time precision, increased quality of final products, and reduced development cost. Overall, companies' competitive advantage can be strengthened as placed efforts are managed in a leaner manner and more aligned with overall business strategy.

Overall purpose

The perspective on managing R&D processes has changed over the years, moving from a technology-centered model to a more interaction-focused view. Simultaneously, the contribution of R&D to companies' overall competitiveness seems to have increased in importance. Many companies have expressed frustration over not gaining sufficient rates of return on their R&D spending – highlighting the management of R&D processes as a vital area of improvement. Recent research goes one step further, appointing integrational issues between different areas of expertise as explanatory reasons. In particular, the interface between technology development and product development has been characterized as showing a high potential for improvement (e.g. Iansiti, 1997), yet is studied by few. Earlier research has typically focused predominantly on R&D management as a whole – neglecting the differences.

Hence, this thesis explores management of R&D processes with special attention to technology development, product development[2], and their interplay. Research issues approached can be classified into two major domains: managing internal organizational interfaces when introducing new technology, and management of technology development and product development scope. The study is conducted in order to explore and increase the understanding of management of R&D processes in manufacturing firms, while also delivering industrially valuable insights and methods.

A.2. FIVE GENERATIONS OF R&D MANAGEMENT

R&D has been studied for a long time within different contexts, economies, and environmental demands throughout the years. The transition from early days' booming markets and economic growth in the 1950s to today's highly competitive and global marketplace is reflected in the way R&D has been managed. Early success stories such as the industrial research laboratories Bell Labs, Xerox Parc and Lockheed Martin Skunkworks have been replaced by companies like the more market-focused 3M, the rapid introductions of new product ranges from Japanese manufacturers like Toyota and Sony, and R&D collaborations like Ericsson's network of companies around the "Bluetooth" technology and standard.

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[2] It is worth noticing that these two processes are interrelated, sometimes hard to distinguish, not to be seen as functioning sequential and sometimes being in part or in whole conducted by external parties, emphasizing the need to consider them simultaneously.

The perspective on R&D processes has been different throughout the years, since the structure and prerequisites of the economy have changed and so has the presumption of best practice. One attempt at describing the last fifty years of evolution within the R&D field is shown in Exhibit 2. Worth noticing is that these five models of R&D generations, though presented on a time scale, hold components or ideas still valid and sought for by many companies, and hence do not represent a map of where companies today are to be placed. Throughout these periods, different industries or companies have functioned as role models or drivers of best practice, a phenomenon that can also be recognized from research results.

R&D Generations	Context	Process Characteristics
First generation	Black hole demand (1950 to mid- 1960s)	R&D as ivory tower, technology-push oriented, seen as an overhead cost, having little or no interaction with the rest of the company or overall strategy. Focus on scientific breakthroughs.
Second generation	Market shares battle (mid-1960s to early 1970s)	R&D as business, market-pull oriented, and strategy-driven from the business side, all under the umbrella of project management and the internal customer concept.
Third generation	Rationalization efforts (mid-1970s to mid-1980s)	R&D as portfolio, moving away from individual projects view, and with linkages to both business and corporate strategies. Risk-reward and similar methods guide the overall investments.
Fourth generation	Time-based struggle (early 1980s to mid-1990s)	R&D as integrative activity, learning from and with customers, moving away from a product focus to a total concept focus, where activities are conducted in parallel by cross-functional teams.
Fifth generation	Systems integration (mid-1990s onward)	R&D as network, focusing on collaboration within a wider system – involving competitors, suppliers, distributors, etc. The ability to control product development speed is imperative, separating R from D.

Exhibit 2: Description of five generations of R&D processes (developed and adapted from Roussel, 1991, p. 39; Rothwell, 1994; Miller and Morris, 1998, p. 19; and Chiesa, 2001, p. 12).

During the first generation of R&D (1950 to mid-1960s), most of the new products that were produced were also sold, new industries emerged, and technology was generally seen as the remedy for all ailments (Rothwell, 1994; Pelz and Andrews, 1966). This first generation of R&D worked under the assumption that the more R&D went in, the more products came out. In short, R&D was seen as an overhead cost (Roussel *et al.*, p. 26). With regard to the R&D process, it was viewed as linear and as focused on pushing technology downstream towards the marketplace (e.g. Quinn and Mueller, 1963) – a marketplace characterized by a demand matching or sometimes exceeding the supply.

During the second generation of R&D (mid-1960s to early 1970s), the supply and demand were in a more stable relationship, competition was intensified, and more emphasis was placed on marketing efforts to increase the sales volume (Rothwell, 1994). Within this environment, more focus was placed on the short-term demand side, neglecting long-term research in favor of ideas from the market. Process-wise, the market-pull effect was strengthened and the process was seen somewhat oppositely as compared to the first generation of R&D – i.e. ideas originated from the market, to be refined and developed by R&D (e.g. von Hippel, 1976). Project management was also introduced to direct and monitor the R&D efforts, and the business side as the internal customer of R&D was highlighted (Miller and Morris, 1998, p. 13).

Further, the third generation of R&D can be discerned during the period of the mid-1970s to mid-1980s, when the economy was shivering with high rates of inflation and demand saturation (Rothwell, 1994). Cost control and cost reduction became the name of the game (Miller and Morris, 1998, p. 15), leading R&D to eliminate wasteful efforts by reviewing and improving the way new technology was developed and monitored within the company (e.g. Galbraith, 1973; Allen, 1977; Roberts and Frohman, 1978). This strong process-focus resulted in a more linked and interaction-focused view of R&D (instead of the two extremes as before), tying the technological capabilities more closely together with the market needs. The portfolio view of R&D also resulted in numerous ways of balancing the risk-reward continuum of probability of technical and market success (Roussel, 1984; Cooper, 1983).

The next identified period ranged from the early 1980s to mid-1990s, when the economy recovered and business people rethought their diversification strategies in favor of returning to their core business, all under a time-based competition paradigm driven by Japan and companies like Toyota, Sony, and Honda (Rothwell, 1994). Overall, the automotive industry was heavily benchmarked and functioned as a role model for many (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992; Aoshima, 1994). The focus shifted from developing products to putting the product in a total business concept, including also for example services, distribution, and multi-product platforms (Miller and Morris, 1998, p. 274). With regard to the R&D process, the new product development process was highlighted, and the integration and parallelization of activities were brought forward as success factors when striving for speed (Trygg, 1991; Eldred and McGrath, 1997; Cooper and Kleinschmidt, 1995).

Finally, the predicted fifth[3] generation of R&D broadens the boundaries for companies' R&D activities, all in the light of increased global competition, rapid technological change, and the need for sharing heavy technology investments (Rothwell, 1994). Hence, R&D needs to interact with the business environment, e.g. competitors, distributors, customers, suppliers, etc., placing more emphasis on the ability to coordinate and integrate systems from different parties (e.g. Iansiti and West, 1997). Examples of this type of rapid system integration are companies from the computer hardware and software industry, e.g. Microsoft Corporation, Netscape Corporation, and Dell Corporation (MacCormack, Verganti, and Iansiti, 2001; Tushman and O´Reilly, 1999). Further, the ability not only to be speedy in product development, but also to control the speed and thus be timely, is in even stronger focus. In line with this logic, reducing the uncertainty due to development by separating the more research-oriented tasks is one common approach, strengthening the need for efficient and effective integration of a coherent whole.

To summarize, the five-fold classification indicates that the perspective on R&D processes is changing, adapting to the surrounding context and prerequisites, and that R&D processes can be a source of vital competitive advantage when facing those changes. The challenge for companies to stay profitable is tougher than ever. Hence, being a fast and timely innovator by bringing new technology successfully to the market is seen as an increasingly important factor determining a company's competitiveness in markets where product life cycles are short and the rate of technological change is high (Iansiti and West, 1997).

Managerial approaches

The management of R&D has changed throughout the years, moving from an isolated view to a more connected and complex situation to handle. The previous section classified and described overall perspectives on R&D processes, using a time scale. This section describes in more detail, and in a more dynamic and coupled manner, the managerial approaches and company responses related to those R&D environments.

Managing R&D processes involves several challenges for firms – e.g. strategic, operational, and methodological. Traditionally, the amount that companies spend on

[3] Equivalent to the description by Miller & Morris (1998) of their fourth-generation R&D model with innovation as the company's responsibility and not constrained by the traditional company boundary.

R&D has been used by business analysts as an indicator of competitiveness, i.e. similar to the first-generation R&D discussed in the previous section (Badawy, 1989). However, Badawy (1989) states that many companies have had great success in developing new technology, though not in managing it to result in commercially successful products. Iansiti (1997) argues further that the R&D spending is less important than "*a company's process for rapidly and efficiently translating its R&D efforts into products that excel in satisfying the market's needs [which] is much more important*". Nevertheless, even though the challenges in managing R&D and R&D processes have changed throughout the years, some issues have stood their ground, and others have arisen. This view is more cumulative and evolution-oriented in contrast to the static description of the five generations of R&D presented in Exhibit 2. This dynamic view is presented in Exhibit 3, where not only the five generations are noted, but also the related company responses and examples of associated managerial approaches.

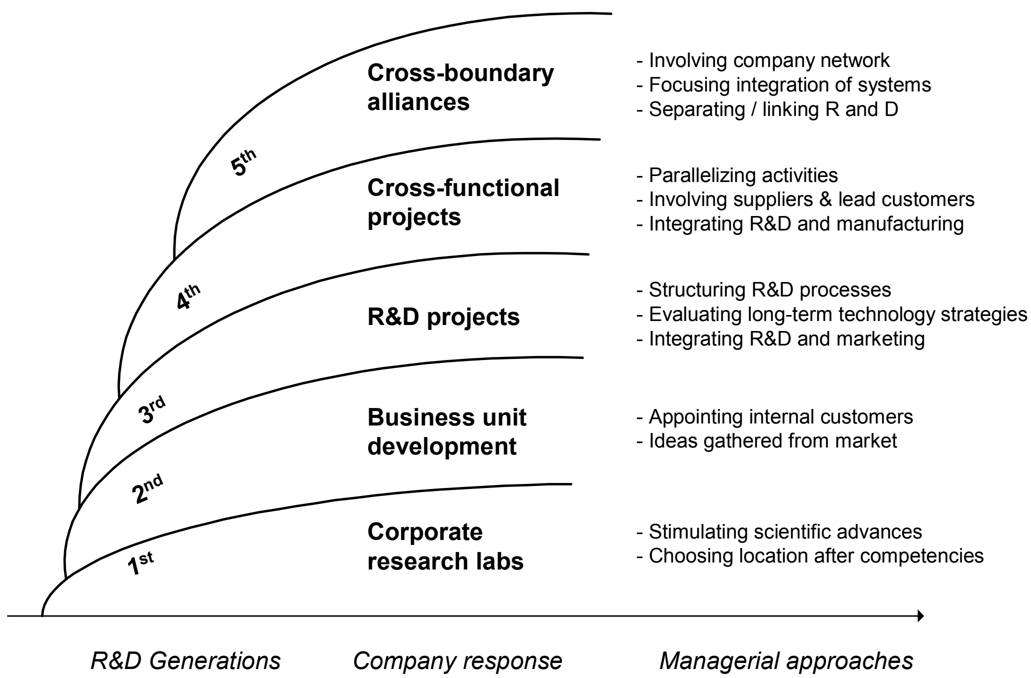

Exhibit 3: Visualization of five generations of R&D management from the early 1950s until today, related company responses, and examples of associated managerial approaches.

Exhibit 3 moves away from describing the characteristics of each generation, to discussing the company responses and related managerial approaches, all in a potentially cumulative manner. Today, industries and firms struggle with a mixture of the noted responses and approaches, all depending on, for example, history, context, and market.

The company reaction related to the first generation of R&D was to create corporate research labs, labs where technology could flourish and where main managerial challenges were to decide the geographical location of the labs and to stimulate scientific advances (Quinn and Mueller, 1963). The characteristics of the second generation of R&D were typically handled by incorporating R&D into the business unit. Ideas were gathered from the market, and internal customers of each R&D task were appointed at the firm, all in order to secure closeness to the market. Further, the characteristics of the third generation of R&D were met with a stronger focus on the R&D projects, introducing portfolio and project management techniques and structured design methods to improve the efficiency. Long-term strategies were evaluated and analyses were made of the consequences of the choices; further, the integration of the R&D function with the market was in focus. The fourth generation of R&D introduced the concept of lead customers, parallelized activities, and involved suppliers in the development efforts in an attempt to bring in other perspectives for increased cross-functionality. Finally, the fifth generation of R&D is met by firms taking on a cross-boundary alliance strategy, involving the company network in both research and development, and linking research to development to enhance the overall precision.

The integration dilemma is clearly evident as a contemporary management issue, involving integration of systems and processes to deliver a coherent and effective whole. A noted trend of separation between research and development (cf. Chiesa, 2001, p. 173; Corso, Muffatto, and Verganti, 1999) to reduce uncertainty and gain speed has placed even tougher demands on managing and integrating R&D processes, a challenge which is the main focus of this thesis. Eldred and McGrath (1997b) note, for example, that the key to more effective R&D is improving its underlying management process – a challenge that is even more intense when separating, or otherwise balancing, research and development efforts. There has, however, been limited research on the interaction between research and development, especially under the prerequisites of today.

Consequently, this thesis deals with management of R&D processes, with a special focus on the interplay between technology development and product development in manufacturing firms. Previous research, as well as practitioners, has highlighted the link between technology development and product development within the R&D umbrella as crucial, and an often neglected issue, when creating and sustaining a successful flow of new technology to the market. This statement, combined with the perceived need of companies to increase the rate of return on technology development, argues for the area to be worth exploring further. The integration of technology development and product development may have been present throughout the first five generations of R&D, but its importance and actuality has been amplified during the latter generations, due to the increased time pressure, the need of higher precision, and the tougher system-integration tasks facing companies in today's context. Hence, having a well-functioning interaction between technology development and product development can increase lead-time precision, increase the quality of products launched at the marketplace, reduce development cost, and become a foundation for competitive advantage as placed efforts are more aligned with overall business strategy.

A.3. DEPICTING TECHNOLOGY DEVELOPMENT AND PRODUCT DEVELOPMENT

In this section the terms used in the thesis are clarified and defined and the differences, as well as the linkage, between technology development and product development are highlighted and discussed.

Clarification of terms used

There is a multitude of different definitions and uses of language for R&D depending on, for example, type of industry, history, academic research domain, purposes etc. Terms flourish such as basic or fundamental research (e.g. Goldman and McKenzie, 1965), applied or targeted research (e.g. Autio and Laamanen, 1995), advanced engineering (e.g. Clark and Fujimoto, 1991, p. 26), product development (e.g. Cooper, 1983), product engineering (e.g. Clausing, 1994, p. 338), engineering (e.g. Babcock, 1991, p. 2), and technical services (e.g. Allen, Lee, and Tushman, 1980) – all related to R&D and meaning different things to different researchers and/or companies (Exhibit 4). Hence, a clarification of terms and meanings is necessary.

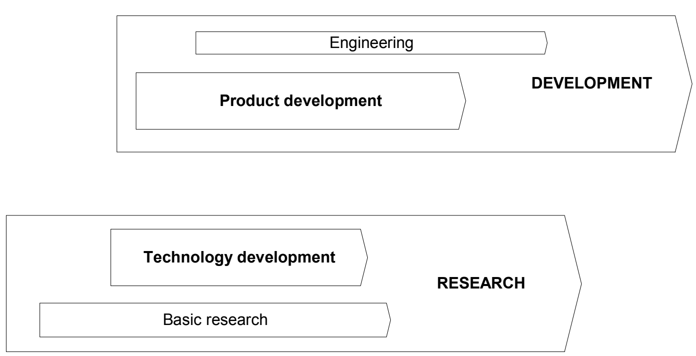

Exhibit 4: Visualization of R&D-related work and surroundings.

Exhibit 4 visualizes R&D-related activities and the surrounding context[4]. The following are characterizations, related to the model above, of R&D-related work[5]:

<u>*Basic research*</u> (fundamental research): Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying phenomena and observable facts, without any particular application or use in view.

<u>*Technology development*</u> (applied research, advanced engineering): Technology development is investigation undertaken in order to acquire new knowledge, though directed primarily towards a specific practical aim or objective – developing ideas into operational form.

<u>*Product development*</u> (development): Product development is systematic work drawing on existing knowledge gained from research and practical experience, directed towards producing new materials, products and devices and towards installing new processes, systems and services.

<u>*Engineering*</u> (product engineering, technical services): Engineering is systematic work directed towards improving already installed processes, systems and services, or produced materials, products and devices.

Further, when it comes to managing R&D processes, the definition can be divided into two basic blocks, i.e. management and R&D processes. These basic blocks have been found to be defined in a respectively consistent manner, and two well-referenced works within the field have been chosen as representing examples and sources (Fayol 1949 and Rothwell 1994). Babcock's (1991, p. 12) review of Fayol's (1949) work refers to management as consisting of the elements "control, organize, and plan", elements that are noted by Babcock, as by Koontz et al. (1986, p. 35), to have "*proven remarkably useful and durable over the decades*[6]". Controlling means ensuring that events conform to the prepared plan, while organizing involves intentional establishment of roles, structures, and interactions throughout the work. Further, R&D processes have been

[4] This visualization is not to be seen as matching the sequences, relations, tasks, characteristics or the like related to R&D. This is a mental map aiding description of the scope of the thesis. It is agreed that there are several interdependencies, company boundaries, difficulties in framing the different tasks, etc. which are not captured in this visualization.
[5] Adapted from the National Science Foundation (1993).
[6] These three dimensions are similar to Ellis (1997, p. 64): plan, organize, lead, evaluate, control; and to Drucker's (1999) view of basic elements of management work: plan, organize, integrate, measure, and develop people – the latter as distinct from the human-development dimension.

studied by many, though defined by few – Smith and Reinertsen (1991, p. 119) declare in general terms that the R&D process covers what will be done, when, and by whom. One recent, more detailed, attempt is made by Chiesa (2001), who discusses the main elements as being leadership, resourcing, systems and tools, and technology acquisition.

Consequently, this thesis views R&D through the movement and transfer of new technology across internal organizational interfaces; it targets applied research and development by using the terms "technology development" and "product development"; further, it does not specifically address manufacturing process-related work or market-related work. Managing R&D processes is also noted to involve controlling, organizing, and planning of elements such as leadership, resourcing, system and tools, and technology acquisition.

How technology development differs from product development

Zedtwitz and Gassmann (2002) remark that the contracted term "R&D" might, without care, beguile us into disregarding the inherent differences of the tasks concerned, tasks that entail different managerial problems. Hence, R&D could be viewed and divided in several ways, for example as consisting of two major dimensions with different characteristics and aims: one exploration-oriented and one exploitation-oriented part (Katz and Allen, 1985, p. 390). In this thesis, the exploration-oriented part matches technology development (research) and the exploitation-oriented part matches product development (development). The former develops technological capabilities, and the latter exploits those capabilities to generate a range of products.

Technology development and product development are two deeply interrelated activities, although with some fundamental differences (White, 1982; Sheasley, 1999; Eldred and McGrath, 1997a). There are several dimensions where technology development differs from product development in terms of task characteristics – namely prerequisites, technical maturity, time horizon, competence needs, process repeatability, and completion point (Iansiti and West, 1997; Kusunoki, 1992). Kusunoki (1992), like Zedtwitz and Gassmann (2002), argues for example that most research has been done by viewing R&D as a whole, neglecting these inherent and critical differences. Technology development is more problem- and concept-centric, while product development pursues solutions and needs on a more detailed level (Exhibit 5).

Dimension	Technology development	Product development
Prerequisites	Problem-focused, often unclear and with a fuzzy target.	Solution-focused, and clearer in terms of targeted market niches as well as appointed development resources.
Technical maturity	The technology is to be evaluated and developed; problems are more of a component nature.	Major technological concepts are framed and chosen; the challenge is more of an integrative and systemic nature.
Time horizon	More long-term, e.g. targeting the product portfolio of tomorrow.	Ranging over a shorter period of time.
Competence needs	Unclear, depending on the nature of the problems, and harder to proactively schedule in time.	Clearer, project-based, and easier to predict.
Process repeatability	Low; greater uncertainty involved, and uniqueness, result in elusive processes with low commonality.	Higher; the process shows more routine tasks and is easier to formalize.
Completion point	Unclear; missions can be to build knowledge, or to demonstrate a certain technology feasibility level.	Sharp, ending with commercialization and launching of new products on the market.

Exhibit 5: Examples of differences in task characteristics between technology development and product development in relation to each other (synthesized from Leifer and Triscari, 1987; Clark and Fujimoto, 1991, p. 169; Kusunoki 1992; Clausing 1992, pp. 317-341; Sheasley 1999).

Further, these differences taken together are the basis on which researchers argue to separate the two tasks from each other, e.g. culturally, resource-wise, management- as well as location-wise (Chiesa 2001, p. 173; Iansiti, 1997). The inherently different logics of the parts of R&D incline us to separately manage technology development and product development in order to gain efficiency and clarity[7] (cf. Allen *et al.*, 1980). For example,

[7] It should also be noted that several different degrees of separation are possible, for example, organizational, cultural, procedural, and legal.

Eldred and McGrath (1997b) argue that products utilizing new technology require a technology development phase prior to, or in parallel with, product development. Separating technology development and product development is also a noted trend (cf. Chiesa, 2001, p. 175; Wheelwright and Clark, 1992, p. 38) and a frequently used way of reducing the uncertainty and increasing the manageability of R&D in manufacturing firms (Chiesa, 2001, p. 173). Summarizing reasons for considering a separation of technology development from product development:

- To increase the manageability of R&D, i.e. being able to apply different types of management adapted to the respective logics (Clark and Fujimoto, 1991, p. 167).
- To reduce the uncertainty of R&D, i.e. decreasing the complexity and risk by developing technology off the critical path of product development, thereby enhancing precision (Magnusson, 1999).
- To raise the quality of the final product, i.e. by introducing well-prepared and tested new technology in a deliberate manner to the product development projects (Clausing, 1994, p. 317).

However, there are also reported drawbacks to conducting such a task division (cf. Zedtwitz and Gassmann, 2002; Magnusson, 2000). According to Lawrence and Lorsch (1969), the more a company differentiates, the more it needs to integrate in order to end up with a coherent, effective whole. Hence, if a task division is not conducted, a high degree of complexity is expected to be found within the R&D environment, although the gain might be a lesser need of integration mechanisms between the two parts. This might be suitable for a certain dynamic environment where, for example, the holistic, integrative, and simultaneous consideration of both technology development and product development is essential (cf. Magnusson, 1999, discussing the Toshiba Corporation case).

Linking technology development and product development

Whether technology development and product development are integratively managed to minimize potential barriers, or separated to increase efficiency, the interaction between technology development and product development has been regarded by several researchers as troublesome, yet crucial (e.g. Chiesa, 2001, p. 173). In the light of its industrial importance, Clausing (1994, p. 19) claims that one of the major cash drains of R&D occurs when new technology concepts are inadequately transferred into the development of a specific product. Similarly, McGrath and Eldred (1997a) argue that the inability to properly manage technology development and link it to product development is frequently the culprit behind many costly delays. Linking technology development to product development involves many dimensions: design of the overall R&D process to enable interaction (e.g. synchronize strategies and schedules), decisions regarding staffing and potential rotation of personnel, methods or mechanisms to use in the interplay, and connection with the surrounding network to secure access to necessary knowledge.

A.4. RESEARCH ISSUES

Throughout the years, the five identified generations of R&D (see section A.2) have faced a certain set of managerial issues. These issues have evolved, diminished or grown in importance and actuality. The dynamic R&D process involving the movement and transfer of new technology intra-organizational interfaces has been highlighted as complex and troublesome to manage. Especially the interplay between technology development and product development has been stated to have large potential for improvement, affecting companies' bottom-line results. The purpose of this thesis is to explore managerial R&D process issues related to technology development and product development as well as their interplay, issues that have grown in importance during the later identified generations of R&D. The specific set of issues that has been approached in this thesis can roughly be placed into two main categories: aspects related to managing internal organizational interfaces when introducing new technology, and aspects related to managing technology development and product development scope.

Managing internal organizational interfaces

The effective and efficient management of interfaces is crucial for larger manufacturing firms with internal R&D capabilities. The term "interfaces" refers to boundaries between functions (e.g. between research and development, or between cab and chassis) or between different R&D phases (e.g. between technology development and product development). Previous investigations within the field that have functioned as a basis for this category and this thesis are:

- The communication-based studies led by Allen (cf. Allen, Lee, and Tushman, 1980). This stream of research has characterized the internal interfaces within R&D as troublesome, though primarily focusing on the interfaces between R&D and other functions such as production or marketing (cf. Souder and Padmanabhan, 1989; Trygg, 1991). Further, the gatekeeper concept was introduced and elaborated (Allen, 1971); the gatekeeper receives information from a wide variety of sources, and acts as an information source for his group (an intermediate role).
- The integration mechanism studies of Roberts (cf. Roberts, 1979) identified the input to the R&D process and the downstream linkages as a potential hindrance to efficient and effective commercialization. This work resulted, among other things, in categorizing and presenting three integration mechanisms (termed “bridges”), i.e. one organizational, one procedural, and one human-based approach – all in order to overcome the identified problem that much excellent research is never used.
- The technology integration studies initiated by Iansiti (cf. Iansiti and West, 1997) were among the first that really pinpointed the interaction between research and development as crucial to management, highlighting the integration tasks and the space between technology creation and exploitation as critical. The focus was on the process of integrating technologies, moving away from a linear research and development view to an iterative view. Further, the main industry in focus was the rapidly evolving computer and software field. The managerial approach suggested is based on setting up a technology integration team, i.e. a team responsible for preparing and making the decisions of what technologies to integrate and how to make them function in a systems product.

The research presented above provides a foundation for the studies in this thesis within the category of managing internal interfaces. To be more specific, aspects of the following issue have been approached in the thesis:

[R1] How can the interplay between technology development and product development be managed, and potentially improved?

Issues not fully answered by previous research involve simultaneous consideration of both sides of research and development when considering technology development and internal transfer to product development.

Managing technology development and product development scope

Managing technology development and product development scope is also a delicate task, involving factors affecting, for example, technology content in released products, timeliness and project costs, and the overall product and project complexity (cf. Karlsson and Åhlström, 1999). The terms "technology development" and "product development scope" refer to the project content in terms of degree of newness, technological risks and opportunities, strategic importance for the firm, etc. Previous investigations within the field that have functioned as a basis for this category and this thesis are:

- The research conducted chiefly within the automotive industry by Clark, Wheelwright, and Fujimoto (cf. Clark and Fujimoto, 1991; Wheelwright and Clark, 1992). This extensive research introduced, for example, new ways of organizing (e.g. the heavyweight product manager), elaborated upon Japanese managerial principles moving away from giant technological steps to a more incrementally based perspective, and emphasized the importance of lead time.
- The portfolio perspective was highlighted with the work of Roussel, Saad, and Erickson (cf. Roussel, 1984), providing guidance to management of the overall R&D efforts in a strategic manner. The work resulted for instance in several graphical views of R&D, typically framed by dimensions such as technological maturity and probability of success or risk, and was exemplified via a food ingredients company.
- The work by Eldred, McGrath, Smith and Reinertsen (cf. Eldred and McGrath, 1997a; Smith and Reinertsen, 1991), researchers and experienced consultants, has resulted in techniques and working methods aimed at improving the management of R&D. The risk of missing deadlines due to a misbalanced project effort in terms of technological content or newness is pinpointed. A process guiding in this respect is suggested, focusing on overall synchronization of R&D efforts, technology equalization (i.e. not only developing the core technology, but also securing necessary supporting technologies), and technology transfer management.

The research presented above provides a foundation for the studies in this thesis within the category of managing technology development and product development scope. Issues not fully answered by previous research involve the continuous and dynamic management of the R&D scope (including assimilation of new methods), i.e. assisting not only the strategists but also individual project managers within companies. To be more specific, aspects of the following research issue have been approached within the thesis:

[R2] How can the R&D project scope be managed in a structured and continuous manner throughout project execution?

Aspects of the two main R&D issues R1 and R2 are approached in Papers I–VII. It is not my intention, nor within the scope of this thesis, to provide general solutions in each of the two categories, but merely to explore aspects thereof and to provide insight and examples of thinking and acting on these issues.

B. METHODOLOGY

This chapter starts with a presentation and discussion of the research paradigm and tradition, follows on to a more detailed description of the conducted studies and associated companies, and ends with an analysis of the methods used as well as a discussion on the quality of data and alternative approaches.

B.1. RESEARCH PARADIGM AND TRADITION

A research paradigm[8] expresses the world-view, the perceptions of scientific research, and the relation to scientific and ethical values of the researcher (Törnebohm, 1974, p. 2). The research paradigm in turn influences the choice of methodological approach. The research at the Department of Operations Management and Work Organization at Chalmers University of Technology has traditionally been conducted in close cooperation with industry, by methods commonly using deep longitudinal case studies from a theoretical starting point of sociotechnical systems (cf. Karlsson, 1979). This is most likely a result of financial industrial support, the relatively free and open access to Swedish companies, and the pursuit of operational and industrially viable research results. The Ph.D. candidates at the department all come from an engineering background; the underlying perspective and the view of research are thereby heavily influenced. As a former colleague states: "*being an engineer is being normative*" (Lundqvist, 1996, p. 15), resulting in aiming not only to generate new theory but also to generate implications for management. This background has strongly guided and affected my world-view and beliefs as to how to conduct research and what constitutes good research. In short, this forms the research paradigm of the thesis, resulting in a pragmatic approach embracing a mixture of traditional positivist and constructivist approaches (cf. Tashakkori and Teddlie, 1998, p. 3).

Further, the research results throughout the Ph.D. period are frequently discussed with and evaluated by industry; for example, each industry project is typically supervised and guided by a steering committee using a milestone approach. This way of working leads to a fair amount of time spent on site in order to get the necessary contextual knowledge. This close relationship, usually to managers, naturally sets its mark on the research being conducted as well as the results achieved. The practice-oriented work performed may therefore not be very conceptual or aggregated, and can be accused of being too

[8] A paradigm can be said to hold four components, i.e. the researcher's knowledge and related assumptions, interests, personal driving force, and abilities to act according to orientation (cf. Törnebohm, 1994).

simplistic or case-specific; however, the value of being close to the studied phenomenon, resulting in insights and lessons well grounded in practice, is high. It is then up to the managers in other companies to apply the experiences and theories within their own contexts and realities. The approach is similar with the action research paradigm (cf. Foster, 1972), although different in the sense that there are seldom stated deliverables; neither am I measuring or involved in the actual process of change itself.

Examples of previous research conducted at the department are the work by Karlsson (1979), Lindér (1990), Lindberg (1990), Tunälv (1991) and Almgren (1999), all of whom have been studying production systems and manufacturing strategies, typically in the automotive industry. Other examples within the product development domain are Carlsson (1990), Trygg (1991), Lundqvist (1996), and Sundgren (1998), who have studied the integration of technical functions, efficiency and organizing aspects, and product platform development, typically from a managerial point of view. Most of the work has also been conducted from a contingency-based perspective, where the notions are deeply rooted that there is no best way to organize and that applying a holistic view is central to understanding.

B.2. EVOLUTION AND SCOPE OF THE STUDIES

The data underlying this thesis come from three longitudinal research projects in the manufacturing industry: the UBI Printer study (UBI), the Volvo Truck Corporation study (VTC), and the Ericsson Mobile Communications study (ECS). When it comes to the previous characterization of different R&D generations (see section A.1), I am not able to position the respective three studies in this thesis as acting entirely within a certain generation. Each study acts instead within a mixture of the characterizations. In order to roughly position the context and environment of the three studies, examples of characteristics (at the time of each study) from each study are provided below[9]:

<u>UBI Printer</u>. The R&D environment at UBI Printer is characterized by a strongly resource-constrained business view, where the electrical and mechanical platforms are updated in sequence. There is a focus on individual project management, equivalent to the second-generation R&D, though the overall platform thinking better matches the elements of the third generation. Further, the customers or suppliers are not taking a major part in the R&D efforts. In sum, the R&D environment at UBI Printer corresponds to a mixture of the second and third generations of R&D.

[9] This is not to be seen as a characterization based on scientifically gathered data, but merely as guidance to the reader.

Volvo Truck Corporation. The R&D activity at VTC, in terms of funding, is seen as an overhead cost, similar to the first generation of R&D; but there is an element of portfolio thinking from the third generation, with movement towards a total concept offering, and more importantly there is a high degree of involvement from the suppliers in R&D – matching the basic level of fifth-generation R&D. Consequently, the R&D activities at VTC constitute a mixture of several different generations of R&D.

Ericsson Mobile Communications. The R&D efforts at ECS, or more specifically in the Bluetooth unit and the parent organization, have a high degree of collaboration with competitors, suppliers, complementary services companies, and customers – well targeting the fifth generation of R&D. The portfolio thinking in terms of working with platforms is well spread; less spread are risk-reward analysis and evaluation systems of the third generation of R&D. Hence, the R&D efforts at ECS match a first attempt towards the fifth generation of R&D.

The three studies can to some extent be categorized or viewed by using the five generations of R&D classification, though not yielding a one-to-one match but rather constituting a mixture thereof. Further, the resulting seven papers (apart from three confidential company reports) are attached as Papers I–VII.

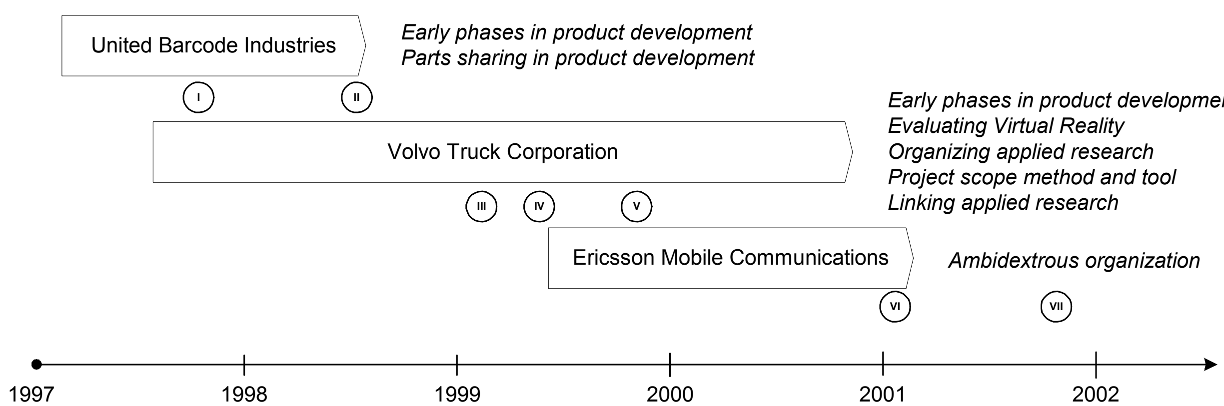

Exhibit 6: Overview of conducted research projects and Papers I–VII (circles with Roman numerals indicate respective papers).

Exhibit 6 briefly reviews the scope of the conducted research projects. All seven papers deal with the management of, and interplay between, technology development and product development. The three studies, labeled UBI, VTC, and ECS, are summarized below. The scope of the research was at first to explore the early phases of product development. This study led to the insight that the foundation of a successful flow of technology is dependent on the planning, execution, and preparation of technology development even before the product development project has begun. Further, the scope of the research was broadened not only to include technology development, but also to extend the initial project management perspective to incorporate the dimensions of integration and differentiation and the management of knowledge.

The United Barcode Industries study

The United Barcode Industries (UBI) study started out during February of 1997, initially focusing on differences between the formal model for conducting product development and the informal process actually in use at United Barcode Industries Corporation. The work concentrated on longitudinally following the development of a new technology platform for the next-generation product family of barcode printers (Exhibit 7). Overall, the focus was on the interface between technology development and product development.

Exhibit 7: Example of a typical barcode printer from UBI Printer (Intermec's EasyCoder 601XP).

The project involved 14 persons (excluding consultants), lasted for 18 months, and had weekly half-day coordination meetings of which I attended approximately 70%. The interaction with the project leader and the team was extensive (e.g. during project meetings and research presentations) and the access to information (e.g. project minutes, blueprints, roadmaps, surveys) was unrestricted and freely shared. The research questions studied were the design, set-up, and execution of the early phases in product development (Paper I), and the managerial difficulties associated with sharing technology and parts across different generations (Paper II).

The UBI project overlapped the VTC project in time, enabling a multi-case study approach for both research tasks. What was revealed during the studies of the early phases was that the industry ought to adapt different front-end process models depending, at least, on the respective project characteristics – contrary to the ongoing academic search for the optimal model. Further, some basic building blocks of the early phases were identified, providing guidance for practitioners. The second paper focused on the transfer management and sharing of parts between different models, a way of working that has long been considered as good design practice and an easy task. However, the study revealed complex managerial challenges that could be categorized into organizational, strategic, technology and cost, and support system-related issues. The complexity and difficulties found in Paper II spurred the interest into technology transfer and integration dilemmas. The UBI project was concluded during late spring of 1998, covering the early phases of the next-generation project as well as the detailed design phases (excluding the pilot production run).

The Volvo Truck Corporation study

The Volvo Truck Corporation (VTC) study started out during the summer of 1997 with a pre-study divided into two parts: one industrial and one theoretically based, both focusing on the early phases of product development at Volvo Truck Corporation (resulting in a company internal report entitled "Concept Development"). Three improvement areas (internal technology transfer, pre-development activities, and decision-making support), suitable for further research, were identified during approximately 25 interviews with managers and engineers from different departments involved in the early phases. The empirical data from the pre-study, together with additional data collection regarding a previous research study concerning a concept vehicle (Exhibit 8) and the UBI study, formed the basis for Paper I and Paper II.

Of the three identified areas, the internal flow of technology towards commercialization was chosen for the main study as of 1998. The main study was entitled "Internal Technology Transfer", and was supported as well as internally coordinated by a steering group consisting of line and project managers from the technology and product development function. The main study continued with the semi-structured interviews, using approximately an additional 25 interviews, in order to analyze the relation between the advanced engineering and product development functions. The interviews were combined with a company-internal survey (779 persons, 69% response rate) with the aim of nuancing and summoning the working practices thereby related at the five different functional areas.

The findings from both the interviews and the survey were discussed with persons ranging from engineers to the top management, as well as summarized in a company-internal report entitled "Internal Technology Transfer". The study revealed two modes of advanced engineering structures, one favoring technology development (termed “myopic pursuers”), and one favoring technology transfer (termed “integrative firefighters”), and resulted in Paper IV. In parallel to the interviews and the survey, a case study, from project start to manufacturing, has been conducted of a concept vehicle (taking approximately two years and followed by weekly half-day project meetings, minutes, reports, separate interviews, attendance at milestone meetings, etc.).

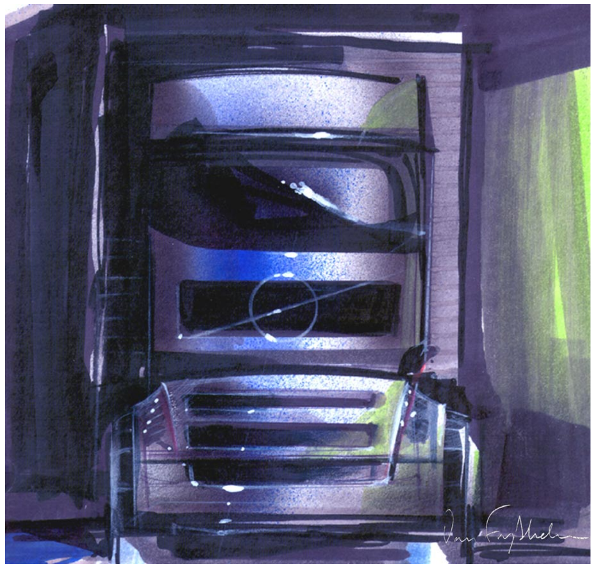

Exhibit 8: Example of a concept vehicle.

During this case study, the opportunity to study an actual replacement of full-size clay models with digital ones, i.e. Virtual Reality (VR) models, in the advanced engineering setting was taken (Paper III). It was shown that VR models are more beneficial to use earlier in the design cycle, when it comes to quickly generating full-size models, than to substitute full-size clay models. Further, during one of the project meetings of this study followed longitudinally, the need for a method or tool for dynamically working with the project scope was perceived, and hence, the development of one was initiated. After a literature review and several iterations with the practitioners, the R&D content graph was developed (Paper V). Finally, during 2000 the last paper (Paper VII) stemming from the VTC study was written upon further analysis of the survey and the interviews, focusing on the link between advanced engineering and product development within the company. Paper VII highlighted a rough situation for applied research, where tasks often are de-staffed and prolonged, and then fail to be used due to not having solutions ready in time for product development projects. The VTC study ended during the autumn of 2000.

The Ericsson Mobile Communications study

The Ericsson Mobile Communication (ECS) study started out at Ericsson Mobile Communications in Lund during the summer of 1999, as a result of Ericsson contacts initiated during my participation in the CHAMPS program "International Management of Technology". Similar to the other studies, a pre-study was conducted where a total of 22 persons involved in technology and product development were interviewed in order to cut out important research issues. This pre-study was done in collaboration with Martin Karlsson, a fellow researcher, and two subsequent studies were put forward to, and accepted by, the steering committee. Turning to the literature, the set-up of separate more or less autonomous organizations was found to be an appraised phenomenon, especially with regard to rapidly developing new technology. However, few researchers had analyzed what I termed the re-integration of knowledge and technology back to the parent organization. Hence, the study I focused on was the knowledge transfer back to the parent organization from a separated skunkworks-like organization, one that had been set up for developing the "Bluetooth" technology (Exhibit 9).

Exhibit 9: Example of a Bluetooth product (Sony Ericsson's wireless headset HBH-20).

The study of the evolution and strategic actions related to the Bluetooth organization was conducted during the autumn of 1999 and the spring of 2000. Further, during the study, it was found that Intel Corporation had been playing a vital role in the execution of an open standard. Consequently, during my stay as a visiting scholar at the Haas School of Business at the University of California, Berkeley, I visited and discussed the Bluetooth case with key employees at Intel's headquarters in Santa Clara. The Bluetooth case study is based on 19 semi-structured interviews that were taped and analyzed by using the NUD*IST software for qualitative data, and through attendance at Bluetooth training seminars, organizational announcements, and company internal presentations;

secondary press has also been used. The study casts some light on the evolution of a dual organizational structure, on potential re-integration efforts and outcomes thereof; it also discusses managerial issues associated with the double-edged sword of integration and differentiation. The study covered the early stages of the Bluetooth development until the announcements of the next step after the release of the first Bluetooth specification (early 2000). The outcome of the study was published as an IMIT (Institute for Management of Innovation and Technology) report, No. 113, and as a slightly revised version of Paper VI.

B.3. METHODS APPLIED

In order to study management of R&D processes, a diversity of methods has been applied – all depending on specific purpose and context for the respective paper and study. The methods used can be divided into three major areas, ranging from broad approaches using surveys to in-depth case analysis and to more action-oriented development of decision tools. Below follows a description and discussion of the methods used.

Broad approach using surveys

Within the field of social sciences, the survey method (qualitative or quantative) is one of the most common empirical approaches (Roberts, 1999). The use of a broader (internal) survey method was applied in the VTC study. The VTC study originated with a more qualitative approach using interviews in order to get a basic understanding of the way technology development was organized, conducted, planned, and funded in the company. However, the VTC organization consisted of five different departments, and I came to the conclusion that using interviews was insufficient and ineffective in order to reach this level of understanding – every department managed technology development in its own manner. Consequently, a company-wide survey targeting R&D-involved personnel at VTC was launched in order to describe, analyze, and model management of technology development. This survey targeted the whole population, all in all 779 identified persons. Further, it encapsulated both technology development and product development personnel, to enable a simultaneous and holistic view of the major parts of the R&D chain.

The strengths in using this kind of internal survey are that misunderstandings of terms and definitions can be avoided, sticking to one company's use of language; a holistic view of R&D processes is provided to a high level of detail; interviews and case studies might follow to illuminate potentially raised issues; and a comparably high response-rate level can be gained. This kind of survey, though, is constrained in terms of generalizing the findings and in terms of applicability to other types of industries. However, the purpose of the study was not to generalize, but to gather an understanding of variations within one single setting, and the potential effects these might have on technology development speed and internal transfer of results. In a way, this study can be seen as a case study where a developed survey constituted the basic platform of understanding. The survey in itself could be categorized as descriptive in nature, i.e. with a clearly defined hypothesis, a response rate higher than 50%, and the aim of understanding a phenomenon (Forza, 2002).

Further, alternative approaches that were abandoned concerned, for example, using a cross-company, cross-industry type of survey mapping, and analyzing technology development and product development as well as the interface between them. The difficulty in defining the appropriate terms, and Hill *et al.*'s (1999) argument for closing the academic/practitioner gap with empirical closeness and continuous interaction to secure viable and industrially useful research results, were the basis for the choice to start within one company setting. A wider survey holds other benefits and could well function as a complement after this study, investigating for example the presence of internal transfer teams and responsibilities, the balancing of technology development vis-à-vis product development and basic research, etc.

In-depth approach using case studies

In all of the studies, different forms of case studies have been used – ranging from short and concise examples in Paper II illustrating internal transfer issues to an in-depth case study of the evolution of the "Bluetooth" technology in Paper V. A case study is described by Leonard-Barton (1990) as *"history of a past or current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives…any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important"*. The traditionally noted weakness of the case study method is its limited capacity for generalization of findings, i.e. the findings are constrained by being situation-specific. However, its weakness is also one of the strengths, enabling learning from a particular case conditioned by the environmental context (Gadde and Dubois, 1999) – putting the results into context and meaning.

Further, in line with this reasoning, Dyer and Wilkins (1991) highlight one of the aims of case study research: to develop exemplars, i.e. stories against which other researchers (or, one might add, managers) can compare their experiences and gain theoretical insights.

Moreover, the case study method was chosen also for its strengths (see Hill *et al.*, 1999; Yin, 1994, p. 3) in approaching the high level of complexity involved in the understanding of R&D processes. The case study method has indeed been argued to be one of the most powerful research methods within the technology and operations management area (Voss *et al.*, 2002). The strengths of the method are its closeness to empirical data and the increase of research that has managerial relevance. The use of case-based research is also noted as a growing trend within the research community (Hill *et al.*, 1999).

To summarize, using case studies as a methodological basis is a way of achieving empirical closeness, contextual validity and interesting research. The phase of collection and analysis, as well as the development of models and constructs, have been conducted by me on site. Most of the case studies performed within the UBI, VTC, and ECS studies, like the classical case studies referred to by Dyer and Wilkins (1991), have been conducted within one organizational context (e.g. Paper IV). There is, though, a natural trade-off between deep understanding of one single social setting and the benefits associated with insights of a more comparative nature. This dilemma has been approached by not only studying the same setting, but moving between three different contexts (electromechanical industrial goods, industrial automotive sector, telecommunication consumer goods) throughout the Ph.D. process in order to widen my own understanding of R&D.

Action-oriented approach developing new tools and methods

In the studies, the development of decision-making tools has not been the stated purpose of a specific study; rather, development of tools has been catalyzed by a need perceived during the execution of the other studies. For example, during the study of a concept vehicle project at VTC, a need for alternative ways of structuring and visualizing the project scope was perceived. Consequently, in interaction with the project leader and the project team, the development efforts began (Paper V). This was also to some extent the case for the analysis of different front-end process models in Paper I, and for the development of the prototyping evaluation method in Paper III. However, the most obvious example of development of a new tool is the R&D content graph developed in Paper V.

Huang (1996) discusses the development of new methods and tools, and argues for the following functional requirements to be approached[10]: gather and present facts, measure performance, evaluate level of goodness, compare alternatives, highlight weaknesses and strengths, diagnose the reasons behind the level, provide directions for potential

[10] Originally developed for suiting Design For X-tools which is not directly equivalent with the targeted tools, but gives some guidance

improvements, predict what-if effects, carry out improvements, and allow iterations to take place. The R&D content graph fulfills most of these criteria by focusing on gathering and presenting facts, forming a basis for measuring, evaluating, comparing, and diagnosing R&D project content; but it is not intended to provide any level of goodness or suggested direction.

Further, the development of new tools has not involved the testing or verifying phases to a large extent outside the specific case environment, but merely focused on development of the tool as such. Development of new tools and methods is action-oriented per se, though there has not been any demand from the steering groups to deliver new tools (except the action research approach: e.g. Lewin, 1946). This has allowed a rather free and open-minded participation during, for example, the VTC study. The process for developing tools has, as noted before, been initiated due to a perceived need, a need which then has been verified by the parties involved. Thereafter, a literature search started seeking solutions, perspectives, or dimensions potentially relevant for the specific need.

B.4. QUALITY OF DATA, AND ALTERNATIVE APPROACHES

The thesis has been demarcated to sharpen the focus; thus, the studies and the results principally concern new product development in larger high-tech manufacturing firms with internal R&D capabilities. The thesis does not directly deal with more engineering-oriented types of work related to products already on the market, nor does it incorporate work of a more research-intensive nature (e.g. pharmaceuticals). The products of the firms that have been studied are also complex, in the sense that they consist of several different technologies, often with different life cycles, and that all need to be integrated to result in a coherent product. Further, time to market has been of utmost importance for the R&D function of the firms. Finally, the focus has primarily been on the R&D work conducted at the Original Equipment Manufacturer (OEM), the focal point for most trade-offs and managerial dilemmas. The aim of the studies has not been to draw far-reaching conclusions based on the sample of cases chosen, but rather to reach an understanding of the processes and issues behind the management of R&D processes – indicating difficulties that manufacturing firms might encounter and potential approaches. The theoretical base consists mainly of peer-reviewed scientific journals, aiming to build on validated and accumulated knowledge within the research community. Prior to each study, extensive theoretical searches have been performed, trying to identify relevant research streams for the issues.

Moving on to more methodological issues, the studies presented in this thesis are not to be seen as either inductive or deductive, but as a mixture of the two approaches, sometimes referred to as an abductive way of working (e.g. Gadde and Dubois, 2001; Kirkeby, 1994). The term "abductive" captures well the research approach taken in this study, i.e. a close interaction between empirical data and theory. This way of working is exemplified by Eisenhardt's (1989) description of an investigator's need of moving back and forth between case companies, research question redefinitions, and potential additional field studies. One clear example of applying this method is evident in Paper V. The process then started with the fact that a need for alternative ways of managing project content was perceived during a project meeting, leading to project scope dimensions derived from theory and then applied and tested in the project, ultimately to be reworked and theorized about. The focus on case studies as a methodological basis is also due to the standpoint that sometimes the full picture can only be revealed by analyzing real life, a situation where some potentially crucial interactive processes (which might be transparent to large-scale surveys) can be identified and explored.

Throughout the thesis work, there have been several different potential routes to choose, choices that no doubt have had an impact on the outcome. In some cases, the identified opportunities have overshadowed the current research focus and design, resulting in bringing that study onboard – widening the overall research focuses. It is my opinion that as a researcher one ought to pursue and exploit potentially valuable opportunities, but bearing in mind the trade-off between more deductive versus more inductive studies, and breadth vis-à-vis depth of the research scope. One of those examples is Paper III, where the opportunity arose regarding a potential exchange of full-scale clay models for digital ones. Another example concerns methodology: the deliberate choice of not pursuing the action research stream.

Consequently, one alternative basic approach for this thesis would have been action research (see Lewin, 1946), meaning that the researchers deliberately take actions within an organization and aim to create knowledge gained from those actions. The researcher acts as an agent of change, with two missions – one of solving problems assisting the practitioner, and one of contributing theoretically (Coughlan and Coughlan, 2002). However, the studies have been conducted by me as an independent observer, free to suggest actions but not to drive and aim for solving problems. If the action research approach had been taken, I would not have been an independent observer, but a participant. Being a participant means taking active part in the implementation of a system and simultaneously evaluating a specific intervention technique – consequently, the process of change becomes the object of study (Benbasat *et al.*, 1987). It is my belief that the action research route holds high value and requires a methodologically skilled researcher, potentially having intimate relationships with, or a special role in, the cases in question.

When it comes to quality of the research being conducted, the constructivist approach introduced by Guba (1985, p. 290) discusses the term "trustworthiness" for validity. The term refers to establishing credibility of the findings and thereby ensuring their quality. Tashakkori and Teddlie (1998, p. 90) present several potential activities assisting in strengthening the quality of research, and the following activities have been applied in this thesis:

- Prolonged engagement and persistent observation: The first technique refers to time spent on site to build trust and to learn the culture. The second technique refers to observations to get depth and to understand the relevance of certain aspects of the social scene. These techniques have been heavily used throughout all three studies.
- Triangulation techniques: Applying a mixture of methods to view a portion of reality from different angles, for example mixing interviews, surveys, and observations when studying a certain phenomenon, as in Papers I and VII. The chosen interviewees or respondents have also undergone a deliberate selection process, to ensure that the purpose of the studies will not be biased by the interviewees' particular organizational background or other elements of their profiles. The selection has also been elaborated and discussed in three categories with different purposes: recommendation, understanding, and problem-centered selection (Arbnor and Bjerke, 1994, p. 240).
- Member checks and peer debriefing: These techniques refer to asking members of the social scene (e.g. from the case companies and colleagues from academia) to check the data, analysis, and conclusions. All results and reports have been discussed and shared in an iterative manner with interviewees and company representatives, as well as via the research community through conference presentations, journal publications, personal contacts and informal discussions.
- Thick descriptions: Increasing the transferability of interpretations and conclusions, in practice this technique means securing detailed descriptions of the cases studied for others to share. One example of this technique is the detailed description of the Bluetooth case in Paper VI.

Hence, the internal (e.g. member checks) and external validity (e.g. thick descriptions) have been approached using several different techniques to ensure high quality of the data, analysis, and conclusions. Further, the research has been carried out with a systems approach, meaning that the use of terms, definitions, and reality matters foremost within the system studied, hence being context-dependent. All data that have been collected and interviews that have been performed have been filtered through the "colleagues and I" view of the world, our values and perspectives (for a discussion of research values and perspectives, see Merriam, 1994). When verifying and ensuring the data collected as well as the perspectives, Arbnor & Bjerke (1994, p. 251) argue that the researcher ought to spend as much time as possible within the studied system in order to mirror it in several different perspectives (see the above technique of prolonged engagement). Finally, the systems approach is in general pragmatic, indicating high validity when the results give guidance for the targeted group. The pragmatic approach is also evident in the wide variety of methods applied, i.e. choosing and applying methods without constraints and depending on the targeted research issue and possible research design. As a former colleague states: "*pragmatism maintains that different metaphors should be used depending upon the phenomenon that is being studied; the research methods should be chosen according to the questions that are asked*" (Magnusson, 2000, p. 16). This view is not constrained to a certain set of qualitative or quantitative methods, but gives more freedom of choice depending on context and purpose. The goal is also to generate practically useful knowledge and viable innovative theory (cf. Wicks and Freeman, 1998).

C. EXTENDED SUMMARY OF THE PAPERS

In this chapter, each of the seven attached papers is summarized, with a wider purpose than just clarifying each paper's contribution. An extended summary is thus provided in order to further elaborate the issues presented in the papers in terms of key dimensions used, limitations of the study, positioning, and challenges approached – issues usually constrained and limited in the journal publication format. This chapter is also used to discuss elements of an integrative nature between the different individual contributions.

C.1. PAPER I: EXPLORING THE "FUZZY FRONT END" OF THE PRODUCT DEVELOPMENT PROCESS

The early phases of product development[11] have been regarded as fuzzy by many commentators (e.g. in terms of organization, process and method) and at the same time as an area where improvements show great potential for the whole R&D process[12] (e.g. Cooper and Kleinschmidt, 1995). In a way, the early phases concretize the interface between technology development and product development, linking emergent technology to market demands in the form of a development project.

One example of an asserted need for other ways of working with process models is the research of MacCormack, Verganti, and Iansiti (2001) in the software industry. They note that traditional stage gate models might be applicable in companies working in more stable environments, but that there might be a need for a more flexible way of working in industries involving higher uncertainty and greater dynamics. Further, Lager (2001, p. 12) brought forward several weaknesses in the overall treatment of process models within the product and process development domain, pinpointing differences between theories and reality in industry, and highlighting the importance of recognizing the development context and the characteristics of the individual projects.

Viewing the early phases of product development, much of the previous research has striven towards developing one single model, ubiquitously applicable – without adaptations to, for example, industry context, type of project, competitive situation etc. (see Cooper and Kleinschmidt, 1995; Smith and Reinertsen, 1991; Kumar and Murphy,

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[11] Often referred to by speaking of the "front end" of product development or by using the term "pre-development activities".

[12] It is worth noticing that the classical view of the early phases' strong influence on project cost, quality, and lead time is under debate with regard to rapidly moving industries. In those industries, vital information regarding opportunities and constraints is not available during the early phase; instead, a more reaction-based approach needs to be taken (cf. Verganti, 1999; Iansiti, 1995).

1997). Early attempts were conducted by Cooper (1983) who defined three main pre-development activities for the early phases[13], activities that were later applied through surveys to a variety of industries and companies in order to cut out successful patterns (Cooper, 1983; Cooper, 1988; Cooper and Kleinschmidt, 1995). Cooper's work has been adopted and followed by, for instance, Kumar and Murphy (1997) who used a similar survey-based approach.

In addition, a scarce attempt at describing and discussing contingencies for different front-end models has been made by Reinertsen (1994) and Khurana and Rosenthal (1998). Reinertsen identifies two different tracks for the front end: a process model common for most projects, and a fast-track front-end model. Khurana and Rosenthal go a bit further, initially discussing the potential need of adapting the front-end model to the product, market, and organizational context of the firm. However, no discussions are found on the potential impact of the type of project, or on how managers are to view and work within the early phases of product development. Hence, the aim of our study is to explore and contrast different early phases of product development and also their applicability to one more general front-end model, all with the aim of assisting managers who work with the early phases, as well as testing the applicability of previous research models and perspective.

Following this, several companies as well as researchers have striven towards defining, mapping, and describing one single process model applicable for the early phases of the R&D projects. This paper indicates that such a single model is far-fetched, arguing for viewing and managing the early phases in a more flexible and dynamic manner. The study showed differentiated process models with respect to sequences, relative time duration, and perceived importance of individual tasks as well as activities performed. Consequently, this implies that it might be less useful to pursue and map out one process model for the early phases of all R&D projects. There is clearly a need for adapting the process models according to, at least, type of project and staffing situation. Further, a potential way of working with the concept of "front-end routes" (Exhibit 10) is provided – consisting of a bundled set of core activities that might be considered when starting up new product development projects. This proposal is not empirically tested, i.e. based upon any performance measures; it is merely to be seen as a mental model or way of working, based on ideas stemming from the author's interactions with the pre-project leaders.

[13] Idea generation, Preliminary assessment, and Concept definition.

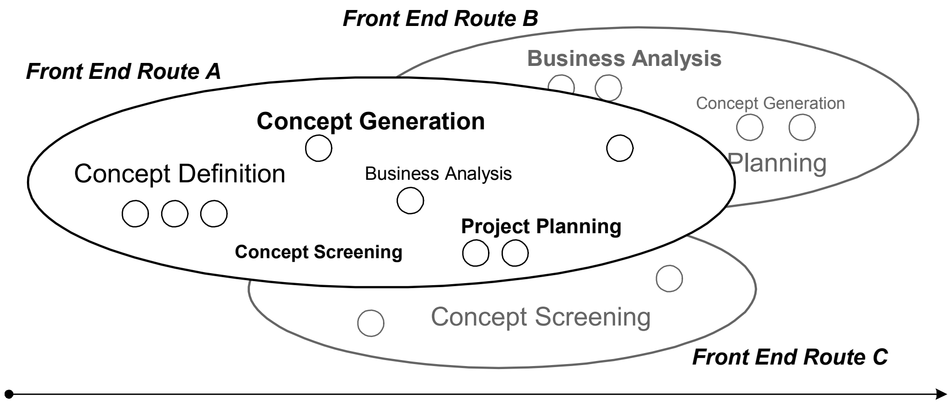

Exhibit 10: Schematic framework describing different activities, their potential sequences and relative priorities and staffing (indicated by circles), as well as enabling a more flexible perspective of different front-end routes.

The intention is that managers should carefully consider the different characteristics and needs for the specific project(s) in question, and then, together with the potential team members, determine which route elements to go for and in what sequence as well as where the higher priorities might lie. This is in line with Verganti (1997) who notes that it is necessary to have both reactive and proactive actions by management, and that proactive actions focusing on identification of critical areas are to be emphasized in the early phases of product development (by building from past project learning). Further, by creating this forum to establish a viewpoint early on, more suitable process models (or at least views more aligned within the team) might be obtained. Once potential routes are established and the work progresses, there seems to be a need for continuous managerial flexibility in terms of staffing, priorities, and advanced planning.

The methodological issues of the study relate to the case-based approach and research instrument, the sample and choice of the three cases, and the scope of the research, dimensions and terms used. First, the explorative case approach was chosen as a consequence of the limited research work that had previously been conducted within the area. At the same time as the literature search was being conducted, similar efforts towards one process model applicable for all projects were being observed at the company in the VTC project. Altogether, the clear direction of research and the indices from the study company (a trend later strengthened by the literature study) motivated the question of how process models for the early phases in different types of projects were composed and managed. The research question would have been improved by also incorporating a broader perspective gained by using surveys, though bearing in mind the extreme difficulties in using appropriate definitions of the phases for each and every company.

As regards the choice of research instrument, a wide variety has been used in order to capture the essence of the early phases, e.g. surveys, observations, company-internal data, and interviews. The elements have been synthesized from previous research, and I put open-ended questions to the interviewees, allowing them to elaborate and to freely describe the early phases. A related issue, too, is the choice of involving the pre-project leaders, at the risk of getting the management's perspective alone, and of receiving a stylized version of the early phases. It is our opinion, though, that the pre-project leaders were heavily involved and hence do not represent the top management's perspective, honest in its beliefs, and that they had nothing to gain from delivering a smoother version. The study would also have been improved in relation to pre-project members; however, as the aim of the study was to function as an initial test of process models for the early phases, the result is clear in itself and indicates an area where more work needs to be done. Second, the choice of the three cases is a combination of research access and relative differences in types of projects being conducted. It was also decided that in-depth studies of three different cases would be enough for the initial test. Third, the scope of the research constrains the study, by discussing only differences in front-end process models. Further, the applicability of the findings might be constrained, for example by the choice of industry setting and product complexity.

Two of the main terms that were used are "early phases of product development" and "process models". The early phases of product development can be designated in many ways: e.g. fuzzy front end, pre-project phase, and pre-study, meaning the initial stage where analyses are conducted regarding the set-up and content of the forthcoming product development project. This set-up also usually determines, or makes suggestions for, the resource allocation (e.g. staffing, budget, IT resources) to the subsequent project, and hence it leads to the working definition used in this study: "the early phases of product development represent work aiming at commercialization of a specific product and definition of the project set-up, which is being conducted before a formal product development project is specified or otherwise stated". Common elements of the early phases are: mission statement, concept generation, concept screening, concept definition, business analysis, and project planning. The early phases of product development, though, do not involve strategic product planning, technology development, or market analysis; the role is more of an integration and screening task with respect to these issues. Finally, the term "process model" refers to descriptions valuable for visualizing the work performed in the early phases of product development. Hence, in this paper the work with the dynamic process model targets the provision of insights for managers involved within the early phases of product development to structure, develop, and reflect upon the activities put forward.

The theoretical contributions in this paper are primarily related to re-focusing research towards different front-end contingencies, instead of the current pursuit of a single front-end process model covering all cases. Furthermore, the study provides illustrative in-depth descriptions of the early phases from three different projects, and puts forward a way of approaching the stated fuzziness that might be useful for both managers in their daily work and the research community when taking the next step.

C.2. PAPER II: MANAGERIAL ISSUES IN PARTS SHARING AMONG PRODUCT DEVELOPMENT PROJECTS

The importance of the commonality issue has increased as a means to control costs, increase component and overall quality, and decrease project lead-time. Which parts to reuse, and when, are vital issues in, for example, applying a product platform strategy. The internal transfer or parts sharing of components or technology might, for instance, occur between technology development and product development, between different products separated in time, and between different concurrent projects.

Nobeoka and Cusumano (1994, 1995), McDermott and Scott (1994), and Ulrich (1995) have all highlighted the benefits of sharing parts, while Muffatto (1996) and Meyer (1997) have gone one step further and also regarded the sharing of parts as difficult, though few examples are to be found of what these difficulties might be, and at what levels they might exist. When it comes to what kind of challenges previous research poses, those are mainly of a technical nature (Hubka and Eder, 1988, p. 342; Pahl and Beitz, 1996, p. 354), focusing on the technology as a potential hindrance to parts sharing. However, many companies have reported not being able to reach the determined commonality targets (e.g. Honda in Muffatto, 1996; Volvo in Sundgren, 1998, p. 35; Ford in Ealey *et al.*, 1996; Boeing in Rothwell and Gardinger, 1988), indicating that the issue of sharing parts is complex to handle. Hence, this paper takes the management's perspective on the issue of parts sharing, with the aim of helping to overcome potential barriers to reaching appointed commonality targets and to widen the academic scope of internal transfer research.

The findings illustrated incidents and potential barriers as well as a way of intentionally working with internal transfer of parts in order to create a reuse-friendly foundation and to avoid unnecessary suboptimizations. Managerial difficulties were found in the companies regardless of size and industry sector, indicating the generic and complex nature of internal transfer. Prescribing a certain degree of commonality is one thing; reaching it is another. Other studies have mainly focused on the technical side of reusability, while this study applied a more systemic view. For example, it was found that a common attitude among managers was to consider reusability as the responsibility of the engineers. This is most noteworthy, especially since the study revealed that engineers often were unable to deal with the difficulties of parts sharing for a number of reasons. An example of the first category, i.e. organizational issues, is related to conflicting aims: it was unclear in several cases whether this was to be considered as the line organization's or the individual project's responsibility. An example of the second category reveals that a strategic issue related to internal transfer is the lack of carry-over targets at the individual project level, and the fact that the commonality issue often was addressed too late in the projects, resulting in low priority and a low degree of commonality.

Third, the technology and cost system-related issues illustrate that, even if it might be technically feasible to transfer and share parts between different products, an obstacle may be the cost of parts – for example, the trouble of having a luxury product share parts with a budget version, resulting in too little price differentiation. Finally, an example of a support systems-related issue pinpoints the need, and difficulties of, evaluating downstream consequences. In one case, the engineer was unable to evaluate the trade-off between potential ease of assembly as a result of a redesign and the purchase cost, resulting in an expensive suboptimization unsuitable for the lower-end products. Overall, the study was explorative in nature, illustrating potential managerial difficulties related to internal transfer of components – a process which is complex due to the need of viewing the process outside the boundary of a single engineer's or manager's traditional responsibilities, and due to the fact that there exist a lot of interdependencies between the potential choices and consequences.

The methodological issues of the study are related to the presented research sample, the researchers' choice of challenges to present, and the stylized way of presenting the case findings as well as the chosen parts dimension. First, the presented research sample may seem unclear, but is in line with the explorative research approach, and represents the choice of drawing on as large a sample as possible – namely the companies that we had been working with for a period of time with the issues. Moreover, a comparative analysis within the same sort of research sample would be difficult to conduct, though the aim of this study lies rather in the domain of providing enough material and insights to assist in developing a broader and more detailed study, besides raising the internal transfer attention. Second, the managerial difficulties highlighted represent an aggregated interpretation of the challenges that the interviewees and companies expressed. The criteria of a stated difficulty were that it was to be stated as a barrier towards effective internal transfer by one interviewee at the company in question. Niklas and I had no quantitative measures, since the study was explorative in nature and since, if the object in question was perceived as a barrier, there was no reason not to take that example into account – transfer problems are local as well as individual.

However, when categorizing and aggregating the different internal transfer difficulties, the foundation to build upon was chosen from a combination of Leavitt's (1965) and Thurmond and Kunak's terminologies (1988). Further, in order to support the findings, persons deeply involved with the commonality issues from the respective companies were given the chance to respond to the categories as well as to the implications. Finally, the use of the term “sharing of technology or components”, or its abbreviation as “parts sharing”, covers a variety of events, e.g. the sharing of parts between different simultaneous product development projects, the sharing of parts between technology development and product development, and the sharing of parts between different projects separated in time. This rather general use of the term “parts sharing” is appropriate for this first attempt within the area; however, it is likely to find that the different opportunities or events of parts sharing may individually differ. One research effort subsequent to this study has been made by Corso, Muffatto, and Verganti (1999), who discuss industry-specific factors affecting platform- or component-reusability strategies. Additional examples concern the internal transfer from technology development to product development, involving not only the complexity related to the technology, but also the inherent cultural differences and attitudes. Still, using the explorative approach, the study exposes several important management issues to be reflected upon when striving towards a desired degree of commonality.

Consequently, the theoretical contributions are mainly related to problematizing an unexplored research area (i.e. outside the usual technical reusability focus) of admitted importance for practitioners when optimizing economies of scale. Reuse of existing parts or technology was found to be a complex task with many cross-boundaries and managerial concerns in a company, some potentially related to the size of the company and the product complexity. It was also found clearly to be not only an engineering issue, but of great importance for management when directing efforts towards the targeted degree of commonality. The challenges related to internal transfer of parts were shown to be found at different levels and related to different categories – organizational, strategic, technology and cost, and support systems issues.

C.3. PAPER III: EVALUATING VIRTUAL REALITY IN AN ADVANCED ENGINEERING SETTING

The introduction of new technology to improve the working methods of developing new products is an area that companies constantly need to address in order to remain competitive or improve their current position. During the 1990s and the beginning of the 21st century, IT has been one of the main enablers for changing ways of working in the R&D environment (Adderio, 2001). In particular, Virtual Reality (VR) technology has gained much attention and interest from practitioners as well as researchers, as a technology potentially speeding up the development process (e.g. by cutting time-consuming prototype cycles: Szefi, 1997), decreasing the development cost (e.g. by minimizing the need for physical models: Trygg, 1994), increasing the end-product quality (e.g. by earlier system tests: Anderson, 1999), and opening up for more interaction (e.g. around visualization tools: Leonard-Barton, 1991). However, as with all new technology it needs to be used in the right setting and with aligned expectations in order to maximize the related advantages.

Previous research has stated the potential benefits related to VR technology (e.g. Clark and Fujimoto, 1991, p. 176; Szefi, 1997), mostly related to saving cost and time in new product development, though few examples have been given of verified savings or improvements (e.g. often provided as an ambition to reach a certain savings percentage: Velocci, 1996). Encarnaçao and Felger (1996) conducted an international survey within the area of VR research, concluding that companies in different industries like Matshushita, BMW AG, NEC were all found to evaluate VR visualization techniques. However, despite the investments and the sporadic claimed benefits, there exist few studies that in a structured manner not only describe the problem targeted by the VR technology, but also reflect and systematically report about the context where the VR technology was applied, the potential alternative methods, and what the implications for future use are. This is particularly the case in the specific area of automotive design, which has long debated and actively sought new methods to replace the traditional expensive full-size clay models at the end of the design cycle (Maier, 1994; Encarnaçao and Felger, 1996). Further, the issue regarding VR models' potential replacement of physical models is complex, one side claiming that "*when the model starts to harden up, so does a lot of thinking*" (Schrage, 1993), and the other arguing for the benefits of having a physical model to view, feel, and continuously discuss (Studt, 1996; Adderio, 2001).

The top management's lack of trust, combined with the ability to review VR models and base decisions thereon, has also been seen as a potential drawback to going virtual (Anderson, 1999). Following this line of reasoning, Kremer (1998) states that the acceptance and working practices need to be systematically tested, and also that the possible gains still are fuzzy (Kremer, 1998). To summarize, the industrial press as well as researchers have highlighted the benefits related to the VR technology, yet studies are scarce that describe the contingencies around the use of VR technology, as are studies working with the evaluation process within a company. Hence, this paper developed a prototyping evaluation method for a Swedish manufacturing company, a method that was applied to a case where VR actually replaced a full-size clay model in a technology development project targeted towards the development of a concept vehicle.

The study revealed that the chosen design phase where the VR technology was applied was probably not the phase to choose for that technology; no substitution of full-size clay models is there to prefer. Instead, the evaluation considered the earlier design phases as more appropriate for the VR visualization tool. The drawbacks of the VR technology were found to be the limited ability to evaluate geometrical features (e.g. shape, surfaces, proportions) and physical attributes (e.g. fit and finish, color, material), while the strengths mostly lie in the capacity for interactive modifications. Consequently, instead of applying the VR technology for verification purposes in the late styling-freeze phase replacing the full-size clay model, it might be more beneficial to apply VR in the earlier design phases – rapidly enabling full-size views and potentially substituting for scale models, and later functioning as a complement for the styling-freeze clay model. It was also confirmed that the use of VR might have a positive impact on project time and cost. Finally, the study raised some outstanding issues, e.g. the management's level of maturity when it comes to confirming the chosen design path, the use of technology development as a test bed for new methods potentially to be transferred to product development, the potential use of VR technology for other purposes such as packaging, serviceability, assembling, etc.

The methodological issues of the study relate to the choice of study object and VR technology, the method used for the study, and the dimensions used for evaluation. First, the deliberate choice of conducting a case study within the automotive field followed because the automotive sector is well recognized for its tough demands on, and use of, IT (e.g. within crashworthiness, product design, and virtual verification of processes) when developing new models. The opportunity then arises to follow, in real time, a replacement of full-size clay models with VR in the technology development domain. Some part of the findings is related to the specific VR technology studied, and might as such have limited applicability. Moreover, the study is limited to the automotive sector. The rapid evolution of VR technology naturally also places a time stamp on the findings.

Second, as regards the method used in the case study, the persons involved were chosen from the product design department (i.e. product designers and modelers), sub-project leaders from the specific technology development project, and two top managers. Hence, almost everyone closely involved in the design review was engaged and responded. However, it would potentially have been beneficial to include customers (for customer inputs), persons from the marketing department (for marketing feedback), and after-sales (for service input). In addition to bringing more persons into the study, another limitation is that there was no full-size clay model to actually make the comparison with – it was taken for granted that the persons involved were so familiar and experienced with the traditional working methods of clay models that they were able to make the comparison. This was indeed the response when the persons were asked the questions. In order to further extend the scope of the study, some data from the survey (e.g. the basis for Paper VII) were also brought in, to provide a sense of the setting wherein the study was conducted. Third, the prototyping dimensions on an aggregated level were synthesized from previous research and operationalized by me. The evaluation is highly dependent on having an appropriate set of measures, and to further strengthen the study those suggested dimensions from the literature were also validated by the interviewees, where they had the opportunity of adding dimensions.

The theoretical contributions of this study are primarily the development and illustration of a method and dimensions for evaluating different types of prototypes, in the light of viewing prototypes as a mediating object for knowledge transfer by interaction. Secondarily, an elaboration of different uses of VR technology and related contingencies was presented. For example, it seems worthwhile to thoroughly consider the choice of process stage where the new method, depending on its characteristics, might be of most value. The more philosophical issue of people’s perception of hard versus soft models was also raised: future research might study the differences in perceptions caused by using such models.

C.4. PAPER IV: DEDICATED VERSUS DISPERSED APPLIED RESEARCH ORGANIZATION

The organization of R&D has been a continuous debacle for many companies as well as for a long time under scrutiny by the research community, altogether picturing a complex and troublesome issue and offering few easy answers. It is clear, though, that having a well-functioning organization for R&D is an important dimension when maximizing the return on R&D spending and securing long-term competitiveness. This paper applies generic organizational theory concerning organizational structures to the domain of applied research, and combines this with the two vital dimensions of technology development and internal knowledge transfer. The study originated from observations at a manufacturing company which had chosen to organize the applied research efforts within its five departments in two basic modes: having applied research conducted by dedicated personnel, or dispersed among a greater number of personnel. The management at the company perceived the two modes of organizing as frustrating and confusing, and sought an answer to the question of “what is the best way of organizing applied research?” The basic data sources used were a company-wide survey of all the R&D persons involved (779 persons, 69% response rate) combined with nearly 50 additional interviews.

Previous research has long pinpointed the applied research stage as an area with large improvement potential, and as vital for long-term survival (Goldman and McKenzie, 1965; Iansiti and West, 1997). The task of efficient and effective developing, transferring, integrating into products, and finally commercializing new technology is no doubt challenging. The way companies choose to organize their R&D efforts has an effect upon how well they succeed in those respects. Examples of troublesome areas related to the organization of R&D, as highlighted by previous research, are: the Not-Invented-Here (NIH) syndrome appearing during work hand-over (Clausing, 1994, p. 336), lack of communication between organizational interfaces (Katz and Allen, 1985), and bad synchronization between technology and product projects and plans (Eldred and McGrath, 1997), as a whole affecting technology development or transfer in several different ways. Previous research has also dealt with the question of how to organize R&D (Jain and Triandis, 1997), although this has typically been done on a more general basis, without following the logic that tasks with inherently different characteristics require a matching of management and organizational structure (Burgelman, 1985; Tushman and O’Reilly, 1997).

Examples of tasks in R&D with different characteristics are applied research and product development, where the former works in an environment of higher technological uncertainty and complexity (Eldred and McGrath, 1997; White, 1977). Scott (1992) puts forward the argument that these differences are significant in explaining different structural characteristics (Scott, 1992, p. 256) – indicating that research concerning product development is not automatically transferred to applied research. Previous research specifically addressing the applied research area or, in particular, the organizational structure's relation to technology development speed and internal transfer area, are scarce. For example, Iansiti and West (1997) argue for addressing the issue by setting up, and focusing on, special technology integration teams (Iansiti and West, 1997). More general discussions about specialization and integration (Lawrence and Lorsch, 1967) offer some advice potentially relevant for the applied research domain, for example also to be found within areas such as alliances (Gomes-Casseres, 1997, p. 92), efficiency and teamwork (Katzenbach and Smith, 1994, p. 119), maximizing the use of specialist functions (Smith and Reinertsen, 1991, p. 141), and, perhaps the most substantial contributions, within organizational theory (Lawrence and Lorsch, 1967; Scott, 1992, p. 102; Galbraith, 1973, p. 31).

Within the latter, Scott (1992, p. 253) suggests two ways of dealing with the high technological complexity and uncertainty. First, the tasks could be divided and handed out to subgroups, a statement favoring a dedicated organizational structure. Second, one could engage very experienced personnel capable of handling the complexity, thus enabling a dispersed structure. Further, Pelz and Andrews (1966, p. 54) depart from the existence of interdependencies between different development tasks when arguing that a mixture of assignments is desirable. This outlook favors a dispersed structure. In sum, there seem to be different benefits of choosing either a dedicated organizational structure or a dispersed one, with researchers arguing for each option, but there are few discussions regarding potential implications that the two suggested modes might lead to in terms of technology development or internal transfer. The suggestions merely end in "the more specialized, the more focused, and potentially the more interface troubles". The questions remain as to what the situation might be in the applied research domain, i.e. what relation exists between organizational structure and technology development speed and internal transfer, and how the interface towards product development may function. Hence, this study aims at applying organizational theory towards the applied research domain in the light of technology development speed and internal transfer, including the interface towards downstream product development.

The two modes of organizations analyzed were the dedicated and the dispersed structure. The dedicated structure is one where appointed persons work more or less solely with applied research. The dispersed structure, on the other hand, strives to involve as many persons as is beneficial by spreading the applied research tasks, and thus involves many more part-timers. It was found that the two structures differed in terms of both technology development speed and transfer. New terms describing the two ways of working were developed, i.e. “integrative firefighters” for the dispersed structure and “myopic pursuers” for the dedicated structures characteristics (summarized in Exhibit 11). The integrative firefighters refer to behavior where technology is not being developed very rapidly, but where the integration and implementation issues are well prepared and considered. In the extreme case, the persons engaged in the applied research tasks are more or less the same team which is later responsible for integrating the very same technologies. The drawbacks are related to the risk that those part-timers will be drawn into more short-term problems of today (e.g. launching projects, quality tasks), thereby not fulfilling their applied research tasks. The myopic pursuers, on the other hand, refer to behavior where technology is rapidly being developed due to a focused effort, while the integration shows more problems. The myopic pursuers relied more heavily on formalized knowledge transfer and reached a high perceived applied research readiness but, as said before, they ranked lower in preparedness for product development.

	Dedicated	**Dispersed**
Technology development	Good ability to work up budget High applied research readiness	Weak ability to work up budget High preparedness for PD
Technology transfer	Formalized knowledge transfer	Informal interactions with many actors

Exhibit 11: Summary of characteristics of the Dispersed (integrative firefighters) versus the Dedicated (myopic pursuers) applied research structure.

Further, contrary to what was deduced from theory, the highest perceived strategic fit and applied research priority were to be found within the dispersed structure – and not within the more focused efforts of the dedicated structure. One possible explanation thereof might be that the dispersed structure has a tighter connection with today’s product development needs, and hence the strategy and priorities are more easily seen as important.

Important methodological issues of the study are numerous, being related firstly to choice of object, secondly to techniques of analysis and interpretation, and thirdly to the operationalization of terms and the applied theoretical domain. First, issues related to the choice of object refer to the constraints of using one single company setting for the study: the generalizability will most likely be limited to the automotive sector within Western Europe. Yet the choice of organizational structure, and the possible implications thereof, will provide inspiration and food for thought to managers considering different modes of organizing applied research, thereby leaving the toughest job to them when the necessary conversion of ideas into their specific context and trade-offs is to be made. Theoretically, it is hard to state a certain correlation based on this study alone; e.g. what makes it say the results are not a consequence of the selection? For example, selecting two different ways of organizing as a unit of analysis, it is not surprising to find that they differ. One response to the issue is that the way in which the study was conducted had more to do with analyzing R&D practices in the five departments, where differences emerged from the empirical analysis and were categorized into the two organizing modes. The potential linkage between organizational structures was also strengthened during the interviews, and hence it also relies on managerial gut feeling which ought not to be underestimated.

Second, limitations worth noticing related to the techniques of analysis and interpretation include the fact that the main measure of technology development speed is the organization's ability to work up a budget. This is naturally not a perfect measure of technology development speed; another might have been data related to historical developments. However, data regarding applied research development speed are hard to measure due to the long lead times, especially when the data brought forward also need to be correlated with the current choice of organization mode. In the absence of a perfect measure, the ability to work up an applied research budget is, in the light of this specific company, not as bad as it might seem without context. The company had for many years, on a monthly basis, managed its applied research depending on its ability to work up the budget, and hence the managers involved with applied research showed progress via the spending budgets. This was most likely a response to the long lead times; if the organizations could show on a short time basis that they were spending and working with applied research, the management felt satisfied. Further regarding methods of analysis, the survey covered the full population but made no statistical omission analysis, merely viewing the individuals and their positions and background visually. The sample also consisted of quite a large group; hence, it is not surprising that significant differences were found, one drawback of using statistical analysis as a means of explaining relationships. Moreover, the limited space available within the frame of a paper put some restrictions on the presentation of the data; in this case the interviews were not given the appropriate amount of space.

Third and last, issues related to the operationalization of the terms and dimensions used and the applied research domain are also of importance when discussing the limitations of the study and the findings. The term "knowledge transfer" is a troublesome one, alone in the focus of separate articles (e.g. Argote and Ingram, 2000; Boland *et al.*, 2001; Szulanski, 2000); e.g. Galbraith (1976, p. 122) categorized and discussed different integration mechanisms already in the 1970s. In this paper, the term departs from the practical viewpoint of knowledge transfer activities, similarly to Jung (1980) who discusses method of documentation, distribution system, informal linkages, and credibility in the eyes of the receiver. Following this line of reasoning, the dimensions boil down to transfer activities measured by which sources are used for spreading new results, which discussion partners are involved throughout the applied research project, and where information is to be found regarding ongoing applied research work. The measures are mostly based on information-processing activities; bearing in mind the weaknesses of solely viewing information flows and thereby not thoroughly capturing the interaction points, indications of interaction possibilities have been added.

Further, apart from the dimensions used, some questions arise related to the chosen static, or structurally oriented, viewpoint of applied research. If applying a more process view of applied research, the two organization modes could be seen as part of a natural evolution, and a question could be asked regarding the equivalence of applied research within the two studied modes (i.e. whether they are working with similar, comparable tasks). The more structurally oriented approach originated from early observations that two main modes existed at the studied company, and that such an approach seemed natural as a start. The next steps, though, would benefit from moving down one level of aggregation and analyzing the applied research dynamics. Further, due to the concise article format, some references of potential value were intentionally left out, for example, the literature on teams (e.g. Katzenbach and Smith, 1994), literature outside the product development and innovation domain (e.g. Gomes-Casseres, 1997), and references within the domain of knowledge and the firm (e.g. Zander and Kogut, 1995). Another, more general, limitation is that the scope is held within the firm, more or less excluding interactions with suppliers and potential alliance linkages.

The study nuanced the picture by presenting benefits and challenges for the two different modes, hence being able to point at what the modes might lead to in terms of consequences for technology development speed and internal transfer. The management could thereby be assisted in the choice of organizational structure, although it should be emphasized that a simple answer to what the best organization is does not exist; this depends on the current context and capabilities, and on what is actually sought. As regards further theoretical contributions, the study puts organizational deliberations within the applied research area under scrutiny, an area where typical studies are of a more broad-based survey type involving several different industry sectors as well as companies (e.g. Gupta and Wilemon, 1996; Cardinal, 2001) and where detailed empirical data are scarce. Iansiti and West (1997) state for example that there is less established understanding of the complex interaction between management of research and management of development processes, while Rebentisch (1997) similarly states that few studies address how companies ought to proceed when transferring technology under a given set of circumstances. There does exist research within the applied research domain, although analysis of organizational structures not along just one dimension (e.g. work satisfaction, rate of return) but combining this with the dimensions of technology development and transfer within the same study is scarce. The combination enabled insights into how different organizational structures might affect technology development and transfer; moreover, by choosing one single setting, an ability to study different types of behavior and comparable attitudes was supplied.

C.5. PAPER V: EMPOWERING PROJECT SCOPE DECISIONS

The scope of R&D projects has long been seen as a potential source of competitiveness and is also a much-debated issue. For example, the less extensive product development scope and, consequently, the more frequent model changes by many Japanese automotive manufacturers in the 1980s were claimed to be one explanation for their strengthened position on the world market. More recent examples are the benefits of modularization and platform approaches, involving strategic standardization and commonality related to the project scope (e.g. Nevens *et al.*, 1990; Meyer, 1997). It is clear that managing the project scope well is an important foundation for successful R&D.

Previous research has highlighted the importance of choosing an appropriate project scope. For example, Karlsson and Åhlström (1999) point out the danger of choosing too narrow a scope, resulting in more-of-the-same products, while Smith and Reinertsen (1991, p. 64) focus on the risk of being caught at the other extreme: the never-ending "megaproject" trap. Achieving a proper project scope seems to be challenging, without noting that there also exist several different levels of project scope, e.g. planning the scope beforehand for a portfolio of products, and managing the scope within an individual and running project. At a portfolio level, there exist some generic tools, mostly based on financial metrics and technology positioning intended to support top management decisions (e.g. Roussel *et al.*, 1991; De Maio, Verganti, and Corso, 1994). De Maio, Verganti, and Corso put forward an example of a risk/relevance matrix to be used for evaluation and for decisions related to acceleration/deceleration of R&D projects. At the lower level, assisting tools that support middle management in the execution and continuous adjustments of the project scope are even scarcer. The content methodology tool presented by Gerritsma and Omta (1998), though, is one example, aiming at measuring project complexity and assessing the firm's overall R&D portfolio in terms of complexity and performance. However, little assistance is provided when managing the scope within different projects during execution. Hence, the aim of this study is to develop and evaluate a managerial tool that assists during the ongoing execution of R&D projects with regard to discussions about the project scope.

This paper addresses the management of R&D project scope, and has developed and pilot-tested a team-based tool to assist in this respect. During my participation in a project meeting targeted towards development of a new concept vehicle within the VTC study, a perceived need for a more structured and deliberate way of working with the project scope was evident and, as a response, the development of the "R&D content graph" was initiated. The R&D content graph can be used on several different levels, either at a portfolio level when viewing and analyzing different types of projects, or at the level studied in the paper – of an individual R&D project used for managing different sub-developments. The tool is built around a mapping exercise of the respective sub-project leaders or persons responsible for different modules within the overall project. They rank their sub-project along the dimensions of:

- Knowledge-building capability
- Implementation possibilities
- Interdependencies
- Technology uncertainty
- Strategic fit (measured by top management)

The tool (Exhibit 12) structures, visualizes, and provides foundations for project managers to communicate and discuss the project scope both internally and externally. The dimensions above have been developed from theory as well as in cooperation with the studied company, and are examples of project scope- affecting indicators. The study revealed some predictive capabilities of the tool, brought structure to the project scope discussion, and was also appreciated by the top management who expressed a wish to apply the tool to the overall portfolio of the company as well.

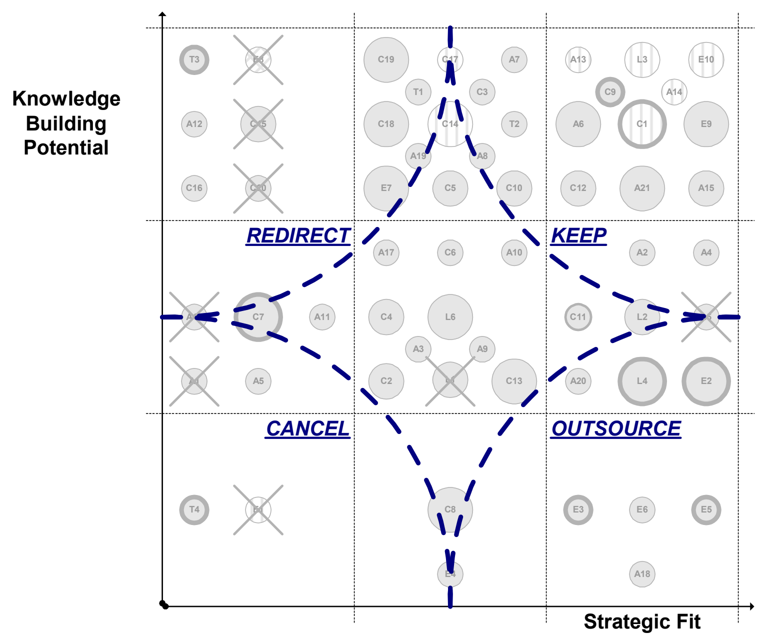

Exhibit 12: R&D content graph: total project scope, including project cuts and potential recommendations (for a description of the use of R&D content graphs and representations of the symbols, see Paper V).

Besides mapping out the project scope, the R&D content graph can also reveal what path it might be appropriate to take, or at least to consider, with the different subsystems (Exhibit 12). For example, the most valuable content for the specific project to continue to work with internally might be the subsystems ranking high on knowledge-building and strategic fit, while the ones in the lower left area might be first to consider canceling. The strategically highly relevant subsystems that do not add to the internal learning might similarly be the ones first to consider outsourcing to a third party. And finally, the subsystems which add to the internal learning, but which might not be very strategically aligned, might be content-considered for re-directing. Managing and aligning technology deliberately within the umbrella of a project, with the assistance of the R&D content graph, could prove to be powerful.

The methodological issues of the study are related to the testing in one project environment, the build-up and use of the visualization method, and to the choice of the five dimensions. First, the testing in one industry and in one company is enough for an initial test and development, but would need to be more fully secured and validated in the long run in other industries or companies as well. Second, the challenges of changing managers' behavior and introducing a new tool should not be underestimated. The tool brings structure and assistance only if certain data are gathered and if the main project manager approves the method and the initial time spent. This kind of devotion is not easy to elicit when other problems are piled up, overwhelming this kind of slightly pro-active solution. Further, the choice of visualization method is just one potential way of viewing the five dimensions; there might exist other, more sophisticated and perhaps flexible, methods not yet tested. Third, the choice of the five dimensions is synthesized from literature and slightly adapted to the automotive industry and to the specific project. This represents a limitation in itself; however, the paper also elaborates upon other influential dimensions opening up for one's own reflections and for adaptations of the reader.

Going into more detail, the knowledge-building capability refers in this paper to the participants' own judgment of how much a specific subsystem actually contributes to the learning and to the building of new knowledge for the members involved. This measure tries to grasp one important purpose of applied research as being the knowledge creator and a source for tomorrow's competitiveness, hence bringing up the question of whether the tasks are challenging enough and not too much of an operations nature. Such a measure is subjective and relative, i.e. biased by the experiences of the team and by the responding persons' personal profiles and wishes. The implementation possibilities refer to the commercialization and integration targets set for the different subsystems, i.e. aiming to align subsystems in time and to individually question the potential dates.

Further, the interdependency measure refers to connections and relations between different subsystems, i.e. aiming to visualize and bring up vital relations which might potentially hinder reduction of a certain subsystem that scores low on the other dimensions but, on the other hand, is crucial for another highly important subsystem. This measure requires certain coordination with the marketing department and is, due to the higher uncertainty, hard to predict.

The technology uncertainty is further captured through the next dimension, i.e. asking whether there exist any fallback solutions to the specific subsystem. If not, the technology uncertainty or risk taken within the whole project is considered as higher. However, the fallback solutions for technology uncertainty represent only one indicator and would be an oversimplification of a troublesome issue. The technology uncertainty issue implies a lot more, for example the technical and integrational challenge. Finally, the issue of strategic fit is measured in this study by the top management of R&D. To actually gain a proper measure of the strategic fit, one would probably need to involve not only the R&D function, but also for example the sales and marketing, customer, and after-sales functions. This tool, though, is not to be considered as using fully secured data, but is merely a rapid tool assisting project scope discussions and designating areas where analysis potentially needs to be done. Individually operationalizing and measuring these five dimensions represents a dissertation in itself; the strengths of this tool are the rapid holistic perspective, the structure, and the interaction within the team.

The theoretical contributions are primarily the development of a new method for dynamically managing project scope in running projects and the identification of dimensions influencing the project scope of applied research tasks. Further, the study brings strength to the tool through the choice of method, i.e. following the project in question longitudinally with the microscope of managing project content.

C.6. PAPER VI: AN AMBIDEXTROUS ORGANIZATION IN PRACTICE

One of the major challenges for companies is to act in today's environment by satisfying the demands of current customers and to simultaneously focus on, and work with, longer-term issues such as securing the technology base for next-generation products and, ultimately, the survival of the company. One approach towards working with these two time horizons is to apply a decoupling strategy where a separate unit is detached from the mainstream organization and assigned the longer-term issues, in order to gain focus, speed, and clarity (Katz and Allen, 1985). Within industry, the role model for applying this decoupling strategy is the Skunkworks organization at Lockheed Martins, a unit composed in the 1940s (Miller, 1995). Several other companies have followed, using the basis of the successful working methods at Lockheed Martin (e.g. IBM, Sony, Apple, and Nokia), though with varying results (Schrage, 1999; Studt, 1996; Day *et al.*, 2001). In fact, applying an organizational decoupling strategy within the area of R&D management is under debate, some arguing for the speed and focus benefits (e.g. Gwynne, 1997; Johnson and Smith, 1985), others pointing to the potential issue of elitism when creating these two organizational cultures (e.g. Schrage, 1999; Frand, 1991; Dougherty, 1992; Cordero, 1991). It is clear that successful application of such a strategy is troublesome for the overall organization. This study analyzes the telecom company Ericsson's decoupling of a separate unit dealing with the "Bluetooth"[14] technology (striving for the creation of a de-facto standard) and the subsequent attempts at re-integration with the mainstream organization.

Duncan (1976) originally coined the concept of working with a dual organizational structure approach in order to become an "ambidextrous organization". Tushman and O'Reilly (1997, p. 14) continued the work with the ambidextrous organization concept, an approach stated to be capable of managing both short-term and long-term issues. Further, Tushman and O'Reilly (1997, p. 171), like Burgelman (1985) and Gwynne (1997), provide a solution consisting of dual structures, where the mainstream or parent organization[15] is more evolution-driven and the smaller unit is more revolutionary and opportunistic by nature. In other words, "*management needs to protect, legitimize, and to*

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[14] "Bluetooth" is the name of a technology effort providing a wireless link between all mobile devices to incorporate applications within data and voice access points, cable replacements, and *ad hoc* networking.

[15] The term Parent organization refers to the mainstream business, i.e. the organization from where the new unit originates.

keep the entrepreneurial unit physically, culturally, and geographically separated from the rest of the organization". This separation has been highlighted by several researchers within the R&D management area as beneficial[16] (e.g. Chiesa, 2001, p. 173; Clausing, 1994, p. 48), for example by decoupling certain specific technology development challenges from mainstream product development – two tasks differing in prerequisites, technical maturity, time horizon, competence needs, process repeatability, and completion point (Iansiti and West, 1997).

The benefits gained by using this organizational approach have been debated, though, mainly due to the trade-off between development speed gained at the smaller unit and potential integration problems with the parent organization. The development speed has been studied and confirmed by many (e.g. Johnson and Smith, 1985, p. 167; Frand, 1991), but the integration dilemma has merely been highlighted (e.g. Schrage, 1999; Tushman and O'Reilly, 1999) and consequently few studies with an integration focus exist. The foothold within this area of research consists of the contingency theorists Lawrence and Lorsch's (1967, p. 1) and Galbraith's (1973, p. 30) more general work within the integration domain. Lawrence and Lorsch (1967, p. 13) studied six organizations and came to the conclusion that the more a company differentiates, the more it would need to put efforts into integration in order to be successful. They stated further that the differences in performance among the studied organizations lay in how effectively these integrated. Galbraith (1973, p. 127) followed this line of reasoning by developing rational mechanisms for integration, for example discussing direct contact, liaison roles (e.g. an integrator), task forces, and teams. Moreover, in the chosen context of having a separate unit and a parent organization, the advice present is in the form of Tushman and O'Reilly's more general assistance on how to integrate the two opposites: articulate a clear, emotionally engaging and consistent vision, build a senior team with diverse competencies, and develop healthy team processes. However, few studies have followed the evolution towards an ambidextrous organization and the related underlying logic or, perhaps even more complex, the potential debacle of integration with the mainstream organization. Hence, the aim of this study is to study an ambidextrous organization approach with focus on the dilemma of integration – termed re-integration in the study – with the parent organization.

The study analyzes strategic actions related to the development of a de-facto standard approach, presents insights into the evolution of a dual structure as well as the

[16] It should be noted that there has been some successful examples where a decoupling strategy for technology development and product development has not been applied in full. One concrete example thereof is Toshiba Corporation, where Magnusson (1999) describes the efforts at Toshiba where, in this case, the technology development and product development is though decoupled geographically, but where the responsibilities for product development and technology development resides in one position (the 'Technology Executive').

subsequent re-integration efforts, and offers a new type of 'Mindset' integration mechanism. It was found that Ericsson Mobile Communication deliberately chose to go for a de-facto standard approach (e.g. by hiring an experienced manager in the creation of de-facto standards), decided that speed and focus were essential – thereby setting up a new entrepreneurial unit – and was early to initiate knowledge re-integration efforts tying the two structures together. Starting with the evolution of the dual structure: Ericsson recruited new and unbundled staff to get a fresh start, was recognized and supported primarily by one champion in the top management, separated out the new unit (budget-wise, structurally, and geographically), and encouraged the new unit to seek valuable opportunities outside the traditional line of business.

However, contrary to suggestions by previous researchers, the new unit did not go for a cross-cultural approach in terms of attitudes and values. The most obvious tension between the parent organization and the new Bluetooth unit followed the prioritization work with the two main customer categories, i.e. the parent organization's mobile phone business and the computer industry (read laptops). Further, with regard to the relation between the two entities, the benefits for the Bluetooth unit were chiefly related to the possibility to borrow experienced engineers and other resources from the parent organization and the legitimacy of using the Ericsson brand and recognition. The drawbacks, on the other hand, were related to being within the Ericsson umbrella, constrained at the time by a general temporary recruitment prohibition, and with the above-mentioned conflict between developing mobile phone solutions and developing other high potentials. Further, the high speed of technology development was attributed not only to the focus gained from having a separate unit, but also to having a strong yet constrained vision, to staff the technology unit with a mixture of new and product-focused personnel, and to base the creation of a de-facto standard upon market shares – obtained through commitment via the Special Interest Group (SIG).

Further, regarding re-integration mechanisms, Ericsson used a variety of approaches. First, it initially allowed some lending of experienced engineers from the mobile phone parent organization, although the main approach was, as mentioned above, the transfer of product-oriented personnel from the parent organization, bringing in all the knowledge about what it takes in terms of documentation, market material, accessories, technology, and support to exist on the market. Second, Ericsson set up several procedural methods, such as the Bluetooth Technology Council and the Bluetooth Technology Review committee top function as coordinators. Third, some organizational structures were put in place, although at the level of individual projects versus the Bluetooth organization (i.e. apart from the SIG establishment for inter-firm integration), such as the System Integration Group and the Functionality Team. Finally, a fourth integration approach was found, i.e. a mindset mechanism, describing the use of different concepts and metaphors in order to direct focus and behavior in a favorable way.

Examples of mindset mechanisms used are “engineers without borders” and “technology products”.

Summarizing, Ericsson succeeded in establishing a cross-industry commitment around the Bluetooth standard, managed to evolve into a dual structure, was the first to launch a Bluetooth product – reaching the technology development goal originally set – and worked deliberately with the integration between the new unit and the parent organization. The questions raised at this point are related to the next step and the forthcoming strategy of the new unit. Four main scenarios were put forward, all based upon the two dimensions of knowledge integration and organizational separation – dimensions of importance when considering potential new business creation (Exhibit 13).

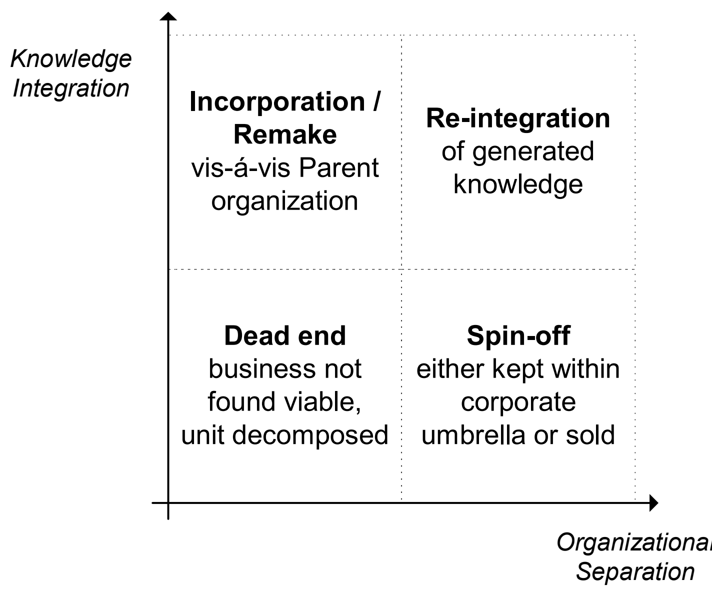

Exhibit 13: Potential entrepreneurial unit scenarios.

First, the new unit might prove unsuccessful and lead to a dead end, resulting in dissolving the unit. Second, a decision is taken to move the unit along in its current direction and continue to re-integrate and exchange new knowledge with the parent organization, a scenario titled ‘Re-integration’. Third, the new unit finds its way outside the decided business frames of the parent organization, or for other reasons is spun off as a separate unit or new company. Fourth, the new unit is moved back and integrated with the parent organization, either becoming the new core and mainstream business in the parent organization or just incorporated[17]. These scenarios, though in typical management style, were found helpful and provided food for thought when discussing the dual structure strategy at steering group meetings at Ericsson.

The methodological issues of the study are mainly related to the output metrics, the choice and potential bias of interviewees, the possibilities of generalizing the findings, and finally the appropriateness of the dimensions used. The lack of output metrics means that it is hard to state the effectiveness of choosing a dual structure[18] instead of some other choice, or actually to state the effectiveness of the applied integration mechanisms. However, as a study ending before any mobile phones were released on the market, and with the idea of rapidly capturing the uniqueness of the applied approach and growing interest of de-facto standard creation, it was my choice to proceed with this limitation in mind. As regards the interviewees, they were chosen deliberately and in collaboration with the practitioners in order to constitute a representative mix of hands-on engineers, high-level strategists, personnel from the parent organization and the new unit, people from different functional backgrounds, and persons involved during different stages. However, it is likely that the study mainly embodies the view of Ericsson, though attempts at checking the statements and data were made by bringing in the lead partner during the Bluetooth effort, i.e. the Intel Corporation. To ensure the quality of the data, all data were taped, transcribed, and analyzed using the Nud*ist software.

However, it should be noted that the analysis of the data in, for example, the case of identifying an implementation and a visionary management layer is hard to perform, and should merely be seen as the position of the interviewees and an indication of a state that most likely would have needed a different tool to capture properly. Further, the possibilities of generating more general findings are related to the choice of conducting case-based research; hence, the aim of the study is not to present such findings, but instead to nuance the picture of dual structure evolution, and especially to elaborate the re-integration dilemma. Finally, other methodological issues relate to the used dimensions. For example, it is hard to tell whether there have previously existed dual structures at Ericsson; and if so, the historical pros of such an approach influenced the choice of the Ericsson Mobile Communications top management to pursue such a road. When viewing the organization at the end of the study, several other new units were

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[17] In hindsight, Ericsson chose to spin off the Bluetooth unit, though not using any stock exchange marketplace. Further, the company has set up a separate unit with the target of selling licenses, and has also applied the decoupling strategy further for other technology development efforts.

[18] There are for example questions raised regarding whether a decoupling strategy within the R&D Management is appropriate in all cases. Magnusson (1999) puts forward the Toshiba case as an example where technology development and product development had not been separated; instead the two different tasks were conducted within the same organization – and they were coordinated and managed by a new type of role within Toshiba, termed "Technology Executives", responsible for the integration of different technology-related tasks with various time horizons.

created in a similar fashion as the Bluetooth unit; thus, the question could be raised whether it is then to be termed a dual structure. Further, when viewing the terms "strategic actions" and "re-integration", they were explained in the study as "*the actions and decisions attributed to realizing the company-wide strategic intent*" and "*attempts at transferring technology back to the parent organization to be incorporated in the products, either pro-actively or in response to direct technology implementation needs*" respectively. Elaborating these a bit further, strategic actions would represent the widely acknowledged decisions and efforts that enable a certain targeted direction. The term "re-integration" would then refer to an outspoken intent by the company to leverage learning and technology gained from the new unit back to the parent organization. In a sense, use of the term "re-integration" indicates the dynamics of the interplay between the new unit and the parent organization.

Finally, the four scenarios developed around the two dimensions can always be questioned, representing a rough simplification of a complex process of strategy and execution. The first dimension of "organizational separation" refers to the degree of separation between the new unit and the parent organization, answering the questions of how tied the new unit is to the parent organization with regard to, for example, location, budgets, business culture, and legal factors. The second dimension refers to "knowledge integration", a term focusing on the symbiosis and the need for re-integration of knowledge between the new unit and the parent organization. The term "knowledge" is a matter of debate in this setting; I refer to information and interaction related to the core technology as well as surrounding parts and packages in order to enable a forthcoming commercialization. Moving towards the four scenarios, it is likely that there exist several other potential outcomes or sub-scenarios, though the main target for using a simplified visualization tool is that it brings up and focuses on vital questions. Further, the practical test is whether it may prove useful as a tool in a managerial setting – a test that this tool holds indications of passing.

The investigation presents a detailed case study of the evolution of an ambidextrous organization at Ericsson, points to vital insights for other companies to learn from when pursuing a similar path, and discusses the integration–differentiation dimensions in a more dynamic manner than previous research. The study moves away from a more traditional, static view of differentiation and integration where it is primarily the environment that is claimed to balance a more dynamic view. The revised perspective takes the time factor into account, allowing for rapidly shifting views – from a differentiating and seeking unit to a more integrative focused unit and vice versa once, for example, a certain milestone has been passed. Consequently, the contingent need and setting for the new unit and the parent organization are also considered. Earlier research has either appraised or abandoned the dual-structure approach, based on reports of successful or unsuccessful cases. This study goes one step further, focusing on an area where the two previous perspectives could meet and find explanatory factors for either kind of results: the re-integration between the new unit and the parent organization. Further, the proposed integrative concepts of Tushman and O'Reilly (1998) have been applied to the case and also developed further. For example, the suggestion of "healthy team processes" has been identified in the study as representing a visionary higher management level combined with an implementation-focused middle management layer.

Moving more into details, several researchers (e.g. Jain and Triandis, 1997, p. 61; Tushman and O'Reilly, 1999) claim that having a strong vision is useful when establishing new units or when developing new technology. This is most likely true; however, what was also found in the study was the importance of also effectively *constraining the vision* (e.g. by cost, scope, etc). This is in order not to have the unit running for too far-fetched a goal, but rather to get the vision down to earth and to take the first step in exploring the road ahead. Further, the widely accepted best practice of having researchers stay with the technology from "cradle to grave" (e.g. Harryson, 1998, p. 191), is questioned. A more nuanced picture evolves where the concept of integrity and the problem-solving skills might be preserved while the commercialization focus is enhanced by using a combination of technology champions and a mixture of fresh and product-focused personnel. As regards other bridging mechanisms, a fourth integration mechanism, apart from the three originally proposed by Roberts and Frohman (1978) – a "mindset mechanism" – has been noticed. It should further be noticed that, despite previous researchers' suggestions, Ericsson did not go for a cross-cultural approach when setting up the new unit. It could be elaborated whether separating out the new unit geographically, budget- and people-wise would be enough to get the sought benefits without also taking on the potential cultural challenge. Most likely, this is a complex issue where the answer is not either/or, but depends on the situation and the vision, all in line with an open systems perspective.

C.7. PAPER VII: LINKING TECHNOLOGY DEVELOPMENT TO PRODUCT DEVELOPMENT

Manufacturing companies are to an increasing extent dependent upon the ability to develop, transfer, and integrate new technology into the product portfolio in a strategic and operationally effective manner. Further, managing new technology is often a task of managing interfaces, e.g. organizational, technical, cultural, and procedural. Previous research has focused greatly on the R&D and production or marketing interface, viewing R&D as one unit of analysis. However, many researchers have pointed to the R&D level of analysis as being too wide, incorporating different task characteristics as well as time targets and cultures. Both practitioners and researchers has also highlighted the transition from technology to product as complex and vital, showing great potential for improvements with regard to product quality, R&D project cost and timing, as well as overall R&D performance.

Previous research has highlighted the importance of the link between technology development and product development (e.g. Chiesa, 2001, p. 15; Eldred and McGrath, 1997; Iansiti and West, 1997). Cusumano and Nobeoka (1998, p. 150), for example, make a strong case for the importance of managing what they term "concurrent technology transfer"[19], an approach where internal transfer of new technology is vital for success. However, few words of advice or illustrations are offered regarding management of internal transfer. Clausing (1994, p. 338) emphasizes the inherent difference between technology development and product development regarding technology uncertainty and complexity, and claims that these differences need to be dealt with in the transfer process. Galbraith (1973, p. 114), Rebentisch (1997), and Aoshima (1994) discuss categorization of different technology transfer mechanisms on a general level, where Aoshima's categorization functions as an example thereof: technology knowledge transfer, transfer process, and codifiability of technology. Further, Leonard-Barton (1995, p. 217) argues on a perspective basis in regard to viewing technology transfer as a continuous process rather than a single event in time (e.g. Jervis, 1975; Scholtz, 1996). It is often possible, though, to identify one moment in time where at least the responsibility is being transferred downstream, a feature termed by Eldred and McGrath (1997) the Technology Feasibility Point (TFP).

[19] Concurrent technology transfer is an example of a multi-project strategy where multiple designs are developed simultaneously. In the study, companies using a concurrent technology transfer strategy reached a significantly higher positive market share change than the others.

There has been extensive work within the overall technology transfer issue, where for example Roberts and Frohman (1978) put forward three bridges used for overcoming internal barriers, namely procedural, human, and organizational. Following this line of thinking, Clausing (1994, p. 335) argues that "*successful technology transfer is to transfer people*". Similarly on the industrial side, Gomory (1989) focused on the joint development efforts at IBM and Harryson (1998, p. 191) describes integrational attempts (e.g. strategic rotation of engineers) being made at several different Japanese companies. The conclusion from both the academic and the industrial sides seems unanimously to identify the human transfer bridge as the most effective, and also to confirm that there are differences between researchers and product developers.

Overall, several different approaches seem to be favorable, though few discussions are found regarding during what circumstances certain methods might be applicable or how effective they might be. Further, it seems that several of the company examples and the studies have not applied a holistic perspective, as they view, for example, either the technology development function or the product development function alone. It is my belief that it is beneficial when studying an interface to view both perspectives at the same time, and also for a longer period of time in order to grasp the complexity and the potential perceptive differences between the groups. The aim of this study is to examine the linkage between technology development and product development by using a holistic perspective on technology transfer. The transfer from technology development to product development is studied longitudinally with the three dimensions of synchronization, transfer scope, and transfer management. Further, this study explores whether there are any differences between technology developers and product developers, and consequently also the potential consequences thereof for efficient and effective R&D.

The study confirmed that there are differences between people working mainly with applied research as opposed to product development – in line with previous research, though this study approaches the potential consequences thereof. It was clear that, in the studied case, differences were found both on a background and on a perception basis. People working within the applied research field had more cross-functional experiences, perceived their work as more advanced and prepared for the subsequent phases, and were more result-oriented as opposed to implementation-oriented, than the product developers. These differences need to be addressed and considered when improving the initial stages of new technology commercialization, for example by clarifying responsibilities and by establishing appropriate procedures and components of before, during, and after the transfer point. More hands-on actions might be approaches to increase the readiness and preparedness of the applied research work in the eyes of the product developers by increasing the number of information channels used for spreading the results, and to focus more on the development of alternative concepts. This constitutes a mixture of different mechanisms in order to achieve a successful flow of technology.

Further, previous research has pointed to the internal human transfer between upstream and downstream phases as vital; however, this study nuances the picture by also introducing the use of suppliers as a means of human knowledge transfer between applied research and product development. Finally, the study revealed that applied research seems to face a situation where the staff often is decreased and the time targets are prolonged, at the same time as the main instigator of using developed new technology is the mismatch in timing. This is probably one of the worse wastes, i.e. when results are being developed but not used due to lack of synchronization. The causes might be found on several levels, not only within project management, but also within the overall strategic planning. Consequently, by applying a more holistic and continuous perspective on internal technology transfer between applied research and product development, it is likely that higher R&D precision can be attained.

The methodological issues of the study are mainly related to the trade-off between depth and width, the developed research instrument, and the "microscope" used in terms of dimensions. First, the chosen trade-off between depth and width was considered as vital for this type of study, making a holistic perspective combined with deep contextual understanding hard to apply on a broader basis. However, this study highlights issues of relevance for another likely step, a study potentially focusing on effectiveness and use of certain integration mechanisms in the company field of choice. Second, the research method was combinatory-based and entailed, among other things, a survey of the R&D personnel involved. The development of the survey was done in cooperation with the company personnel, which is a strength at the same time as it might prove a weakness – i.e. the development might have been biased by the persons involved. However, I made sure of engaging both people from the applied research area and people from the product development area in order to minimize those potential affects. Third and finally, the dimensions used could prove to be another source of bias, i.e. the systematization from previous literature, illuminating certain kinds of behavior and disguising others. However, it is hard to argue for another approach than to build on earlier research when investigating previously identified phenomena.

The study revealed a multi-facetted context, where barriers and enablers could be found within the three identified dimensions as well as within the characteristics and attitudes among the technology developers and the product developers. Leonard-Barton's view of technology transfer as a continuous process was strengthened, a process that needs to be managed deliberately and continuously. One implication thereof is support for the indicated vital pre-commercialization knowledge among the product developers, potentially affecting ongoing and planned technology development activities in order to achieve efficient transfer. Ensuring efficient internal transfer may help to lower the risk of late integration of new technology, potentially leading to gains in development flexibility (cf. Verganti, 1999). However, while viewing, identifying, and improving the transfer event in itself might be desirable, this is not enough to attain an efficient interface and continuous transfer of new technology downstream. The study also went one step further down from Eldred and McGrath's (1997) notion of the TFP point, and illustrates a case suggesting how to actually improve the quality of the solution at this moment by pro-active actions and by applying a more holistic perspective. The specific findings as such might be company-specific, but the challenges and the chosen approaches together with their relations may prove a foundation for identifying and further understanding the link between technology development and product development.

D. IMPLICATIONS FOR MANAGING R&D PROCESSES

This chapter begins by synthesizing the conclusions of Papers I–VII, followed by a more normative chapter elaborating potential managerial approaches, and finalized by a discussion regarding potential future research issues.

The purpose of this thesis is to explore, and increase the understanding of, management of R&D processes with special attention to technology development, product development, and their interplay. This aim is approached by studying two main categories or research issues, namely managing internal organizational interfaces and technology development and product development scope. The seven attached papers each deal with specific topics which have crystallized by getting input from industrial partners as well as from academia, topics that have been narrowed down in order to enable theoretical contributions. Consequently, this thesis consists of seven papers each with individual aims, research problems, and empirical data. Notwithstanding, these seven papers do all represent different aspects of the more general research area of management of R&D processes, contributing to this larger domain as well.

D.1. MANAGING INTERNAL ORGANIZATIONAL INTERFACES

It was indicated in previous research that a key issue when successfully transforming new technology into commercially viable products is to overcome organizational interfaces. Specifically, the interface between technology development and product development was seen as a culprit for effective R&D utilization and as having a large potential for improvement. In order to study this interplay, technology development and product development as well as the interface need to be approached.

Early phases of product development

Paper I approached the research issue formulated as “what activities are performed at the early phases of product development, how are they interrelated, and how can companies work with these phases to improve overall timeliness and speed?” When starting up a new product development project, the early phases of product development have frequently been referred to as the fuzzy front end – indicating an unclear way of working in those phases. Hence, in order to approach this interface to technology development, models of the early phases of product development and their applicability to different types of R&D projects were reviewed, in order to improve the project transparency, lower the sensitivity, increase positive repeatability, and consequently increase the efficiency in the early phases of product development.

The study in question analyzed process models or ways of working within the early phases, issues that can be approached in different ways. For example, working with the design process of the early phases by using the predominant management logic would possibly result in trying to force the – most likely already developed – process model for the main product development project to fit these earlier phases too. What the practitioners potentially strive for is using the process model in order to gain a foundation to offer some transparency, and also to get a basis for planning of resources and for decision support in the early phases of product development. Working with process models potentially also reduces the cost of changing staff within the project; i.e. the forthcoming steps are already mapped out and planned in a recognizable way for the substituting project staff members. However, the challenge for management is not to compel the management of the product development project to function also for the earlier phases, but – due to the higher uncertainty and claimed fuzziness – to actually develop a dynamic method matching different types of front end projects. This is not a trivial task, and the proposed front-end routes may be of some guidance along the road.

The study also focused on the more generic issue of securing and accumulating knowledge gained from previous projects or tasks. The basic assumption is that there is an efficiency potential in learning from previous projects, and thus the management needs to address both the issue of how to leverage these previous experiences and, in its own project, how to accumulate and secure the learning for subsequent projects. Bartezzaghi, Corso, and Verganti (1997) argue for the long-term importance to competitiveness of exploiting synergy and learning among R&D projects. Hence, there is strength in terms of efficiency when encapsulating learning from repeated projects; however, there is also a risk of falling into the trap of being too tied to historical methods – i.e. being caught in the dominant management logic (cf. Edlund and Magnusson) and thereby hindering new, potentially better, ways of working.

Responding to the research issue, Paper I gives some answers illustrating activities (mission statement, concept generation or screening definition, business analysis, and project planning) of the early phases of product development. But to fully describe what activities are being performed, one would need a broader approach involving other industries and companies as well. Paper I describes the relatedness between the activities as regards sequence, priorities, weighted importance, staffing, and time allocation. It is important to bear in mind the variation depending on project type that was inferred, indicating a need for flexibility in those phases reducing the value of using one process model for the early phases. This finding also calls for re-focusing academic efforts towards different front-end contingencies, instead of the current pursuit of one single front-end process model covering all cases. Finally, the issue of how companies can work in the early phases was approached by developing a schematic framework consisting of working with different front-end route concepts. It was concluded that flexibility in terms of staffing, priorities, and advanced planning was needed, and that managers ought to consider the type of project in question when choosing a certain front-end route. Further, establishing a cross-functional forum early to handle potential front-end route decisions is suggested. Paper I also illustrates and provides in-depth descriptions of early phases from three different projects.

Organizational forms of R&D

Moving upstream from the early phases of product development, Paper III and Paper VI approached the research issue regarding "what effects different organizational forms of R&D could have on the speed of technology development and on the internal transfer of new technology". Paper III targets the research issue by reviewing and analyzing two different organizational forms of applied research. Paper VI builds on the ideas gained in Paper III, and starts from another standpoint, viewing a dedicated and organizationally separated R&D unit in terms of technology development speed and internal transfer.

Starting with Paper III, the management issues analyzed in this paper relate to the choice of organizational R&D structure and the implications for the processes of technology development and internal transfer. One challenge for R&D managers is to choose and work with an organizational structure that matches the needs and requirements of R&D; i.e. if the technology development speed is the overshadowing task, it is more plausible for them to choose a structure with a more dedicated organizational flavor. On the other hand, if competitiveness is based on a smooth transition from technology development to product development, a more dispersed structure is probably favorable. After, or facing, a choice of organizational structure, the study indicated certain related managerial challenges or potential weaknesses. It is of great importance for improving the R&D efficiency to be aware of, and to deliberately work within the structure to overcome, those weaknesses. If the problems are stated and transparent, they are easier to approach. These potential problems were found, for example, within the staffing, funding, and monitoring practices of the two structures analyzed. For instance, it was concluded that the two structures were largely each other's opposites, the dedicated structure favoring rapid technology development and the other favoring internal transfer. These two different organizations were conceptualized, and the dedicated structure was dubbed "myopic pursuers" while the dispersed were dubbed "integrative firefighters", highlighting the challenges and the inherent strengths in each form. The contextual description and the specific transfer methods being applied within the studied company also constitute a contribution as such, framing and illustrating the conclusions and findings.

Moving on to Paper VI, the implications and managerial challenges related to setting up a separate new organizational unit for rapid technology development were studied. Previous research has often stated the benefits of such an approach; however, the focus of Paper VI is not only on speedy development, but also on the important linkage back to the parent organization. The challenges facing managers in this study seem to be to create highly differentiated, yet highly integrated, organizations over time depending on current and future needs, to be able to secure access to necessary knowledge by rapidly and effectively developing new technology. These issues can be divided into three stages: establishing a differentiated structure, reaping the benefits of having a separated unit, and integrating the knowledge back into the parent organization. Evolving into a dual organization structure, establishing differentiating factors as well as reaping the benefits of a separated new unit, presents a tough managerial challenge for firms - in particular, to actually leverage existing business operations without hampering or otherwise negatively affecting the new unit's business potential. Using the full power of an ambidextrous organization enforces rapid entrances into new strategic and viable business areas. Issues relevant for management of R&D processes are, for example, staffing and resourcing decisions regarding the new unit, setting up or accessing a necessary business network, and establishment of integrating mechanisms, monitoring system, and coordination responsibilities between the two structures. These initiatives aim at improving the interaction between, in this case, mainly the entrepreneurial unit's technology development and the larger unit's product development efforts.

It was shown that the traditional view of using separated, dedicated organizations holds great value in terms of focus, but also involves several integration challenges with respect to the parent organization. A new term for this special kind of situation was used: re-integration. The term refers to the efforts primarily by the new unit to re-integrate new technological knowledge back in the parent organization to be utilized in projects and forthcoming products. Further, a dynamic view of integration and differentiation, also taking the time factor into account, was revealed. Previous views were chiefly based on environmental factors resulting in a certain level of integration and differentiation. The evolution and set-up of the new unit revealed several stages where the majority of the tasks were directed either to more integration or to more differentiation; hence, a constant strain between these two forces was found. Finally, Paper VI nuances the notion of having a strong vision by emphasizing the benefits of constraining such a vision, questions the stylized fact of the benefits having researchers stay with the technology from "cradle to grave", introduces a fourth integration bridge termed a "mindset mechanism", and opposes previous research suggestions of single-mindedly going for a counter-cultural approach when setting up the new unit.

Responding to the research issue concerning organizational forms of R&D, it is concluded that the organizational form seems to have an impact on technology development speed and internal transfer of new technology. Having a more dedicated organizational structure favors technology development speed, while having integration troubles with internal transfer of new technology; the opposite holds for a dispersed organizational structure. For example, in the form where a dedicated unit is separated off with the purpose of developing a certain technology, it was clear that speed and focus were gained, but also that re-integration issues arose. These conclusions ought to be tested on a broader basis, potentially introducing other organizational forms or nuances as well.

Interplay between technology development and product development

Paper VII (and to some extent Paper III) reviewed the research issue of "how the interplay between technology development and product development can be managed, and potentially improved". This issue summons the discussions regarding management of internal interfaces. The aspects involved concern the synchronization of technology development tasks with product development, management of transfer scope of technology development, and handling the internal transfer – all to ensure that the appropriate technology is in place when needed.

The synchronization of technology development tasks with product development is to be viewed not only as a match between the technology strategy and the product launch strategy, but also on a more operational level. Considering the long-term cycle and aim of technology development, the continuous review and discussion about resource planning and management of the tasks are vital. Hence, enabling rapid re-focuses or accelerations is needed (e.g. when called for due to competitor launches, changing market demands, etc.). A second challenge in the study relates to the transfer scope, i.e. increasing the R&D efficiency by rapidly reaching a proper, manageable scope. For example, a project-scope gap was evident in the study, showing vital differences in what the product developers sought and needed as compared to what was actually delivered, differences that carry consequences for the performance of R&D (e.g. in terms of perceived readiness for the next phase, result-oriented versus implementation-oriented personnel, etc.). Finally, the actual execution and transfer of the new technology consist of a challenge as to what method or mechanism to choose and how to pursue the transfer. Overall, a properly planned, managed and executed continuous internal technology transfer provides benefits related to R&D efficiency and precision as well as securing quality throughout the process. Further, to improve the overall R&D utilization and commercialization efforts, it was clear that simply focusing on the transfer event in itself is not enough. One example thereof is the importance of product developers' preknowledge about ongoing and planned technology projects, knowledge that affects their willingness to adopt the new technology.

Paper VII also reviews the management of technology development, concluding that one major reason for not adopting new technology into product projects is bad timing. This implies that technology development often is late. On the other hand, it was also found that a typical technology development project often was de-staffed and prolonged – though with a constant project deliverable. Paper VII pinpoints managerial actions aimed at improving the interaction between technology development and product development, actions that are categorized in three areas: synchronization efforts, managing the transfer scope, and managing the actual transfer. Examples of approaches are to increase the implementation focus of the technology developers through, for example, development and documentation of more alternative concepts, to increase the number of information channels for spreading the results, to include cost estimates, and to conduct more system tests.

D.2. MANAGING TECHNOLOGY DEVELOPMENT AND PRODUCT DEVELOPMENT SCOPE

The balance between technology development and product development has been a matter of debate for quite some time, emphasized by the Japanese companies' product development strategy during recent decades. The issue relates to the degree of technological maturity and the risk that companies can take in their product development projects, and what development ought to be handled separately.

Sharing technology between R&D projects

Companies having a portfolio of products based on a common base of technology need to address the issue of effectively sharing technology and components, in order to optimize the technological content or degree of newness. Paper II approached the research issue concerning "what the managerial difficulties related to sharing technology between R&D projects might be". The management issues dealt with in Paper II are related to leveraging previous project experiences and technology through the reuse of existing solutions – with the aim of reaching a desired level of technology or component commonality between different projects.

Previous research has primarily dealt with the technical issues of transferring and reusing parts across different projects and products. However, this study concluded that the issue of parts sharing is much more complex – involving organizational, strategic, technological, cost, and support systems issues as well. Acquiring knowledge through parts sharing is effective in terms of cost, lead time, and quality. However, it should also be noted that the sharing of parts also shifts focus for the engineers. This shift means that they work less with re-development of solutions or parts that already exist, and more with selection and integration of existing parts and with the unique (potentially of greater customer value and of a more daunting character) development tasks in the project. Overcoming difficulties of parts sharing facilitates and accelerates R&D processes, while at the same time it decreases the cost of internal transfer of technology as one channel for the necessary knowledge acquisition. Hence, the internal transfer or sharing of parts was found not only to be an engineering issue, but also to be of great importance for management.

Responding to the research issue, it can be concluded that the managerial difficulties related to sharing of new technology are numerous, ranging from technological challenges to cost, organizational, strategic, and support system issues. An example thereof is that the commonality issue is delayed until late in the R&D project, making sharing of parts troublesome. In order to fully answer the research issue, a wider picture needs to be drawn, involving other industries and parts sharing opportunities.

Evaluation of new R&D methods

Paper IV approached the research issue termed "how companies can apply and evaluate new prototyping methods in R&D". This paper reviews challenges related to the evaluation of new prototyping methods in general, and the use of VR in particular, with the aim of accelerating R&D processes.

Evaluating different prototyping methods consists of reviewing the learning, investment, and security related to the traditional methods in use, as opposed to the potential benefits and the associated risk of the identified new methods. Since new methods continue to arise, this is not to be taken opportunistically, but as a certain process or way of working with identifying, evaluating, and matching new prototyping methods with the demands and characteristics internally. The evaluation and matching are a complex issue, involving not only a separate evaluation of the method as such, but also the task of testing the new method in the most appropriate domain (e.g. technology development, product development, engineering) and project phase (e.g. earlier or later in the cycle). The benefits sought seem primarily to be a reduction of project lead-time and, secondarily, to reduce the project cost and to increase the product quality. New prototyping methods in R&D are largely visual within the application of IT – i.e. VR visualization techniques, haptic models, IT expert systems. Hence, product designers and management need to continuously address the evaluation and application of new prototyping methods in order to stay on the edge, potentially by using a process for how to handle new method evaluations.

In the studied case, they chose to pre-test a new method (based on a potential prototyping exchange of full-scale clay models for virtual reality) in the technology development phase, instead of increasing the uncertainty of product development. The evaluation of new prototyping methods was seen as advantageously pre-tested in the less time-pressured environment of technology development. It was concluded that the specific clay model substitution was not possible in the late design phase where it was applied; instead, the prototyping method would possibly be more suitable as a complement in this phase but as a substituting technology in the earlier phases. Hence, the choice of matching the characteristics of the method with process stages seems to be essential when applying new methods, and ought to be given careful attention. Further, structured methodology and related potential dimensions for evaluating new prototyping methods were developed, involving dimensions such as cost, feedback time, representativeness, and knowledge-building capabilities.

Approaching the research issue, Paper IV presents a structured evaluation procedure for new prototyping methods, involving dimensions such as knowledge-building capability (e.g. geometrical features, physical attributes), representativeness, feedback time, and management link. This methodology might be further developed in order to capture a wider range of methods than prototyping to evaluate.

R&D project scope

Returning to the issue of managing technological newness and risk in R&D projects, Paper V develops and pre-tests a new visualization tool and methodology to aid in this process. The research issue approached was “how the R&D project scope can be managed in a structured and continuous manner throughout project execution”. The issues dealt with in this paper relate to the continuous management of R&D project scope, a perspective where reviews and monitoring could be handled in a more visualized and structured manner, supported by a specific developed method.

The challenge for project and top managers approached in this study is the dynamic and continuous management of project scope, i.e. how to choose among different contents, how to communicate the choices, and how to bring structure to such potentially infected discussions. The benefits sought are to increase R&D investment precision by focusing on the most vital content and thereby reducing the risk of unwanted R&D cuts or spending, and to assist project managers in the daily content decisions. It is also beneficial to be able to communicate the project scope, vertically as well as horizontally, in a structured and presentable way. Hence, the method and tool developed affect the review and monitoring process of R&D projects, as well as strengthening the surrounding support systems.

Previous research has concluded that having a well-balanced content is of critical importance for project success. It was also noted that in many cases there is an ongoing battle of creeping specifications, resulting in a constant change of project content in terms of technology. However, few managerial tools are available to guide project managers to view, analyze, and make decisions regarding technical content throughout the project execution. In order to be able to make such decisions, the tools developed, termed 'R&D content graphs', were based on five dimensions identified as influencing R&D project scope. These dimensions were (as adapted for technology development projects): strategic fit, knowledge-building capabilities, implementation possibilities, interdependencies, and technology uncertainty. The tools' predictive value was also pre-tested, indicating potential actions for project managers to consider.

Responding to the research issue, Paper V presents a detailed, pilot-tested, and structured tool for managing R&D project scope. The tool is built up from five dimensions: knowledge-building capability, implementation possibilities, interdependencies, technology uncertainty, and strategic fit. It is targeted for use by the management team during the execution of R&D projects. This tool represents one of potentially many ways of working deliberately with R&D project scope. Further studies might be directed towards applying this method in different contexts and covering the portfolio level as well.

To summarize, managing technology development and product development involves several different dimensions, ranging from choices regarding introduction of new methods, and individual R&D project balancing, to overall portfolio management of R&D efforts. Hence, pursuing a certain balance of R&D holds high operational and strategic importance.

Remark on findings

The purpose of this thesis was to explore management of R&D processes with special attention to technology development, product development, and their interplay. This was done by studying aspects of two main categories – managing internal organizational interfaces and management of technology development and product development scope. The aspects studied have concerned early stages of product development, organizational forms of R&D, the interplay between technology development and product development, the sharing of technology between R&D projects, the evaluation of new R&D methods, and the R&D project scope.

D.3. ELABORATION OF MANAGERIAL APPROACHES

This section elaborates upon a potential sixth generation of R&D and concludes with a discussion of relevant future research issues in this field.

Towards sixth-generation R&D management

Throughout the five identified R&D generations, the complexity of R&D has continually expanded. Drivers of complexity have been, for example, the need to take *more aspects* into account (e.g. interoperability, industrial design, environmental, manufacturability, and after-market considerations), the demand to cooperate and interact with *more actors* outside the traditional R&D departments (e.g. with marketing and manufacturing functions, with suppliers, competitors, and distributors), and the necessity of efficient and effective commercialization of new technologies (e.g. timely, efficient deliveries of new products with predicted quality). The need for taking more aspects into account is driven by product and technology complexity; the demand to cooperate with more actors is driven by larger technological investments and rational specialization; and the necessity of efficient and effective commercialization of new technology is driven by rate-of-return demands and the cost of being late. Hence, facing this rising complexity challenge, management of R&D is predicted to take on a set of new working methods resulting in a new identifiable generation. The route forward involves issues of a more-of-the-same character; i.e. it is likely that there will be a continuous expansion of the complexity of R&D driving an increased number of aspects to integrate and actors to involve.

However, apart from this evolution, a more radical shift is predicted to characterize the sixth generation of R&D management. This shift towards sixth generation of R&D management is predicted to return to the roots, i.e. back to the purpose of the first generations corporate research labs, one pursuing more radical innovations. One could see this as a re-focus towards the research part of research and development. The corporate research labs as such are not predicted to resurface, instead the re-focus is taking on other approaches. The bases for this new shift or new set of approaches are a broader multi-technology base for high-tech products and a more distributed technology-sourcing structure. There will be a palette of technology-sourcing strategies available, e.g. corporate research labs, internal corporate venturing, technology company acquisitions, intellectual property acquisitions, corporate venture capital, joint ventures, independent research groups or networks, and internally driven R&D (cf. Granstrand and Sjölander, 1990). The strategic choices are related, for example, to the R&D intensity of the firm, the industry context, and the business strategies.

The multi-technology aspects refer to products consisting of a broader technology basis, e.g. from basic mechanical products to infotainment products building also on biotech, telematics, and software functioning in a broader system delivering also related services. Traditional networks of companies (automotive, telecom, etc.) are thereby not sufficient to deliver these new kinds of products, instead new alliances and cooperation need to be established cross borders and based on functions instead of technology – increasing the demands on companies' combinatory capabilities. Much of the breakthrough research will not be a result of one company's lab efforts, instead breakthroughs will be based on joint efforts from loosely tied networks of smaller players driven more of pure interest than profits. In a way, early examples strengthening this view is evident from the independent programmers contributing to the Linux operating system, powerful enough to challenge the prime example of a de facto standard - Microsoft's Windows system.

The need for companies to keep up with, tap into, and stay connected with the research efforts around the world is even more accentuated. This means that the research part of R&D in the long run weakens its solid ties to one company, merely being part of a larger ecosystem. There have been several attempts targeted at development alliances, now the turn has come to niche-based alliances also within the research efforts, involving actors as disperse as the Universities, independent freelancers, temporary interest groups, and competitors. The knowledge about ongoing research efforts and their potential implications and results may also lead to daring to have greater flexibility in the development cycle, thereby increasing their precision.

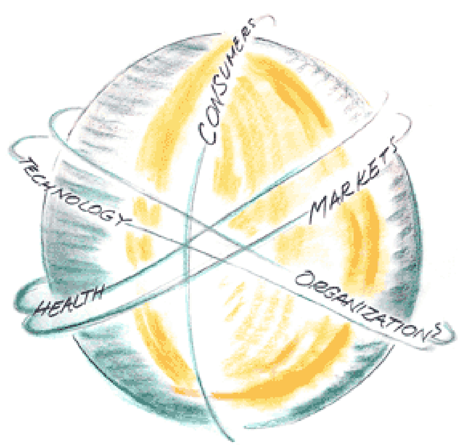

Figure 1: Sixth generation of R&D management: global, connected, and nimble research efforts in a multi-technology context.

This shift is conducted with the aim of increasing the likelihood of recognizing, joining, and developing breakthroughs affecting whole industry segments. It is also a stylized fact that when predicting the future, the business impact of technological changes is overestimated in the short run, while underestimated in the longer run as wildcards[20] occur more frequently with a larger impact than would be expected. Hence, there is a larger risk/reward ratio than evident in the earlier generations of R&D that now need to be taken into account. Within this new kind of R&D system, new opportunities or companies will be formed, functioning as intermediaries for the research efforts towards the potential users or developers. Those distributed intermediaries might function as marketing channels for the research efforts, as segment information providers, and as seekers of new application areas. Managing this multi-technology, multi-project network will be a daunting task.

In sum, the sixth generation of R&D management is expected to re-focus the research part, and to enlarge and enhance the capabilities by connecting to loosely tied multi-technology research networks. The pursuit of breakthroughs will take on other organizational approaches and open up for new players in the arena. In short, "*chance favors only the prepared mind*"[21].

Remark on R&D generations

The notion of R&D generations is a difficult term, especially since most companies constitute a mixture of the generations and since the relevant time period for them most likely differs depending on industry segment, demographics, company age, research intensity, legislation demands, etc. Hence, the question could be asked: what constitutes a generation, and why is the term generation useful to depict? My experiences are that the concept behind generations is easy to grasp and communicate, points to different types of approaches with related pros and cons, and describes in some senses an evolution within the area – all with the aim of assisting companies to improve their R&D capabilities, and to develop a common language for researchers and companies to work with. It is important to realize that the notion of R&D generations is one way of communicating different management approaches under certain conditions and contexts.

[20] A wildcard represents an event with low probability of occurrence which, if it occurs, has a dramatic impact. Wildcards and their impact have been studied by, for example, the Institute for the Future in San Francisco.

[21] Citation from Louis Pasteur.

Introducing the cluster approach

This section is of a more normative nature, providing my own thoughts upon managerial approaches to R&D processes, a section that is also focused on potential solutions. It is worth noting that the examples of actions given here are not intended to provide answers to all the issues mentioned in this thesis, but merely to shed some light and illustrate aspects of R&D management actions that might be worth pursuing. In view of the previously identified research issues in the thesis, the proposed approaches and perspectives in this section are based on the following problems (cf. Paper IV and VII):

- Technology development efforts tend to be fragmented, i.e. initiated, managed, and communicated within the respective function or department, resulting in late system integration and testing and in a risk of R&D inertia. Further, the interplay between technology development and product development tends to be overlooked and transfer issues not pinpointed, potentially resulting in a lower level of R&D utilization than is needed.
- Technology development tends to focus excessively on the core technology in question, lacking enough evaluation, documentation, and/or analysis of alternative concepts and/or supportive technologies. This might result in a narrative phase of technology development, potentially complicating effective implementation in new product projects.
- Technology development experiences the "rubberband" effect of resources on behalf of the closer-to-market product development, resulting in a misbalance of R&D efforts, and in technology solutions often being late and down-prioritized. This situation endangers technology-based companies' long-term survival and competitiveness.

These problems reside chiefly within the fifth generation of R&D, facing the system integration challenge and the need for a timely and synchronized total R&D effort. The managerial approaches mentioned below ought to minimize the negative effects of internal organizational boundaries and introduce techniques assisting management of the overall R&D scope.

Facing the upcoming challenges, companies need to industrialize, manage and link the technology development phase in a tighter manner, and also to structure and improve the early phases of product development to evaluate, incorporate, and pursue rapid integration of targeted technologies. Manufactured products of today are complex systems products[22], consisting at their core of a number of different technologies, where features and functions work across the traditional functional divisions (e.g. motor, cab, chassis, transmission, etc.). The need for all these technologies to be properly integrated in order to function as a coherent whole is not questioned, resulting in companies establishing teams for systems engineering tasks and packaging of components and sub-technologies. What have also been noted, following the product-platform perspective, are the strengths and potential residing in the intelligent configuration of a set of technologies, possibly leading to new offers and innovations.

However, this potential is not appropriately exploited by working along the traditional functional divisions, only to be challenged later with the systems integration tasks. An alternative way of working with technology development tasks is to move the system integration tasks further upstream, by introducing technology development projects that cut across disciplines. Thereby, greater attention would also be given to the implementation issues, forcing a perspective wider than one's own technology performance. Further, respective technology development efforts tend to be exposed to changes in budgets, having trouble defending the appointed resources. It is widely recognized that assigning a few hours a week to some fuzzy ongoing technology development is common practice – whether or not the hours have been put in. Hence, it is suggested that larger clusters of technology development efforts should be created.

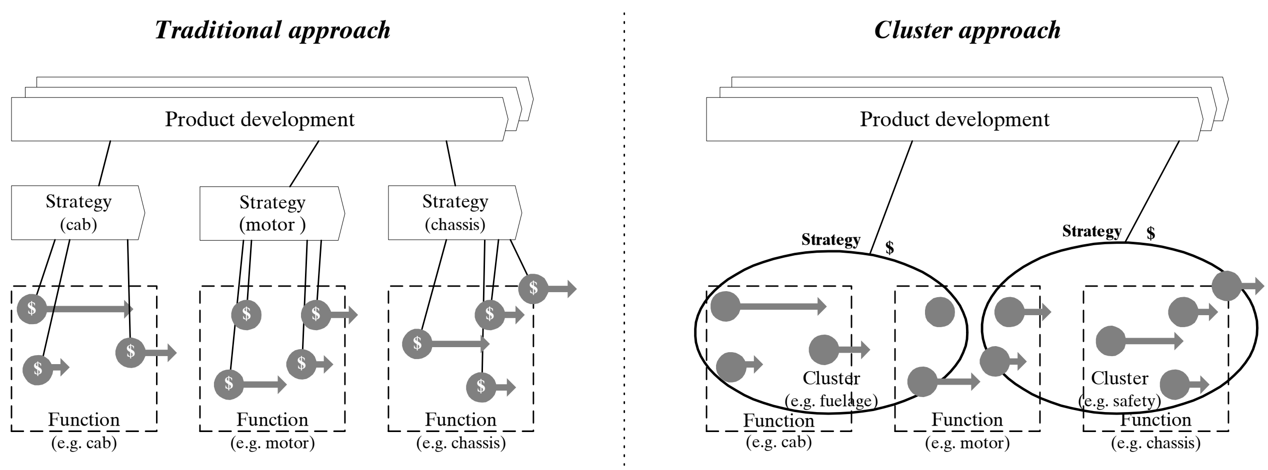

Exhibit 14: Traditional approach versus the cluster approach for managing technology development (grey circles indicate technology development efforts).

[22] A systems product can also be seen as consisting of the company's whole offer to the customer, i.e. including for example service aspects, financial solutions, guarantee offer, and so on.

Exhibit 14 indicates an approach termed “traditional” and another termed the “cluster” approach. The traditional approach illustrates a scenario where each technology development effort is managed, staffed, and budgeted within the respective department. These individual efforts are then aligned with the overall functional strategy, to be incorporated in product development. The cluster approach takes a cross-functional strategy, gathering technology development efforts around the customer-driven features. These clusters have their own budget, steering group and staffing, and are then cluster-wise aligned with the overall strategy.

Describing the cluster approach in more detail, the clusters cut across disciplines working with, for example, the function of passenger safety, where all efforts – no matter where these are functionally organized – should be directed by one steering group in control of the appointed budget. This steering group should be able to acquire the necessary resources internally or externally, and should also be in charge of directing the whole cluster’s efforts toward the strategic goals, with respect to technology achievements and time frames, of the company. Having a critical mass of efforts within one area would be easier to defend and communicate internally, and easier to direct strategically (via for example R&D content graphs), and would also allow for reallocation of resources within the group. For example, it would be possible for the safety cluster to avoid having persons work sporadically within some projects; instead, the potential of having those persons work within more projects would allow greater focus. Further, the allocation decisions, whether of staffing or budgeting or otherwise, would be delegated to the cluster itself, attaining greater flexibility. Using the cluster approach would potentially result in less fuzzy de-staffing and prolonging of technology development, achieving a more synchronized total R&D effort that cuts across disciplines. In sum, the benefits of the cluster approach are:

- Communicability
- System focus and leveraging synergies
- Strategic alignment
- Monitoring and staffing situation

Another action suggested to approach the fragmentation of technology development is to pursue a more centralized procedure for presenting, communicating, and reviewing relevant, non-classified information about planned, ongoing, and finished projects for the company network. By involving and notifying a greater number of people, the feedback loop is strengthened and the overall awareness of where the company is heading is improved. This would ease the transfer stage and lessen the potential Not-Invented-Here syndrome. Another action that might assist the likelihood of a transfer of the results is to demand suggestions for suitable introduction-time targets and likely products for the new technology, all to raise the implementation awareness. When it comes to raising the quality of the technology development results, the development of fallback solutions or other alternative concepts would save time downstream. It might be necessary to state the minimum number of alternative concepts, or at least a potential fallback solution, that ought to be considered and documented before finishing the work. One potentially fruitful procedure, which would also alleviate frequent changes of project staff, would be to work with a visualized technology choice tree, indicating the choices made in the project and why those choices have been made (similar to a technology roadmap).

In conclusion, the importance of considering technology development and product development simultaneously is crucial, avoiding unnecessary suboptimizations and potential undermining of companies' competitiveness. Further, communicating and linking R&D effectively to the rest of the company network is of utmost importance, especially with regard to timing issues, scope, and overall strategy.

Future research

Studying management issues is complex and often difficult to grasp. It is my belief that a healthy interaction between practitioners and academics is the route to travel when advancing in this field. Upcoming managerial issues related to R&D seem to be connected with the heavy investment needs for advancing technology development, pushing alliances and mergers that result in managing geographically and potentially also culturally dispersed R&D activities. This challenge is similar to the discussion of dispersion versus dedication following Paper IV, an integration challenge that now seems even more evident. Specific examples of future research topics within this area are:

Integrating and balancing technology development and product development efforts, considering involvement not only of suppliers, but also of competitors and complementary partners in offering a total service. What effect might the larger scope of R&D have on technology development speed, transfer of knowledge, and overall system integration effectiveness? What potentially new integration barriers might be found in this structure – e.g. can suppliers be utilized as bearers of knowledge throughout a R&D cycle, and what managerial difficulties may that bring?

Second, the issue, dealt with in Paper II, of reaching economy- of-scale benefits also in the product development phase calls for intelligent commonality policies and practices, avoiding cannibalization and erosion of brands. Altogether, the need and use of long-term scenario planning to face heavy technology investments and to achieve distinct brand values are of utmost importance. Yet, as always, long-term planning and actions must be complemented by short-term flexibility in order to manage the rapid changes of today's market conditions and technology integration hallmarks. Specific examples of future research topics within this area are:

How can long-term planning be complemented by short-term flexibility in an efficient and effective manner? Under what contingencies is a certain process model applicable to work with? How can inherently different product brands utilize the same set of basic technology without eroding the values while maximizing the cost benefits and other gains?

Third, the R&D function needs not only to incorporate product features and enhance the production capabilities. A wider range of responsibilities and considerations must be envisaged already during the R&D phase. Issues of serviceability, financial solutions, functional development and sales, marketability, and distribution channels emerge – altogether resulting in R&D that yields, not products, but total offerings and packaged solutions for the current and future customer base. Fourth and finally, alongside the above challenges, the innovativeness and renewal of the firm (see Paper VI) need to be approached deliberately, using procedural, human, and organizational mechanisms in a proper manner. Specific examples of future research topics within these two areas are:

How can established companies utilize organizational approaches for probing new offerings to the market, and how can the R&D function operate while taking greater scope into consideration?

In sum, the R&D capabilities ought to address also inter-firm potentials and collaborations, to widen in scope in terms of developing new concepts, and to deliberately work with the long-term renewal of the firm. Further, more future research topics might also be related to continue the work of the sixth-generation of R&D management, involving issues of, for example, strategic R&D decision making in a multi sourcing context.

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