Mälardalen University Press Dissertations
No. 93

PERFORMANCE IN PRODUCT DEVELOPMENT - THE CASE OF COMPLEX PRODUCTS

Stefan Cedergren

2011

MÄLARDALEN UNIVERSITY
SWEDEN
School of Innovation, Design and Engineering

ISBN 978-91-86135-99-7
ISSN 1651-4238
Printed by Mälardalen University, Västerås, Sweden

Mälardalen University Press Dissertations
No. 93

PERFORMANCE IN PRODUCT DEVELOPMENT - THE CASE OF COMPLEX PRODUCTS

Stefan Cedergren

Akademisk avhandling

som för avläggande av teknologie doktorsexamen i datavetenskap vid
Akademin för innovation, design och teknik kommer att offentligen försvaras
fredagen den 14 januari 2011, 13.00 i Beta, Mälardalens högskola, Västerås.

Fakultetsopponent: Dr Tomas Rahkonen

MÄLARDALEN UNIVERSITY
SWEDEN

Akademin för innovation, design och teknik

Abstract

This research addresses the concept of performance in the development of complex products. More specifically, its aim is to study how performance is perceived and measured within large global companies, and how performance measurement systems can be designed in a systematic way.

The exploratory results regard how performance is currently perceived and measured. It is argued that performance measurements are focused on the later stages of the development of complex products, thus making it difficult to perform changes during the development. The focus is on lagging rather than leading indicators of performance, hence it is concluded that focus is on reporting the result rather than the causes of the result. In line with these findings is the weak link between what managers perceive as success factors and what is measured, the perception of performance being influenced by what is measured, rather than the reverse.

The prescriptive results focus on the development of models and frameworks to be used during the development of complex products. A general method for developing performance indicators is presented. The concept of *Products in Development* is proposed, this making it possible to monitor how value is created during the development of a product. Both these models aim at complementing the currently used performance measurement system in order to support effective and efficient development of complex products.

The method used in this research is mainly focused around the collection of qualitative data through a focused group interview, multiple case studies,and industrial reference-group seminars. A survey has also been used to complement the qualitative with quantitative data. The use of various research methods has made it possible to triangulate the data, thus strengthening the validity of the findings.

ISBN 978-91-86135-99-7
ISSN 1651-4238

Performance in Product Development – The Case of Complex Products

Stefan Cedergren

Swedish Summary

Denna avhandling behandlar prestanda och effektivitet i utvecklingen av komplexa produkter. Mer specifikt är syftet att studera hur begreppet effektiv produktutveckling uppfattas och mäts inom stora globala företag och hur effektiva mätsystem kan utformas på ett systematiskt sätt.

Den första resultatdelen fokuserar på hur produktutvecklingseffektivitet uppfattas och mäts idag. I dagsläget fokuserar mätetal för prestanda på de senare faserna av utvecklingen av en ny produkt, vilket gör det svårt att genomföra förändringar under utvecklingen. Fokus ligger på att mäta resultatet, inte det som påverkar resultatet vilket leder till att fokus hamnar på att rapportera resultatet snarare än dess orsak. I linje med dessa resultat är den svaga kopplingen mellan vad cheferna och beslutsfattare uppfattar som viktiga faktorer för att bli framgångsrik och vad som mäts. Det finns även indikationer som tyder på att synen på vad prestanda är inom produktutveckling påverkas av det som mäts, i stället för tvärtom.

Den andra resultatdelen fokuserar på att utveckla modeller och ramverk som kan användas under utvecklingen av en ny produkt. En generell metod presentas i syfte att utveckla indikatorer som kan användas under utvecklingen av komplexa produkter. Dessutom föreslås modellen *Produkter under utveckling*, vilket gör det möjligt att utvärdera hur värde skapas medan det utvecklas. Gemensamt för båda dessa modeller är att de syftar till att komplettera det mätetalssystem som för närvarande används för att utvärdera produktutvecklingseffektivitet.

Forskningsmetoden som används i det här arbetet är främst inriktad på att samla in kvalitativa data genom en fokuserad gruppintervju, ett flertal fallstudier och industriella referensgruppsseminarier. En enkätundersökning har också genomförts för att komplettera med kvantitativa data. Då olika forskningsmetoder har använts har triangulering mellan data nyttjats, vilket stärker validiteten av resultaten.

Acknowledgements

Studying for a PhD is a complex occupation with many different sides. Some days, I have had some of the loneliest, uphill, depressing tasks I have ever undertaken, but mostly, it has been a truly enjoyable experience, cooperation with several people interacting and contributing in the creation of new knowledge. Looking back at my four years and more of research studies I realize that I have been fortunate to meet and work with so many competent, generous and enthusiastic people.

This thesis would not have been possible without the supervision of my Professor Christer Norström. You have always believed in me and always impart encouraging and inspiring feedback and comments whenever we meet. I am also grateful for the supervision Dr. Anders Wall and Lars Cederblad have provided me and the experience you have shared with me. Dr. Stig Larsson, the last addition to my team of supervisors, thanks for giving me your support and the feedback that I really needed at the end.

I would also like to thank Tomas Angelhag, Dr. Göran Backlund, Magnus Bäckström, Staffan Elfving, Lars-Olof Gustafsson, Professor Magnus Larsson, Mikael Meyer, and Peter Oom for the time that you have invested in my project and the important contributions you have made, not only by championing my research studies but also by participating in the industrial reference group seminars. This thesis would not have existed if you had not given me your support. Moreover, I would like to acknowledge the financial support from the participating companies and the KKS financed research school, SAVE-IT for funding this research.

Thanks are also directed to Level Twentyone Management for not only employing me as an industrial PhD student but also adding to my development in thinking and acting more like a consultant. To my industrial mentor Thomas Edström thank you for sharing your experiences and giving me advice when needed.

Furthermore, Peter Wallin, without your help during the interview process this work would have been more time-consuming, less productive and less enjoyable. I would also like to acknowledge all the positive people in the working environment at IDT and the BESS group of which I have become a member. Also I would like to highlight the importance of other colleagues, such as Dr Daniel Sundmark, Dr. Joakim Fröberg, Diana Malvius, Håkan Gustafsson, Ylva Wretås, and Professor Jakob Axelsson in giving input, reading and commenting on my writings. Moreover, I have also been fortunate to cooperate with Joakim Eriksson. Our common research interest, but different backgrounds, has always been a good breeding ground for creative thinking, when we find the time to meet. Dr. Anton Jansen, thank you, for your help and input during the design of the survey. I would also like to thank Dr. Jayakanth Srinivasan for interesting and constructive discussions and all your comments regarding my writings.

I would also like to thank the people engaged in ProViking and PIEp for admitting me with open arms to their research community by allowing me to attend doctoral courses and workshops that have been of considerable assistance in my research as well as being enjoyable experiences. A big thank-you also goes to Victor Miller for working intensively on the improvement of my English.

As a researcher you tend to take your work with you, or, as has been the case in point recently, sit too long at the computer. Thus, I am thankful to have an understanding and supporting mother and father, backing me in whatever endeavor they find me engaged. Lastly, but most importantly I would like to thank my wonderful wife Jessica, for always being there to support me and encourage me in following the strange ideas I come up with, such as pursuing doctoral studies. Together we have a wonderful son Alexander and I look forward to spending more time with you both.

Stefan Cedergren

December, 2010, Västerås, Sweden

Preface

For me to become a researcher was not a given. At 10 years of age, I dreamed that when a “grown-up” I would study for a Master of Science degree in engineering. It was therefore not surprising to me that I eventually found myself in Linköping studying applied physics and electrical engineering, specializing in mathematics and automatic control systems. At that time, the idea of my becoming a researcher in performance measurement and product development was still beyond my horizon.

My interest in control systems pointed me in the direction of Bombardier and Västerås for my master’s thesis project. It turned out well, landing me after graduation in a position in development engineering at Bombardier. During this time I was commuting weekly between Västerås and Linköping, where my wife was still studying.

To occupy my spare time in Västerås, I had decided to study business economics. At about the same time I was engaged in a large international development project at Bombardier and I became aware of performance in product development as an interesting topic. After spending close to four years at Bombardier I was ready for a new challenge and noticing an advertisement for a vacant position as an industrial PhD student working with performance in product development, I recognized immediately that this was the challenge I was looking for.

When my research career began, as a typical engineer, I was often thinking in a strictly positivistic manner. However, being immersed in a research atmosphere, I have developed “philosophically” and learned to appreciate hermeneutic thinking. I now see myself as problem-oriented, not being afraid of seeking solutions based on the character of the problem rather than the opposite. I have always been driven by challenges. It will be interesting to see where I find them in the future. To begin with, there is a marathon in Berlin in September, for which I am already enrolled.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

This doctoral thesis addresses the concept of performance in the development of complex products. More specifically, the aim of this research is to study how performance is perceived and measured within large global companies, and how this can be improved. Developing complex products is a knowledge-intensive process and the single greatest challenge that managers face, as argued by Drucker (1991), is to raise the performance of knowledge workers. The ability to evaluate performance may be an important part in improving performance in this context.

This chapter starts by discussing why it is important to focus on measuring and managing performance in product development. This is followed by a presentation of what is meant by “complex products”. The objectives of the research and its organization are then presented, and the chapter concludes with a complete list of my publications and an overall outline including some of the contributions of this research.

1.1 The Importance of Performance Today

Not long ago product development was viewed as a purely technical process. Today, product development has transformed into something that is strongly coupled to an integrated business and technical process involving several top corporate functions (Goldense and Cronin, 2009). Goldense and Cronin argue that during recent decades of product realization practice, there have been several large breakthroughs having a positive effect on the overall performance of product realization.

A revolution within logistics began in the early 1980s and through Fed Ex and other standardized carriers; it became possible to deliver products worldwide in a novel, more efficient way. Today we more or less take for granted the possibility of having a product a delivered, anywhere in the world within 24 hours. This revolution within product delivery beginning in the 1980s made it even more important to develop and establish efficient and effective manufacturing processes. Hence, it is not surprising that a manufacturing transformation, based on the work by Deming and Juran, beginning in Japan, spread across the world during the 1980s. Nowadays, even if it is not always shown in practice, the optimization of a manufacturing process, from an academic standpoint is a fairly well understood task.

Next in line, and the central issue for success, became product development and design, something that has proven to be a much more challenging subject. The first step in this evolution began with the acknowledgment of the importance of integrating product development and manufacturing, as an alternative to “engineering” throwing the product over the wall to “manufacturing”. The next step in the product-development evolution was to acknowledge the importance of how product requirements are handled and to improve this. Attention was directed to the early phases of the development process resulting in the introduction of a collective framework for the early phases known today as the fuzzy front end (e.g. Koen et al., 2001; Verworn, 2008).

Next in line, in this chain of revolutions, became the commercialization part of product development. Similar to the interface between product development and manufacturing, the relation between product development and commercialization could be described like throwing the developed product over the wall to the marketplace. Team reviews against goals, post-launch management reviews and improved product maintenance policies rounded out a process structure that now started with a concept, continuing to post-launch reviews (Goldense and Cronin, 2009).

Portfolio management of new products became the next revolution, resulting in an important change in perception of product development, as an investment rather than as a cost. Managing the development of new products as a portfolio, refers to collectively managing a group of current or proposed development projects in order to best achieve the organization's overall goals.

Despite these revolutions, there remains much to be learned regarding the management of product development. One conclusion to be made from this is that the easiest challenges were completed first and the harder more complex challenges lie still ahead.

1.2 The Importance of Measuring Performance

Product development is regarded as important for product-delivering companies. One evidence of its importance is that the total product-development related spending by the 1000 largest companies in the world, in the year 2002, exceeded one quarter of a trillion dollars (Cooper, 2005). Today it is generally acknowledged, by all product-delivering companies, that product-development investments are important in order to remain competitive. Some researchers even take it one step further e.g. Wheelright and Clark (1992) argue that doing product development well has become a requirement for being a player in the competitive game; doing product development extraordinary well has become a competitive advantage. Crawford and Di Benedetto (2008) even claim that a successful new product does more good for an organization than anything else.

Moreover, it has been verified in several meta-studies that management can influence the success of a new product (Ernst, 2002). A popular statement when performance improvements initiatives are discussed is that what you cannot measure you cannot improve. Being able to measure and/or evaluate the performance of product-development activities is generally acknowledged both in the literature and in practice as being of inherent importance (Driva et al., 2001). In this research a slightly different perspective is argued for; if you are not aware of the performance you cannot manage it.

There are reasons other than improving performance for it being important to evaluate performance in product development. Tatikonda (2008) argues that without performance measurement in product development, we cannot answer the most fundamental questions of “how well are we doing”, “what have we learned” and “what should we do in the future”. Chiesa et al. (2009b) have reviewed the literature relating to relevant objectives for evaluating performance in product development and identified the following:

1) Diagnosing activity for supporting decision making
2) Motivating personnel
3) Enhancing communication and coordination
4) Learning
5) Reducing risks and uncertainty
6) Improving performance

Davila et al. (2006), emphasize on improving performance, by pointing out that one important ingredient in a high performing product-development process is not just to be able to evaluate performance, but also to use this information to decide on improvement actions. Jou et al. (2010) similarly argue that measuring and analyzing the performance of an existing product-development procedure, and pinpointing and resolving any inherent problems, are the keys to improve product-development performance.

Traditionally, performance improvements are achieved by focusing on, and strengthening the processes that have been relatively easy to quantify in measurements, e.g. the manufacturing process or the purchasing function. There are also plenty of performance measurements related to, for example, the productivity of the operation process (Hill, 1993; Slack et al., 2007). In contrast, the innovation and product-development literature is characterized by a diversity of approaches, prescriptions and practices that can be confusing and contradictory when it comes to measurements (Adams et al., 2006). Hence, one difficulty when measuring performance in product development is to be able to evaluate what is not easily quantified.

Research in the US reveals that only 52 percent of the total spending on product development is devoted to projects become financially successful (Page, 1993). There are of course differences depending on market segment, type of product etc. Still, if a production site showed similar results it would not survive, at least not with the present management. Also, it is important to acknowledge the fact that it is those 52 percent that will have to account for 100 percent of the product-development investment. An increase in the success rate of the product-development process will therefore not only increase future revenues but also decrease the overall cost load, which directly affects a company’s profit positively. An alternative is to increase the performance of the product-development process and thereby be able to do more with less.

The stock market shows increasing interest in a firm’s ability to be successful with product development, and the proportion of New Product Sales to Total Sales (Whitley et al., 1998) is one of the most commonly used measurements of the success of a company’s product-development process (Teresko, 2008). However, this measurement of performance, despite many positives, also has some limitations. For instance, if new products sales relate to the products developed during the last five years, it is also a measurement lagging by five years. It says nothing about any improvement initiatives carried out by the organization today. It is important to remember this in evaluating an organization – many changes may have been made during this time period. Also, being able to measure the outcome of the product-development process does not help an enterprise to improve or even pinpoint where improvements need to be made in the process. Measurements of such as the ratio of new products sales to total sales is more externally oriented in reporting performance and should not be used internally to improve current product-development activities.

The difficult task of valuing promising ideas for new products in monetary terms, has forced companies to view their spending on product development as a cost rather than an investment. Measurements related to cost is per definition a lagging indicator of performance (Parmenter, 2010). This explains why input measurements like R&D spending as a percentage of sales, or total R&D headcounts are among the most commonly used measures of product development (Teresko, 2008). Moreover, accounting rules require that investments in product development be treated as a cost; even though the economic reality is that they are more of an investment (Hartmann et al., 2006). The limited treatment of productivity may as argued by Cooper and Edgett (2008) be explained by the concept being relatively new. Similarly, Parmenter (2010) argues that very few organizations monitor their key performance indicators. Leading indicators of performance are measurements that can be used by managers and decision makers during the development.

1.3 The Importance of Managing Performance

In contrast to what has been described in Section 1.2, there is a debate if product-development activities should be measured at all. Within the performance-measurement literature there are early reports of the dysfunctional use of performance measurements. Ridgway (1956) argues that the mounting interest in performance measurements, foster the idea, that if progress toward goals can be measured, efforts and resources can be more rationally managed. However, the complexity of large organizations requires better knowledge of organizational behavior for managers to make best use of the personnel available to them. Ridgway (1956) argues that even where performance measurements are used purely for purposes of information, they are probably interpreted as definitions of the important aspects of that activity and hence have important implications for the motivation of behavior. The motivational and behavioral consequences of performance measurements are inadequately understood.

More recently, Hauser and Katz (1998) have summarized seven pitfalls, identified in practice, related to measuring performance in product development:

1) Delaying rewards – It is in the present, when actions and decisions are being made, that rewards will be appreciated, - rewards will be undervalued if they are granted too far in the future.
2) Using risky rewards - There is a ‘risk cost’ associated with any measurement based on vague or uncertain outcomes that are beyond the control of the managers and employees subject to the metrics.
3) Making measurements hard to control - The engineering team will be influenced more by the measurements they can affect directly than by those on which they have only a small impact on.
4) Losing sight of the goal – There is always a risk of ending up with a misaligned measurement system that blurs the intended goal.
5) Choosing measurements that are precisely wrong – There is a natural desire to seek precise measurements with great accuracy, but this, however, easily leads to sub-optimization.
6) Assuming your managers and employees have no options – The goal of a performance-measurement system should be to make your managers and employees work smarter not harder.
7) Thinking narrowly – The measurement system contributes to an increase in the focus of the organizations on the current paradigm.

A conclusion from this list of pitfalls is that it is easy to end up using a performance-measurement system that, rather than support the achievements of the organizations objectives, makes the objectives more difficult to achieve. With these pitfalls in mind it is not surprising to find that only 35 per cent of executives, in a survey by the Boston Consulting Group, are satisfied with their company's current measurement system related to developing new products (Andrew et al., 2008).

Moreover, a well known concept regarding performance measurements and improvements is the performance paradox. The basis of the performance paradox is that if you deliver, you only qualify to deliver more (McGregor, 2005). Cohen (1998) argues that the potential for the performance paradox exist when

- The organization experiences a decline in performance after a history of success.
- The organization can achieve significant improvements in performance with existing resources.
- The management team or a subset of the management team has a good sense of what to do to reconcile the performance shortfall.
- Despite the understanding, know-how, and even readiness that may exist within an organization, the management team actually acts contrary to a course of action that, if taken, would dramatically improve the performance.

In this research it is argued that it is important to acknowledge both the possibility of dysfunctional use of performance measurements and the performance paradox, when researching performance measurements in a product-development context. It is acknowledged that there is no easy answer to the question whether performance in product development should be measured or not. However, this research was set out with the perception that performance should be evaluated. It is important to remember that measurements themselves are objective, but may have important implications, both for god and bad, depending on how they are used in the management of product development. The results of using performance measurements depend on how the information is used by managers and decision-makers in an organization. The view of performance measurement in this research, is in line with the argument by Neely and Najjar (2006) that the true role of performance measurement is as a means of management learning and not as a means of management control.

1.4 What are Complex Products?

Complex systems consist of many interacting subsystems and components (Ulrich and Eppinger, 2008). In this research, the term complex products is used to describe products that typically include software, electronics, and mechanical components, where especially the software component has grown in size, complexity, and not the least, importance. New functionality added to these products usually involves software. In for example a new car, up to 90 per cent of all new innovations are realized using electronics and software (Broy, 2005). Typical examples of complex products are found within telecommunications, automation, defense, transportation, and the automotive industry. Complex products are usually developed in large organizations, with many stakeholders involved. Hence the need to evaluate performance may be especially important in order to enable a shared common understanding of the current performance.

There are several different terms used in the literature to describe the same or similar products. COPS (Hobday, 1998), software-intensive systems (McDonald, 2010), knowledge-intensive products, technology-intensive products (Jagle, 1999), and high-technology products (Mallick and Schroeder, 2005) are typical examples of possible designations of such products.

The product-development process is affected by the type of product that is to be developed. Typical characteristics that may affect the process is if the product is to be developed from a blank paper or if it is the further development of an already established product, is it being developed in a large or small organization, is the product realized purely through software or does it include e.g. mechanical parts to be assembled. Complex products may well differ from other types of products, especially low cost, mass produced, commodity goods based on standard components (Hobday, 1998).

In order to manage the technical complexity in the development of complex products, these products are often divided into smaller subsets that can either be outsourced or developed in-house. Especially, during the last ten years, there has been a strong trend to distribute the development activities to several sites, both national and international, making the management function even more challenging. Moreover, due to the large organization often involved in developing complex products, there is a need for cross-functional development teams. In such a team setting, collaborative decision-making is important to enable high performance in the product-development process. This is one reason why decision-making activities should be supported by a performance-measurement system.

Complex products are often developed in a business-to-business setting and they usually have a long life-span. The development of complex products is therefore often more evolutionary and incremental in its nature, compared to what may be the case within e.g. consumer products. Usually, there is a product-line architecture or platform as the basis of complex products, in order e.g. to manage the technical complexity of the product and shorten the development time for a new product. Product-line architectures or platforms are often used and shared between products. Complex products may be described as evolving products, i.e. products built around a platform and/or architecture, in order to re-use components, to keep the development costs low, something that is important due to the often low volume of these types of products.

1.5 Research Objectives

The purpose with this research is to contribute to knowledge within the field of evaluating performance in the development of complex products. The focus is on performance measurements, from the perspective of managers and decision-makers involved in the development of complex products.

As this research is within the applied sciences, it will not only aim to contribute to theory but also to contribute to practice. The overall objective that initiated this research and has guided this research from the start is: How performance, in a complex product-development context, can be measured in order to increase the understanding of the relation between technology, process, organization, competence, customer, business, and leadership. In order to limit and make a contribution to this overall objective, two research objectives have been derived:

1) To evaluate the current state of practice and identify challenges of measuring performance in the development of complex products.
2) To add to knowledge by addressing one or several of these challenges i.e. by developing models and tools based on the knowledge derived from this research project.

Hence, this research aims to contribute to the current state of knowledge both in a descriptive and a prescriptive manner.

1.6 Research Organization

The research presented in this thesis has been conducted together with seven different companies, all developing complex products but with different non-competing products and markets. This research set-up has been possible since the participating companies share similar problems, making it possible to have regular industrial reference group meetings, sometimes organized as a focused group interview or workshop to test and validate the emerging research findings. The industrial reference group meetings are further described in Section 4.3. Having seven companies actively participating in this research through industrial reference group meetings has been important since this research is inductive in its nature.

This research has been sponsored by the KK foundation, through the research school SAVE-IT, together with the seven participating companies. During this research the PhD student has been employed by Level 21 Management that also has taken part in this research mainly by adding further industrial experience and competence.

1.7 Publication List

The results from this research have resulted in a number of papers that have been presented and accepted in scholarly publications. The complete list of publications, written as part of this research, is presented below.

Thesis

1. Performance and Performance Measurements in Complex Product Development, Stefan Johnsson, Licentiate thesis, Mälardalen University Press, October, 2008

Journal papers

1. PMEX – A Performance Measurement Evaluation Matrix for the Development of Industrial Software-Intensive Products, Stefan Cedergren, Anders Wall, Christer Norström, International Journal of Innovation and Technology Management, Accepted for publication in 2011.

2. Evaluation of Performance in a Product Development Context, Stefan Cedergren, Anders Wall, Christer Norström, Business Horizons, ELSEVIER, Volume 53, Issue 4, July-August 2010, Pages 359-369.

Book chapters

1. A Performance Evaluation Framework for Innovation, a chapter in Innovation in Business and Enterprise: Technologies and Frameworks. Stefan Cedergren, Anders Wall, Christer Norström, IGI Global Inc., July, 2010

Conference papers

1. Towards Integrating Perceived Customer Value in the Evaluation of Performance in Product Development, Stefan Cedergren, Stig Larsson, Anders Wall, Christer Norström, PICMET, Bangkok, July, 2010
2. Limiting Practices in Developing and Managing Software-Intensive Systems: A Comparative Study, Peter Wallin, Stefan Cedergren, Stig Larsson, Jakob Axelsson, PICMET, Bangkok, July, 2010
3. Challenges with Evaluating Performance in Product Development, Stefan Cedergren, Anders Wall, Christer Norström, 17th International Product Development Management Conference, Murcia, Spain, June, 2010.
4. Analyzing the System Architecting Value Stream, Håkan Gustavsson, Jakob Axelsson and Stefan Cedergren, EuSEC, Stockholm, May, 2010
5. Performance Evaluation of Complex Product Development, Stefan Johnsson, Diana Malvius, Margareta Norell Bergendahl, International Conference on Engineering Design, ICED'09, Stanford, CA, USA, August, 2009
6. A Conceptual Evaluation Framework for Performance Measurements within Industrial Product Development, Stefan Johnsson, 16th International Annual EurOMA Conference, Göteborg, Sweden, Editor(s):Mats Johansson and Patrik Jonsson, June, 2009
7. Performance Evaluation in an Industrial Product Development Context, Stefan Johnsson, Performance Measurement Association Conference, School of Business, University of Otago, Dunedin, New Zealand, Editor(s): Professor Ralph Adler et al., April, 2009
8. Issues Related to Development of E/E Product Line Architectures in Heavy Vehicles, Peter Wallin, Stefan Johnsson, Jakob Axelsson, 42nd Annual Hawaii International Conference on System Sciences, IEEE Computer Society, Hawaii, USA, January, 2009

9. PMEX – A Performance Measurement Evaluation Matrix for the Development of Complex Products and Systems, Stefan Johnsson, Christer Norström, and Anders Wall, Proceedings of the Portland International Center for Management of Engineering and Technology 2008 Conference, Cape Town, South Africa, July, 2008.
10. What is Performance in Complex Product Development?, Stefan Johnsson, Peter Wallin, and Joakim Eriksson, Proceedings of the R&D Management Conference 2008, Ottawa, Canada, June, 2008.
11. Modeling Performance in Complex Product Development – A Product Development Organizational Performance Model, Stefan Johnsson, Joakim Eriksson, and Rolf Olsson, Proceedings of the 17th International Conference on Management of Technology, Dubai, U.A.E., April, 2008.
12. Modeling Decision-Making in Complex Product Development by Introducing the PDOPM, Joakim Eriksson, Stefan Johnsson, Rolf Olsson, Proceedings of the International Design Conference – Design 2008, Dubrovnik, Croatia, May, 2008
13. A Productivity Framework for Innovative Product Development, Stefan Johnsson, Lars Cederblad, Christer Norström, and Anders Wall, Proceedings of the 5th International Symposium on Management of Technology, Hangzhou P.R. China, June, 2007.

My contributions: I am the sole or main contributor of journal paper 1-2, the book chapter, and conference papers 1, 3, 6, 7, 9 and 13 which are co-authored with my supervisors. In conference paper 2 I participated with ideas, part of the empirical data and the analysis. In conference paper 4 I participated with ideas and some of the analysis. Conference paper 5 was written as part of a PIEp Tiger Team Writing Workshop and written together with Dr. Diana Malvius, while Prof. Margareta Norell Bergendahl participated as a supervisor. Conference papers 11 and 12 are based on a common model developed jointly by the authors; while I was the principle contributor to and author of conference paper 11 for which the model was applied in a performance perspective and similarly Joakim Eriksson author and main responsible for applying the model in paper 12. I was the main contributor to conference paper 10, Peter Wallin participating in the data collection and Joakim Eriksson contributing to the development of the model, (also used in conference papers 11 and 12), on which the study was based.

1.8 Contributions and Outline of the Thesis

The main contributes related to the first objective of this research include:

1) There is no link between success factors and what is being measured by the performance-measurement system.
2) The architecture or technology aspect was identified as an important success factor but it is rarely addressed explicitly by the performance-measurement system.
3) Product management is not integrated in the performance-measurement system related to product development. Focus is instead on evaluating activities related to the project management function.
4) The measurement system is not focused on the early phases of product development but rather on the later phases of the development.
5) Value is not measured by the performance-measurement system, the focus being on time, cost, and quality. Value creation seems to be taken for granted.

It is therefore concluded that the current way of measuring performance is not supporting managers and decision makers during the development of a new complex product. On the basis of the findings related to the second objective, the following list of contributions is argued for:

1) A framework for evaluating and analyzing performance in complex product development, by categorizing the activities as planning, implementation, and sales and delivery activities.
2) The PMEX – A method to evaluate the performance-measurement systems currently used in product development.
3) The PCRM – A general model for performance criteria for product development.
4) The DPI – A method for designing performance indicators that focus on integrating relevant performance criteria and success factors when developing, in particular, leading measures of performance.
5) The concept of PiD – A method that integrates customer value as a measure of performance during the development of a new product.

Figure 1 presents an overview and the relations between the different chapters in this thesis. The related literature within the area of performance measurements and product development is extensive. In order to present a survey of the research area, Chapter 2 includes a frame of reference intended to introduce the literature and the gaps relevant for this research. The frame of reference is intended to give an overview of the field of performance measurements and product development. This chapter is divided into four main sections: developing complex products, performance in product development, success factors in product development, and performance measurements in product development.

Some of the findings in this chapter include the confusion in the used terminology, especially related to performance in product development which makes research more problematic. Most studies in the management of product development tend to focus on general product development, not complex products in particular. This may imply that specific challenges related to the development of complex are neglected. Moreover, an extension of the definition of product development by Ulrich and Eppinger (2008) is proposed. This definition especially stresses the early activities of product development that, especially from a performance evaluation point of view, are overlooked in favor of output measurements. The frame of reference is concluded with an overall discussion of the findings.

In the following chapter, the research questions are derived from the gaps in the literature identified. The research questions consist of two sets, one exploratory, aiming at the identification of challenges and the current state of practice related to performance measurements in complex product development. The second set of research questions is more prescriptive in nature, aiming at contributing with solutions to some of the identified challenges. The ensuing research methodology chapter gives the overall perspective of the methodological concerns regarding this research. It introduces the research journey, including the conducted studies, leading up to this thesis. This research has adopted research methods for collecting both quantitative and qualitative data; the latter is mainly obtained through case studies.

The six chapters, Chapter 5-10 in Figure 1, are categorized in two sets (Chapter 5-7 and Chapter 8-10) according to how they relate to the two sets of research questions. Chapter 5 proposes a holistic framework for evaluating performance by categorizing the activities in product development as planning, implementation, and sales and delivery activities. Further, the important success factors for planning and implementation activities in developing complex products are identified. The technology in terms of the architecture, in particular, is regarded as a success factor for the implementation activities but this is not acknowledged in the general literature of product development. The proposed framework is then further developed into a performance measurement evaluation matrix (PMEX) in Chapter 7. The PMEX was designed in order to analyze what is measured, why it is measured and what is not measured by the current measurement system. Findings from studies of the use of the PMEX include that performance measurements tend to focus on the later stages of the development, while measurements related to the early planning activities are rarely used. Hence, it is concluded that the focus of the performance measurements is on reporting the result rather than its causes.

Chapter 6 is the third and final result chapter in the exploratory part, and it focuses on the challenges encountered in evaluating performance in complex product development. A strong link between how performance is perceived and how it is measured is presented. The focus is on time, cost, and quality while, for example, the concepts of creating value and developing the right products is missing. There is also a weak link between the perceived success factors and what is measured. Hence, it is concluded that focus is on what is easily quantified rather than what might be important to measure. Also, there is a consensus that the currently used performance-measurement system needs to be improved, but there are no ideas of how to change the current situation. Hence, it is concluded that a change in how performance is measured must begin with changing how performance is perceived in order to be able to develop criteria that can be used in the design of performance measurements.

Chapter 8 is the first chapter in the prescriptive result part and it focuses on developing a general model for performance in an organization. This is based on the three dimensions of knowledge gap i.e. the new knowledge that should be created in order to achieve the objectives, effectiveness i.e. to what degree the objective matches the output, and efficiency i.e. what has been created divided by the resources consumed in order to create the output. These three dimensions are applied to a product strategy, project management, and development activity level in a product-development organization. Hence, it is possible to adopt a system perspective when analyzing and evaluating performance in the development of complex products.

The model described in Chapter 8, designated the Performance Reference Criteria Model (PCRM) and it is used in the development of a method for designing performance indicators (DPI). The DPI method can be used to develop leading indicators of performance by integrating and iterating performance criteria (what) and success factors (how) related to an overall performance objective. The focus is thus directed to what affects performance rather than how the result can be measured and performance indicators can then be derived accordingly. Chapter 9 presents the DPI method and the findings from verifying the method in a case study.

In Chapter 10, the final result chapter, a model, Products in Development (PiD), is introduced that enables customer value to be evaluated during the development of a new product. The PiD is a method used to bridge the gap between the value assessed in a business case before the development project is initiated and the outcome of the development project as determined after the product has been introduced to the market. A value perspective during the development can also be used to complement and thereby balance the current focus on time and cost.

The thesis is concluded with Chapter 11 and Chapter 12. The former includes a discussion and analysis of the overall findings and how they relate to the specific research questions. Chapter 12 presents the overall conclusions and the managerial implications of this research, as well as the implications for theory and future research.

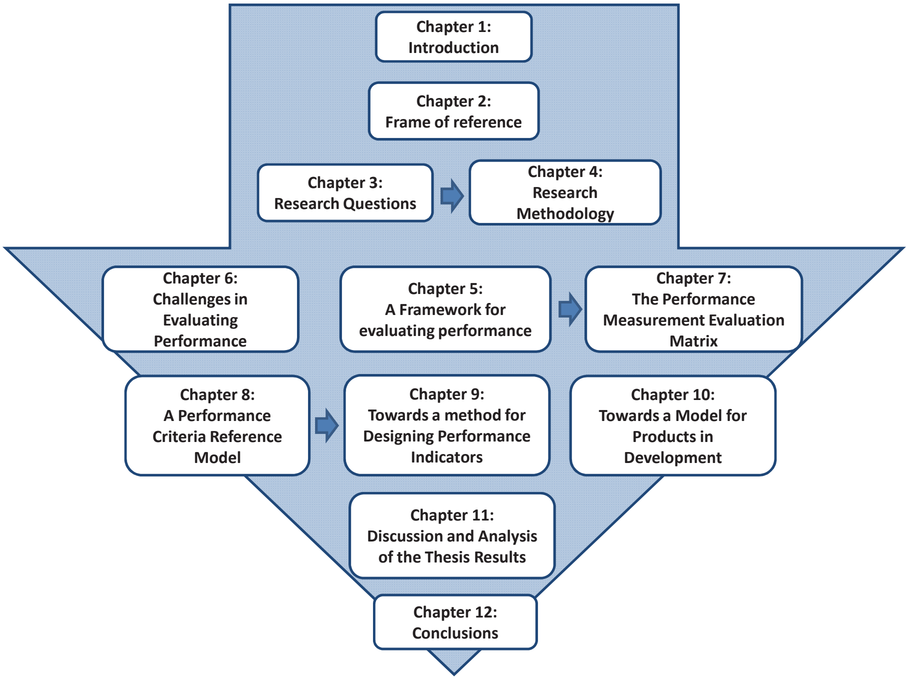

Figure 1. Thesis outline and dependencies of the chapters in the thesis.

Chapter 2 Frame of Reference

The aim of this chapter is to present an overview of the related literature and the research gaps identified in this research. It begins by defining and discussing product development, this being followed by a review of what performance is and how it is described in the literature. The chapter continues with an overview of success factors related to managing product development identified in the literature. A brief general overview of the literature relating to performance measurement is then given and how it is used to evaluate the product-development process. A discussion of issues and identified gaps in the current literature in relation to the objectives of this research concludes the chapter.

2.1 Developing Complex Products

It is generally acknowledged that bringing new products to the market is one of the most important issues in business research today (Hauser et al., 2006). It is important since it contributes to the economy by generating revenues and profits to a corporation, that otherwise would not have been generated (Annacchino, 2007). The ability to develop and deliver not only one but a steady stream of new successful products to the market is a prerequisite to becoming and remaining competitive for every product-delivering company.

The importance of product development in so many ways might be the reason why product development has attracted researchers from several research disciplines. Loch and Kavadias (2008) identify researchers within the field of economics, marketing, organizational theory, operations management, and strategy active in the field of product development. In a review of the literature focusing on product-development decisions, by Krishnan and Ulrich (2001), at least four common perspectives, i.e. marketing, organization, engineering design, and operations management, were identified. Similarly, Andreasen and Hein (1987) argue that marketing, design, and manufacturing should be considered to be the functions most central to product development. Software and systems engineering literature offers an alternative to this. Software and systems engineering is however seldom discussed in the literature of product-development management e.g. marketing and operations management. In the software engineering literature there are indications of the use of theories from e.g. the marketing and operations management literature at recent conferences and workshops such as the International workshop on software product management and the International Conference on Software Business.

2.1.1 Defining Product Development

One consequence of researchers from various field of research being engaged is the abundance of terms used in describing the development of a product. Examples include, but are not limited to, innovation, product innovation, product development, R&D, engineering design, and new product development. However, as Marxt and Hacklin (2005) point out, these terms have evolved and broadened into essentially meaning the same thing. In this research the term product development is adopted in a holistic manner, similar to what may be described as product innovation.

Definitions of Innovation

The term "innovation" originates from the Latin word *nova* meaning new. Innovation is related to the term invention that implies the creation of something new. However, the term invention differs from innovation in the sense that an invention is not required to add value to something or someone, as an innovation does. An invention is more the solution of a problem or an issue.

Burgelman et al. (2001) argue that an invention is the result of a creative idea or concept, while innovation is the process of turning the invention into a commercial success. Also, Saren (1984) defines innovation as the process by which an invention is first transformed into a new commercial product, process or service. It can be distinguished from both invention – the discovery of a new technique, and diffusion – the innovation's adoption or imitation.

An important aspect of innovation as is pointed out by Myers and Marquis (in Trott, 2008) is that innovation is not a single activity that can be isolated.

> Innovation is not a single action but a total process of interrelated sub processes. It is not just the conception of a new idea, nor the invention of a new device, nor the development of a new market. The process is all these things acting in an integrated fashion.

Innovation is not only something that is of interest to the academic community. The international company 3M, a recognized world leader within innovation, recently defined innovation as something closely connected to creativity. 3M emphasizes the close relation between innovation and creativity, according to:

> Creativity: the thinking of novel and appropriate ideas. Innovation: the successful implementation of those ideas within an organization.

Ideas and creativity are often mentioned as important ingredients of innovation. To be creative may be described as to look at an issue in a novel way and an idea can be described as a recipe for dealing with an issue. Hence, innovation may be expressed as the implementation of a creative idea and benefit from the result.

With these definitions of innovation in mind, the management of innovation demands different skills and principles than general management (Goffin and Mitchell, 2005). Trott (2008) concludes that innovation management includes all of the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product or manufacturing process or equipment. Trott (2008) further argues that if one accepts that inventions are new discoveries, new ways of doing things, and products are the eventual output from the inventions, then that process from new discovery to eventual product is the innovation process. This definition of innovation implies that product development is a part of the innovation process.

Definitions of Product Development

The term product development is often used without a proper definition. In an overall perspective product development may be self-explanatory i.e. the development of new products. However, product development is ambiguous in the sense of what is included in the process and what is not included. When does product development start and when does it end? Table 1 presents an overview of some definitions in the literature. It is interesting to note the evident similarities in the various definitions of innovation and product development.

Table 1. Overview of definitions of product development

Definition of product development	Reference
Product development is the transformation of a market opportunity into a product available for sale.	(Krishnan and Ulrich, 2001)
Product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.	(Ulrich and Eppinger, 2008)
Product development consists of the activities of the firm that lead to a stream of new or changed product market offering over time. This includes the generation of opportunities, their selection and transformation into artifacts (manufactured products) and activities (services) offered to customers, and the institutionalization of improvements in the new product development activities themselves.	(Loch and Kavadias, 2008)
The goal of the product-development process is to create a “recipe” for producing a product. The recipe must conform to the requirements stemming from customer or market needs. The recipe includes the product design, its constituent materials, its production process, and plans for its distribution, operation, support, and disposal. The product-development process consists of a myriad of activities working together to produce the recipe.	(Browning, 2003)
The effective organization and management of activities that enable an organization to bring successful products to the market, with short development times and low development costs.	(Wheelright and Clark, 1992)
Product development is a cross-functional team-intensive work that creates successful new products by linking upstream activities, e.g. R&D, marketing, and design engineering, with downstream activities, e.g. manufacturing engineering, operations and quality control.	(Hong et al., 2004)

The definition of product development by Ulrich and Eppinger (2008) has found broad acceptance within the research community. Our research acknowledges this definition and argues that from a performance evaluation perspective, it is important to have a holistic process interpretation of product development. The objective of product development may be expressed as the creation of a *recipe* for producing a product (Browning, 2003), with new or different characteristics, that offer new or additional benefits to the customer. Hence, such a recipe must conform to the requirements stemming from customer needs. A customer need is a description, in the customer's own words, of the benefits to be gained by a future product (Griffin and Hauser, 1993). Based on the identified needs a product requirement specification is developed aiming at satisfaction of the targeted needs. Hence, it is argued that when deciding which costumer needs are to be satisfied, the business case related to these needs is also decided on. The process of identifying customer needs is thus a key activity in the product-development process in order to develop successful products. It is therefore argued that the tools and methods used to perceive a market opportunity should also be included in the definition of product development. The identification of a market opportunity may not be easily identified but it is decisive for performance in product development. If the market opportunity is wrongly perceived, the result of product development cannot be economically successful, however effective the performance of the realization of the product. With this in mind the following definition of product development is proposed.

> Product development is the set of activities beginning with the processes and tools used to perceive a market opportunity and ending in the production, sale, and delivery of a product fulfilling that market opportunity.

This definition is an extension of the one provided by Ulrich and Eppinger, by including and emphasizing the importance of the processes and tools used in the early stages of the process when the scope of the development activities is determined. Traditionally, the product-development process is initiated when it is already decided what customer needs are to be satisfied, and the goal of the product-development process is to satisfy these predefined needs.

Based on the proposed definition, product development is to be considered successful if its products not only satisfy the needs and requirements of its customers, but also generate profits to its shareholders, and creates value to its stakeholder at large. Moreover, the proposed definition of product development implies a process, similar to innovation, which spans several different functions within a company, not only the engineering department as has traditionally been the case.

2.1.2 Product Development Models

The literature provides an abundance of different models for the development of new products. Saren (1984) categorized the models for developing new products, as:

1) Departmental-stage models – the process is divided into a series of stages associated with the departments of the firm;
2) Activity-stage models – the process is broken down into a series of activities in a sequence;
3) Decision-stage models – the process is broken down into a series of decision sequences;
4) Conversion process models – the transformation of inputs, such as raw materials, scientific knowledge and manpower, into outputs i.e. new products;
5) Response models – where the innovation is represented as the firm's "response" to some internal or external stimulus.

The departmental-stage models and activity-stage models are the categories most commonly presented and discussed in the textbook literature (Trott, 2008). However, the decision-stage models are interesting since they address one of the most important practical problems i.e. the number of options and the lack of information on which to base decisions during the development of new products.

A Generic Process Model of Product Development

The generic product-development process model, by Ulrich and Eppinger (2008), shown in Figure 2 includes six phases.

Figure 2. A generic process model for product development

The first phase *Planning* precedes the project approval and launch of the actual product-development project. A new product is often developed in a project setting and the output of the planning phase is the project mission statement, including targets for the product, business goals, key assumptions, and constraints. A project is defined by the Project Management Book of Knowledge (PMBOK, 2004) as a temporary endeavor undertaken to create a unique product, service, or result. Organizing the development of a product as a project is therefore suitable. The *Concept development* identifies the customer needs and different concepts satisfying them are developed and evaluated in this phase. *System level design* includes the definition of the product architecture and the decomposition of the product into subsystems and components. Once the system level design is completed the *Detailed design* begins, followed by the *Testing and refinement* phase. The generic product-development process is finalized with *Production ramp-up*, during which the production workforce is trained and remaining problems in the production process are solved. The product-development process thus described appears to be linear and straight forward; but within industry this process is often highly iterative and non-linear.

The Stage-Gate Model

The Stage-Gate model proposed by Cooper (1990) based on the Booz, Allen and Hamilton's model (BAH) establishes the main guidelines for analyzing the product-development process from a performance-evaluation point of view. It is both a conceptual and an operational model, intended to move a new product from the idea stage through to market launch and beyond (Jiménez-Zarco et al., 2006). The Stage-Gate model presents the product-development activities as a complex system that consists of two independent and parallel processes: the development process itself and the evaluation process (Jiménez-Zarco et al., 2006). Figure 3 shows the Stage-Gate model, consisting of a series of stages, in which the project team undertakes the work i.e. completes various activities to reduce business risks and advance the project to the subsequent gates, where go/kill decisions are made i.e. to whether or not to continue to invest in the project (Cooper, 2008). The focus during the gate decision procedures should be on three key issues: quality of execution, business rationale, and the quality of the action plan (Cooper, 2001). The development process according to the Stage-Gate model begins with an ideation stage, designated "discovery", and concludes with a post-launch review.

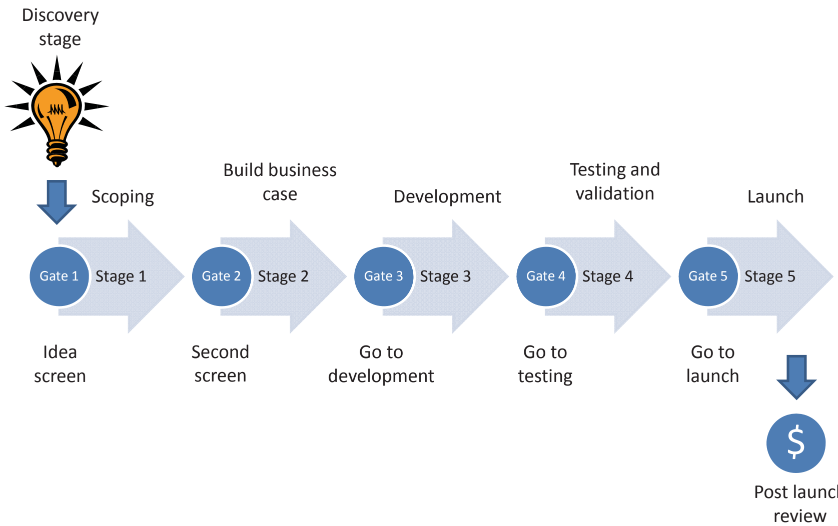

Figure 3. The Stage-Gate Model

The Stage-Gate model is one of few frameworks that analyze the development processes from a performance evaluation point of view (Jiménez-Zarco et al., 2006). The Stage-Gate model usually consists of four to eight stages and gates in a process modified by the company (Jiménez-Zarco et al., 2006). There is an adapted version of the Stage-Gate model in Figure 3 which aims at supporting technology-development activities (Cooper, 2006).

The Stage-Gate model differentiates between the early phases, often labeled "the fuzzy front end" (Verworn, 2008), of development, and the implementation/realization phases. Literature relating to the fuzzy front end is expanding (e.g. Koen et al., 2001; Reid and de Brentani, 2004; Russell and Tippett, 2008) and acceptance of the importance of the fuzzy front end is increasing. Reinertsen (1999b), who coined the term, argue that the fuzzy front end is often lengthy, poorly understood, and full of opportunities for improvement. Kim and Wilemon (2002) argue that effectively managing the fuzzy front end of the product-development process is one of the most important and difficult challenges facing managers.

The Stage-Gate model is one of the most widely used for managing product development. American best practice studies indicate that 74 per cent of the participating organizations use a Stage-Gate model or similar process during product development (Cooper et al., 2004c). The use of a formal process has increased to 79 per cent, while 15 per cent indicate they have an informal process and only 6 per cent report not having a process for product development (Barczak et al., 2009). Moreover, there are close similarities between the generic phases in the product-development process and the stages in the Stage-Gate model.

Lean Product Development

A popular methodology for managing the development of complex products in a system perspective is Lean Product Development, inspired by the Toyota Product System and partly transferred to product-development activities (Morgan and Liker, 2006). The concept of waste is however much more straightforward in a repetitive manufacturing operations than in the inherently non-repetitive activities of product development (Reinertsen, 1999a). There is also the basic difference in the development process not having a product, a physical object, as output, but rather information, which is the recipe for making products. Hence, Reinertsen (1999a) argues that value in product development is added by creating new and useful information. Waste is also different in product development as compared with the waste from the different sources identified by Womack et al. (1990). Further, Reinertsen (1999a) argues that "leanness" must be based on the overall business economics rather than only focusing on the expenses.

Front-loading the process means providing the projects with the right amount of resources to enable the development project members to investigate, understand, evaluate, and define the product system as precisely as possible during early development phases. Decision quality may be improved by allowing the project members to increase the amount of learning activities in early phases, and delaying decisions until the right amount of learning is achieved. In a “lean R&D system” the manager’s most important responsibility is to delay decisions until the last possible moment in order to maximize the time for learning of relevant issues (Ward et al., 1995). The last possible moment is calculated by e.g. backtracking when a cast die needs to be ordered from a sub-supplier, thereby defining when the final as well as the interim decisions of cast die design need to be made (Morgan, 2002). In product development, designs are also to be made on the lowest possible level in the organization to enable the people with the most knowledge of the product to make the most informed decisions possible.

Other Models of Product Development

Several further methods for organizing product development are described in the literature: concurrent engineering (e.g. Carlson-Skalak, 2002), integrated product development (e.g. Andreasen and Hein, 1987), etc. A central theme in these methods is collaboration. Within e.g. integrated product development, focus is on cross-functional teams, an aspect that is especially important for complex product development (Norell, 1992). In order to be successful, the product-development process must involve all of the functions in a company. The development of complex products which incorporate large numbers of components requires the management of interdependent systems of products to maintain an overall view, and to avoid sub-optimization (Malvius, 2007). Integrated product development requires the integration of work procedures, information management and support tools to permit the management of the complexity in an efficient and effective way (Norell, 1992). The emphasis on cross-functional product development reflects the general increase in complexity, no single individual possessing sufficient knowledge or skills for developing and maintaining increasingly complex products.

With this in mind it is argued that successful product development is fundamentally a multidisciplinary process. However, product-development teams typically need to include personnel from different functional areas that might be measured against different goals and performance requirements. This may potentially interfere with and even hinder high performance in product development. Hence, it is important to engage in a holistic view of performance in product development.

Product development was previously described as the developing of a recipe for a new product. Traditionally, the recipe created during the development includes the product design, its constituent materials, its production process, and plans for its distribution, operation, support, and disposal. This is particularly the case in the development of physical goods. However, in the context of developing complex products that include software, this view must be adapted since software development normally has a limited production stage.

2.1.3 What are the Key Gaps and Conclusions?

The key gaps and conclusion in the literature related to the development of complex products can be summarized as:

- The literature relating to the management of product development i.e. marketing and operations management, seldom focuses on the management of the development of complex products. Instead the focus is most often on the management of the development of general products of which complex products may be one part.
- There are several different interpretations of product development, especially during its early phases. There is general agreement on which activities are typically executed but the early phases before a development project is initiated are not necessarily included or only mentioned casually.
- There appears to be a mismatch between the definitions of product development and the development models used in practice. When defining product development, the importance of a market opportunity may be stressed. However, the concept of the fuzzy front end and the importance of front-loading are generally accepted in the literature but according to Reinertsen (1999b) poorly understood.
- There is evidence of an increasing use of formal product-development processes. However, only 44 per cent report their process to result in successful product development. This may be because the varied needs of the product-development process, e.g. the needs of formalization differ between the early and later phases of product development.

2.2 Performance in Product Development

In the literature there are several different ways of describing performance, but there are few commonly accepted definitions or terminology. Studies of the performance of product development often focus on the output and outcome of successful products (e.g. Cooper, 1990; Henard and Szymanski, 2001; Molina-Castillo and Munuera-Alemán, 2009; Montoya-Weiss and

Calantone, 1994). Still, in line with the argument of Tatikonda and Montoya-Weiss (2001), a distinction should be made between operational and product performance. Product performance relates to the financial and market performance of developed products. Operational performance relates to achieving project goals such as adherence to schedule, budget, and quality requirements. Traditionally, operational performance has been particularly related to the cost aspect and more recently the time perspective (Chen et al., 2010). O'Donnell and Duffy (2005) also point out that it is not only the development activities themselves that affect the performance of the product. The nature of the product may also influence the performance of the development activities e.g. the development of a more complex product may require more time (Griffin, 1997a).

2.2.1 The Notion of Performance in Product Development

Performance, in general, is a term commonly used but seldom defined (Neely et al., 2005). Hence it is not surprising that performance in product development is interpreted differently by different researchers. Expressions such as "increased performance" or "positive influence on performance" are commonly used but their explicit meanings tend to be ambiguous. O'Donnell and Duffy (2002b) even argue that the literature related to performance has hindered its development due to the lack of or inconsistency in the definition of terms. One possible explanation of this unsatisfactory situation is the exceedingly interdisciplinary nature of performance management research, involving many fields with varying states of maturity and methodological practice (Ermolayev and Matzke, 2007).

Table 2 presents an overview of various definitions of performance. The common way of defining performance is result-oriented, and does not indicate if, or not the performance is in line with expectations.

Table 2. Overview of definitions of performance related to product development

Definition of performance	Author
Performance is efficiency and effectiveness	(Säfsten et al., 2010)
The level to which a goal is attained.	(Dwight, 1999)
Efficiency and effectiveness of purposeful action	(Neely et al., 2005)
A complex inter-relationship between seven performance criteria: effectiveness, efficiency, quality, productivity, quality of work life, innovation, profitability/budgetability	(Rolstadas, 1998)
Performance is intentional action	(Ermolayev and Matzke, 2007)
Total product quality, lead time and productivity (level of resources used).	(Clark and Fujimoto, 1991)
Development time, development productivity (use of resources) and total design quality	(Emmanuelides, 1993)
Performance should be defined as an actual accomplishment, outcome, or a result.	(Harbour, 2009)

Performance is, when defined, often translated into effectiveness and efficiency as two separate dimensions of performance (e.g. Neely et al., 2005; Säfsten et al., 2010). Still, as argued by Tangen (2004) concepts such as effectiveness, efficiency, and performance are often misused and confused with each other. The terms efficiency and effectiveness are presented in more detail in Section 2.2.2 and 2.2.3.

In this research performance in product development is viewed in line with the arguments by Ermolayev and Matzke (2007) who suggest, on the basis of the etymology and the standard dictionary definitions of performance, that the term performance is derived from the root concept for intentional action. Hence, performance should be defined as intentional action. This definition of performance is valid under all circumstances and for all context-specific situations. Moreover, all other performance-related concepts should be defined as originating from this root concept. This is of central importance as the performance of something is always context-dependent. Also, not all actions are intentional. The notion of intentional action can be contrasted with accidental as well as with unintentional action. It may be difficult to distinguish between these in a measurement system in which the focus is often on the output or the outcome of an activity. In conclusion, what is required of people performing in product-development project activities is goal-directed adaptive behavior guided by overall objectives and current knowledge with the use of committed resources.

Another important dimension of performance, seldom used within product development, is productivity. Cooper and Edgett (2008) define productivity in product development as output, measured as new product sales or profits, divided by input, measured as development costs and time. One limitation to this way of defining productivity is that it reports the productivity as it was one or several years ago and will remain a lagging indicator of the performance of the product-development activities. This is due to the difficulty of measuring the output of product development, an issue since the middle of the sixties (Szakonyi, 1994). Within manufacturing, productivity is one of the most frequently used measures of performance. One reason may be that the output from the manufacturing process is more tangible and directly converted into revenues. Also, since the concept of product-development productivity is relatively new, there are few hard numbers on results achieved in industry. A recent best-practice study reveals that very few companies measure or report their product-development productivity as a business metric (Cooper et al., 2004a; Cooper et al., 2004b; Cooper et al., 2004c).

2.2.2 Product Development Effectiveness

In the Oxford dictionary effectiveness is about producing the result that is wanted or intended (Wehmeier et al., 2005). Sink and Tuttle (1989) describe effectiveness as doing the right things at the right time, with the right quality. Neely et al. (2005) argue that effectiveness refers to the extent to which customer requirements are being met. In keeping with this definition, product-development effectiveness may be conceptualized as the degree to which the firm's objectives related to the desired product-development outcomes are met. This could be in terms of e.g. generation of new innovation projects and new patents, production of relevant scientific knowledge, the acquisition of a reputation for scientific results, and the ability to attract and recruit outstanding human capital. Table 3 presents an overview of definitions of effectiveness.

Table 3. Overview of definitions of effectiveness

Definition of effectiveness	Author
An effective product-development procedure can meet the demands on quality, time-to-delivery and cost limitations of a corporation.	(Jou et al., 2010)
Effectiveness refers to the extent to which customer requirements are being met.	(Neely et al., 2005)
Effectiveness is related to the attainment of objectives or goals.	(O'Donnell and Duffy, 2002b)
Effectiveness which involves doing the right things, at the right time, with the right quality etc, can be defined as the ratio between actual output and expected output.	(Sink and Tuttle, 1989)
Effectiveness is the degree of accomplished of objectives, and shows how well a set of results are accomplished.	(Sumanth, 1994)
Effectiveness in manufacturing can be viewed as to what extent the cost is used to create revenues.	(Jackson, 2000)
Effectiveness refers to what extent the actual result (output in quality and quantity) corresponds to the aimed result.	(van Ree, 2002)
Effectiveness is the degree to which a predetermined objective is met.	(Ojanen and Tuominen, 2002)

2.2.3 Product Development Efficiency

In the Oxford dictionary efficiency is used to describe the ratio of the amount of energy supplied to a system and the amount it produces (Wehmeier et al., 2005). It can also be used to mean skillfulness in avoiding wasted time and effort. Neely et al. (2005) describe efficiency as a measure of how economically a firm’s resources are being utilized, providing a given level of customer satisfaction. Efficiency is similarly described as doing things right, often expressed as a ratio between resources expected to be consumed and resources actually consumed (Sink and Tuttle, 1989). However, this definition of efficiency seems to be more of an efficiency aspect of the planned activities and the predictability of the organization, not of the product-development process. Table 4 presents an overview of various definitions of efficiency.

Table 4. Overview of definitions of efficiency

Definition of efficiency	Author
Efficiency measurements involves evaluating resources to determine whether minimum amounts are used in the making of these outputs	(Cordero, 1990)
Efficiency is a measure of how economically a firm's resources are being utilized, providing a given level of customer satisfaction.	(Neely et al., 2005)
Efficiency is seen to relate to the use of resources.	(O'Donnell and Duffy, 2002b)
Efficiency is an input and transformation process question, defined as the ratio between resources expected to be consumed and actually consumed.	(Sink and Tuttle, 1989)
Efficiency is the ratio of actual output attained to standard output expected, and reflects how well the resources are utilized to accomplish the result.	(Sumanth, 1994)
Efficiency means how much cost is spent compared to the minimum cost level that is theoretical required to run the desired operations in a given system.	(Jackson, 2000)
Efficiency refers to the ratio between aimed resources use and the actual resources use in order to transform an input to an output	(van Ree, 2002)
Efficiency is the degree to which inputs are used in relation to a given level of outputs.	(Ojanen and Tuominen, 2002)

2.2.4 Relationship between Efficiency and Effectiveness

Most definitions in Table 3 and Table 4 define efficiency and effectiveness in a manner that does not support the evaluation of the two performance dimensions. In an attempt to clarify the confusion in terminology used to describe performance, O'Donnell & Duffy (2002b) developed a performance model, based on the IDEF0 framework (Colquhoun et al., 1993). A general model of an activity according to the IDEF0 framework is shown in Figure 4. An activity uses resources to transform an input to an output under the direction of goals and/or constraints. The input refers to the initial state of knowledge prior to the activity, while the output is the final state of the performed activity. The resources represent not just the people involved in the activity but also other resources utilized e.g. computer tools, materials, techniques, and information sources. Goals and/or constraints are specific elements of knowledge that direct the change in the state of the activity from the initial input to the final output state.

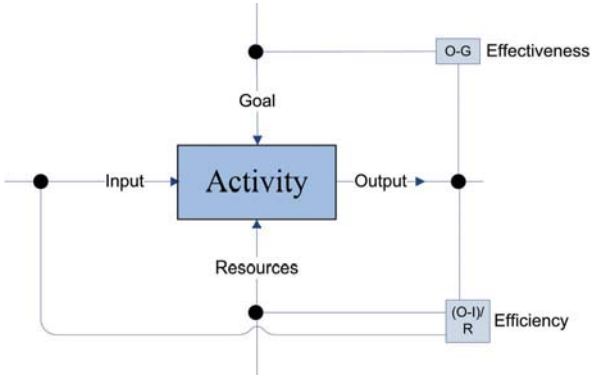

Figure 4. Efficiency and effectiveness of an activity

O'Donnell & Duffy (2002b) use this activity model to define effectiveness and efficiency, as shown in Figure 4. Effectiveness is defined as how the output meets the goal, i.e. was the intended output created? Efficiency is defined as the difference between the output and the input, divided by the resources consumed by the activity i.e. the cost of performing the activity. Efficiency is often expressed as a ratio, hence often simpler to measure than effectiveness, whether it is based on time, money or any other dimension.

The product-development process depends on both efficiency and effectiveness in the performed activities in order to be successful. Although the best-performing organizations are both effective and efficient (Katz and Kahn, 1978), there may be trade-offs between the two (Mahoney, 1988). Progression along one performance dimension could entail regression along another. Thus, an organization can be effective, efficient, both, or neither.

2.2.5 What are the Key Gaps and Conclusions?

The key gaps and conclusions in the literature related to performance in product development can be summarized as:

- The confusion in the terminology related to performance is an obstacle that all measurement practitioners must deal with.
- Performance is an ambiguous concept and always context-dependent. Hence, it is important that there are methods and tools that managers and decision makers can use in order to develop an understanding of performance in their own context. However, there is little support in the literature, one exception being the framework developed by O'Donnell and Duffy (2002b) based on the IDEF0 model of an activity.
- The literature presents several different initiatives for describing performance, but there is no commonly accepted definition or terminology. In this research effectiveness and efficiency, as defined in Figure 4, are used as two dimensions of performance.

- It is important to distinguish between operational performance and product performance. In this research the focus is on operational performance that will lead to product performance. Since, performance is viewed as intentional action, unintentional product performance that is the result of accidental circumstances is not to be considered high performance.

2.3 Success Factors in Product Development

The idea of having a limited set of factors that affect the performance of the development of new products is appealing for both practitioners and researchers. As a result, a considerable amount of empirical research on the determinants of new product-development performance is reported in the literature (Ernst, 2002; Montoya-Weiss and Calantone, 1994). No prescribed common criterion can, however, explain how successful new products are created (Poolton and Barclay, 1998).

The SAPPHO project (Rothwell et al., 1974), was the first effort to analytically compare commercially successful and unsuccessful products in the same market (Abdel-Kader and Lin, 2009). The conclusions from this project are that successful companies have a much better understanding of customer needs, attend more to marketing and advertising, perform product development more effectively, encourage more use of outside expertise, and authorize and promote responsible and experienced professional employees to senior management levels. Abdel-Kader and Lin (2009) summarize the conclusions of the SAPPHO projects as:

> Professional employees and good management skills are the key to success.

Tang et al. (2005) identified a distinct set of success factors for product development: *Leadership, Organizational culture, Human resources, Information, Product strategy, Project execution, Product delivery, and Results*. Leadership involves key characteristics of the project manager, the power delegated, and whether there is a clear strategic direction for the development project. The Organizational culture involves the extent to which management takes advantage of the established values of the personnel to improve project output. Human resources involve management's actions to improve the skills and the work environment. Information is concerned with the treatment of information as a valuable asset, its quality, and whether it is systematically collected, shared, and analyzed. Product strategy includes the product planning processes and the extent to which they promote readiness for implementation and product delivery. Project execution involves key issues of the product development process e.g. stage 3 and 4 in Figure 3. Product delivery considers to what extent manufacturing, sales, service and support are considered; or whether the product is just “tossed over the wall” when developed. Results evaluate the project from multiple dimensions such as financial and market, customer satisfaction and loyalty, organizational effectiveness, product results, and benchmarking.

In a thorough review of critical success factors by Ernst (2002), the following categorization, as previously developed by Cooper and Kleinschmidt (2007), was adopted: *Customer integration*, *Organization*, *Culture*, *Role and commitment of senior management* and *Strategy*. Adams et al. (2006) present another review drawing on a wide body of the product innovation literature, and identified the following seven categories as important in the product innovation process: *Inputs management*, *Knowledge management*, *Innovation strategy*, *Organizational culture and structure*, *Portfolio management*, *Project management*, and *Commercialization*. Further, Bessant and Tidd (2007) argue for the following success factors in product innovation: *Market knowledge*, *Clear product definition*, *Product advantage*, *Project organization*, *Top management support*, *Risk assessment*, *Proficiency in execution*, and *Project resources*. Product advantage involves product superiority in the eyes of the customer e.g. delivering unique benefits to the user and a high performance-to-cost ratio. Market knowledge, i.e. assessment and understanding of customer and user needs, is critical. A clear product definition, defining target markets, clear concept definition and benefits to be delivered must be determined before the development activities begin. Holistic risk assessment including market-based, technological, manufacturing and design sources must be built into the business and feasibility studies. The use of cross-functional multidisciplinary teams carrying responsibilities is important within the *Project organization* from beginning to end. *Project resources* include financing, human skills, and material resources; the firm must possess the right skills to manage and develop the new product. *Proficiency in execution* includes all the activities of the product innovation process. *Top management support* is important through the complete product innovation process from concept to launch.

In a meta-review, by Chen et al. (2010), of the success factor literature especially focusing on decreasing the development cycle time, the success factors were grouped into process, project, team, and strategy. Table 5 presents an overview of the success factors identified as important for product-development speed. Chen et al. (2010) further argue, on the basis of their findings, that process and team characteristics are more generalizable and cross-situational consistent determinants of product-development speed than strategy and project characteristics. This review differs from other reviews in the sense that it is focused on the time dimension, not the cost or product success as is most usual (e.g. Molina-Castillo and Munuera-Alemán, 2009). Few meta-studies focus on the time perspective as an aspect of product-development performance. One exception is the review by Gerwin and Barrowman (2002). The early but very influential review by Montoya-

Weiss and Calantone (1994) found that certain factors related to strategy and the development process are most strongly linked to performance in product development.

Table 5. Success factors in product-development speed.

Success factor	Definition
Top management support	Senior management's favorable attitude and commitment to product-development initiatives.
Goal clarity	The extent to which a product-development project's vision, mission, goals, and definition are clearly identified and communicated.
Process formalization	The use of explicit rules and standard procedures in the product-development process.
Process concurrency	The extent to which stages of the product-development process overlap or are conducted concurrently.
Iteration	The process of building and testing a prototype in a product-development initiative.
Learning	The process through which a project team gains or creates knowledge in performing product-development activities.
Team leadership	The degree to which a project's leader possesses skills, knowledge, and experience relevant to both management and technical aspects of the project.
Team experience	The degree to which team members possess experiences, knowledge, and skills.
Team dedication	The degree to which team members dedicate themselves to a product-development initiative.
Internal integration	The degree of cooperation among multiple functions and interaction among team members in a product-development initiative.
External integration	The involvement of external partners like suppliers and customers in a new product initiative.
Team empowerment	The decision-making autonomy of the project team

In the review by Henard and Szymanski (2001) they conclude that out of the 24 determinants of product-development performance only five, i.e. product advantage, market potential, meeting customer needs, predevelopment task proficiencies and dedicated resources, are salient determinants of product-development performance.

In another meta-review, Pattikwa et al. (2006) found that 15 out of the 34 antecedents are cross-situationally consistent, suggesting a more stable relationship between determinants and product-development performance across original studies than the review by Henard and Szymanski. Further, Chen et al. (2010) suggest that the difference between the results of these reviews is partly dependent on the different methods applied in the review procedure. Finally in the review by Gerwin and Barrowman (2002), two process factors were found to be significant determinants of product performance, while product definition and organizational contexts are not. The factors related to process are overlap and integration tools, and formal methods, and the two team factors are cross-functional team and team head's influence.

2.3.1 What are the Key Gaps and Conclusions?

The key gaps and conclusions in the literature related to success factors in product development can be summarized as:

- Most of the success factors are rather obvious from a practitioner's point of view since they are specified on a general level. The larger issue is rather how to fulfil them in a successful way.
- All the success factor studies focus on general product development rather than specifically on the development of complex products. This may explain why the success factors are general in terms. For example senior management support could be accomplished in several different ways. From a performance evaluation perspective it is not the case of having or not having the success factor, it is rather several degrees or maturity levels for how senior management support have a positive influence on performance in product development. It is also argued that the need for senior management support may vary depending on the context.
- All the success factor studies translate performance into one measurable dimension such as time or cost. There seem to be no studies combining two or several dimensions of performance.

2.4 Performance Measurements in Product Development

Performance measurements have inspired numerous researchers with functional backgrounds as varied as accounting, operations management, marketing, finance, economics, psychology, and sociology, all actively working in the field (Neely, 2007). This may explain why the common body of knowledge within performance measurements in product development is small, despite the results of a vast amount of research being available. In a recent review of the performance-measurement literature by Taticchi et al. (2010), conclude that four authors within performance measurements are the leading scholars within the field: Kaplan (management accounting), Neely (operations management), Banker (accounting/operations research and information systems), and Charnes (mathematics/operations research). All of the four leading authors have somewhat different disciplinary backgrounds.

Neely (2005) concludes, based on a review of the publications within the performance-measurements literature, that performance measurement is not and can never be a field of academic study because of its diversity. In a response to this the same author set out to create a common body of knowledge by editing Business Performance Measurement (Neely, 2007). The focus in this common body of knowledge is on the marketing, operations management, management accounting, and supply-chain management functions. Unfortunately, an explicit focus on product development is missing. Jiménez-Zarco et al. (2006) argue that there are few studies that have analyzed the product-development process from a performance-measurement system perspective.

At the same time, there are several reports of companies struggling with the issue of evaluating performance in product development (e.g. Kerssens-van Drongelen and Cook, 1997). In a survey by the Boston Consultancy Group only 35 per cent of senior managers were reported to be satisfied with the system in current use for measuring performance in product development (Andrew et al., 2008).

2.4.1 Key Terms Defined

Performance measurement can be defined as the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to be derived from the action by its management (Slack et al., 2007). Sinclair and Zairi (1995) argue that performance measurement is the determination of how successful an organization has been in attaining its objectives, whereas performance measures are the numerical or quantitative indicators that show how well each objective is being met. Korpela et al. (2006) point out that the very notion of corporate success is derived from a company’s performance, which in turn is a reflection of its decision-making in relation to its strategic objectives, markets and whole range of internal and external circumstances. Thereby, one can argue that performance measurements really are critical for an organization’s success.

Kerssens-van Drongelen et al. (2000) interpret performance measurement as the part of the control process that has to do with the acquisition and analysis of information about the actual attainment of a company objectives and plans, and about factors that may influence plan realization. This is in line with the argument by Merchant and Van der Stede (2007), that performance measurement belong to the more general function of management control systems that exists in order to increase the likelihood of achieving the objectives set by the organisation. Usually the control system is viewed as having two basic functions; *strategic control*, determining if or not our strategy is valid, and *management control*, ensuring that our employees are likely to behave in order to realize the strategy (Merchant and Van der Stede, 2007).

Melnyk et al. (2004) define a metric as a verifiable measure, stated in either quantitative or qualitative terms and defined with respect to a specific reference point. In order to be effective, metrics need to be understood and make sense to the person using the metrics. Kerssens-van Drongelen et al. (2000) argue that it is important to differ between metrics and a measurement method, since a metric can be measured in many different ways. A typical example is the customer satisfaction with a new product that can be measured by an index of items in a customer questionnaire, or by counting the recorded number of customer complaints etc. Hence, it is important to distinguish between the advantages of different methods and the various metrics that can be measured by using these methods.

Performance Measurement Method Taxonomy

The literature contains several attempts to categorize performance measurements. One classical classification is to divide them into quantitative and qualitative measurements depending on the data gathered. For example computational methods clearly lead to a quantitative value e.g. time to market has been six months, whereas assessment methods usually result in a qualitative indication of the metric value e.g. time to market has been “good” or “unsatisfactory” (Kerssens-van Drongelen et al., 2000). In practice, quantitative measurements tend to focus on what can be quantified not necessarily what is important (Steele, 1988).

Historically, performance measurements have been financially oriented, hence quantitative in nature. Eccles (1991) argues that there has been a revolution within performance measurements. At the heart of this performance-measurement revolution lies a radical decision: to shift from treating financial figures as the foundation for performance measurement, to treat them as one among a broader set of measures. Dividing the performance measurements into financial and non-financial is common within the management accounting literature (Kaplan and Atkinson, 1998). The problem with this taxonomy, especially for product development, is that the cluster of non-financial measures is still very large (Kerssens-van Drongelen et al., 2000).

Chiesa and Frattini (2007), propose further to divide the quantitative measurements into objective and subjective indicators. Quantitative objective indicators are numeric metrics obtained from the application of a definite algorithm, i.e. bringing the same evaluation independently from the person responsible for the measurement e.g. percentage of projects concluded on time, number of citations of company's researchers publications. Quantitative subjective indicators are numeric metrics based on the personal judgment of an expert, whose subjective evaluation is translated into a numeric score through alternative techniques. Finally, qualitative subjective metrics are not expressed numerically, but through the personal judgment of the evaluator.

Another classification of performance measurements is lagging or result oriented measurements and leading or process oriented measurements. Lagging or result oriented measurements tell an organization where it stands in its efforts to achieve goals but not how it got there, or even more important, what it should do differently (Meyer, 1994). Leading or process measurements monitor the tasks and activities throughout an organization that produce a given result (Meyer, 1994). Such measurements are essential for cross-functional teams that are responsible for processes that deliver an entire service or product to a customer, such as the product-development process (Meyer, 1994). Leading indicators include measurements affecting the process, while lagging indicators measure the result of already performed actions. Parmenter (2010) argues for a more practical approach by dividing performance measurements into four categorize:

1) Key result indicators - tell you how you have done
2) Result indicators - tell you what you have done
3) Performance indicators - tell you what to do
4) Key performance indicators tell you what to do to increase performance dramatically

Further, Parmenter (2010) concludes that it is easy to convert a key performance indicator into a result indicator by simply expressing it in financial terms.

2.4.2 Why Measure Performance in Product Development?

There are several reasons why it is important to measure performance in product development. In general, performance measurements are important because they affect people's behavior. "What gets measured gets done" (Peters, 2002), and "You are what you measure" (Hauser and Katz, 1998), are two well know citations within the performance-measurement literature.

Hauser and Katz (1998) argue that performance measurements, whether they are used explicitly to influence behaviour, to evaluate future strategies, or simply to take stock, will affect actions and decisions. Thus it is important as argued by Loch and Tapper (2002) to adopt performance measurement that encourages behavior that will achieve the goals of the organization. They operationalize this purpose into:

1) Alignment and prioritization: cascading measures from strategy
2) Evaluation and incentives
3) Operational control
4) Learning and improvement

Davila et al. (2006) argue that for a product-development process to be successful, it must be possible to measure its performance. Measuring the performance of the product-development process is especially important for managers and decision makers in order to answer fundamental managerial questions such as "how well are we doing", "what have we learned" and "what should we do in the future" (Tatikonda, 2008).

Sink and Tuttle (1989) argue that the main focus of the performance-measurement system is to provide managers with the information needed to be able to make decisions about the actions to be taken in order to improve the performance of the organization. In a review of the literature, Chiesa et al. (2009b) identified several objectives of companies evaluating performance in R&D. Performance evaluation is required for:

1) Diagnosis activity for supporting decision making, for monitoring the progress of projects along the critical dimensions of time and costs, and for evaluating their profitability.
2) Motivating personnel, aiming at tailoring people's behaviour to the firm's overall objectives.
3) Enhancing communication and coordination by providing useful information in order to facilitate people's interaction and enhance knowledge sharing.
4) Learning i.e. an improvement in the knowledge of the R&D activities and of the external technological and market context.

5) Reducing risks and uncertainty by providing useful and systematic information. This has the potential to reduce both technical and commercial uncertainty.
6) Improving R&D performance by focusing on the efficiency with which individuals or organisational units perform specific tasks or accomplish specific goals.

Sink and Tuttle (1989) stress that measurement, when done properly i.e. when linked to a purpose or goal that managers and employees have accepted, can drive and motivate performance improvement. Similarly, Lynch and Cross (1991) argue that the purpose of performance measurement is to motivate behaviour leading to continuous improvement in customer satisfaction, flexibility, and productivity. In this research, the focus is on measurement supporting managers and decision makers involved in product-development activities in their work of improving the performance of the development process.

2.4.3 Important Characteristics of Performance Measurement Systems

It has long been recognized that performance measurement has an important role to play in the efficient and effective management of organizations (Kennerley and Neely, 2002). This illustrates an important fact: measurement alone is not a direct value-adding activity; value is added when the result of the performance-measurement system is actively and adequately used by management and decision-makers. However, although new product-development projects are inherently multidisciplinary, studies of development projects typically adopt a singular functional perspective of performance (Tatikonda and Montoya-Weiss, 2001). If this is the case, supporting integrated product development is not especially important for the development of complex products.

The basic function of any performance-measurement system lies in its integration into operative processes and in its integration into operative processes and in its actual use in prompting improvements leading to improved performance in the area targeted (Godener and Soderquist, 2004).

The Important Link to Strategy

The need for companies to align their performance-measurement systems with their strategic goals is well documented in the literature (e.g. Amaratunga and Baldry, 2002; Gregory, 1993; Eccles, 1991). Some authors even argue that performance measurements can enhance the strategic management process (Bourne et al., 2000). Kennerley and Neely (2002) have identified the need for effective deployment of business objectives down through the organization and the subsequent measurement of performance in critical areas, as key elements of sustainable competitive advantage. There are certainly many success stories in aligning corporate strategy with performance measures (Bourne and Wilcox, 1998), but there is also a growing literature addressing the difficulties of implementing performance measurement initiatives, e.g. (Bourne et al., 2003; Neely and Bourne, 2000).

However, recent studies suggest that managers do not adjust their performance-measurement system to support changes in strategy (Johnston and Pongatichat, 2008). One possible explanation is that there are few papers describing how to design performance measurements according to the contextual needs of the organization.

The Importance of Management Learning

Neely and Najjar (2006) argue that the true role of performance measurement is for management learning not management control. Learning is viewed in this research as an improvement in the knowledge of the organization's internal product-development activities as well as the external technological and market context. Performance measurement is conceived here as an instrument for gathering systematic information and therefore as a means to stimulate learning. Since the output of product development is difficult to quantify, the focus should instead be on learning where the organization stands and how it might improve (Szakonyi, 1994). With all those perspectives in mind it is important, as Neely (2000) points out, to have a holistic systems perspective in the performance evaluation.

The Importance of Performance Criteria

Although measurements is both fundamental and critical to success in product development (Davila et al., 2006), performance measurement in product development is still nascent (Tatikonda, 2008). In an extensive review of measurements within innovation by Adams et al. (2006) it was concluded that there exists a plethora of extant measures, obviating the need for the development of new measures. However, there are few performance-measurement design processes that specifically focus on developing performance criteria, before the performance measurements are decided on. Hence, there is a risk that the role of measurement makes the measurements important themselves; rather than focusing on what is important to measure, focus is on what is measurable. This is not an ideal situation since an effective performance-measurement system needs to iteratively deal with both performance criteria and performance indicators (Gharajedaghi, 2006), as illustrated in Figure 5.

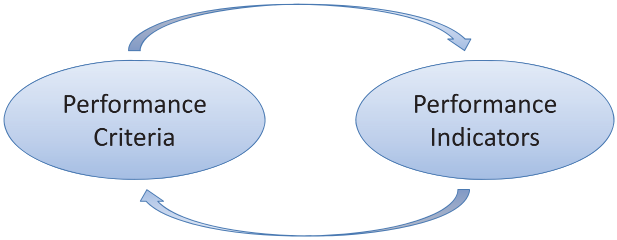

Figure 5. An effective performance-measurement system needs to iteratively deal with both performance criteria and performance indicators

2.4.4 Performance Measurements Frameworks

Several performance-measurement frameworks exist in the literature. There are several different perspectives from which a measurement can be analyzed. Tatikonda (2008) proposed a framework for performance measurements as presented in Figure 6.

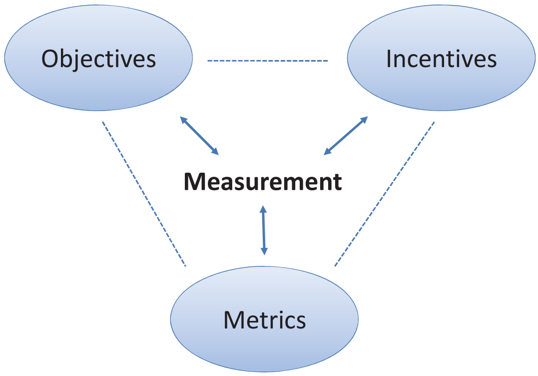

Figure 6. A performance-measurement framework

It implies that a measurement can be analyzed according to the objectives, how it is measured (i.e. the metric) or if there are any incentives related to the result of the measurement. The literature stresses the importance of performance measurements compatible with the objective of the measurement and the contingency factors (Kerssens-van Drongelen and Cook, 1997). When measurements are discussed it is important to clarify which perspective is used.

One early framework is the *Performance Measurement Matrix* proposed by Keegan et al. (1989), that categorize measures as being cost or non-cost, and internal or external. This early framework is one of the first more widely spread frameworks to reflect on the need for a more balanced performance-measurement system (Neely et al., 2007). Another framework is of the Strategic Measurement And Reporting Technique (SMART) pyramid, that supports the need to include internally and externally focused measurements of performance (Lynch and Cross, 1991). In the SMART pyramid the objectives and measurements can be viewed from three directions (Ojanen and Tuominen, 2002). First, are the objectives related to internal or external effectiveness of operation? Second, are the objectives set for the department, process, workgroup or individual and third, to which entity do the objectives belong? The SMART pyramid is shown in Figure 7.

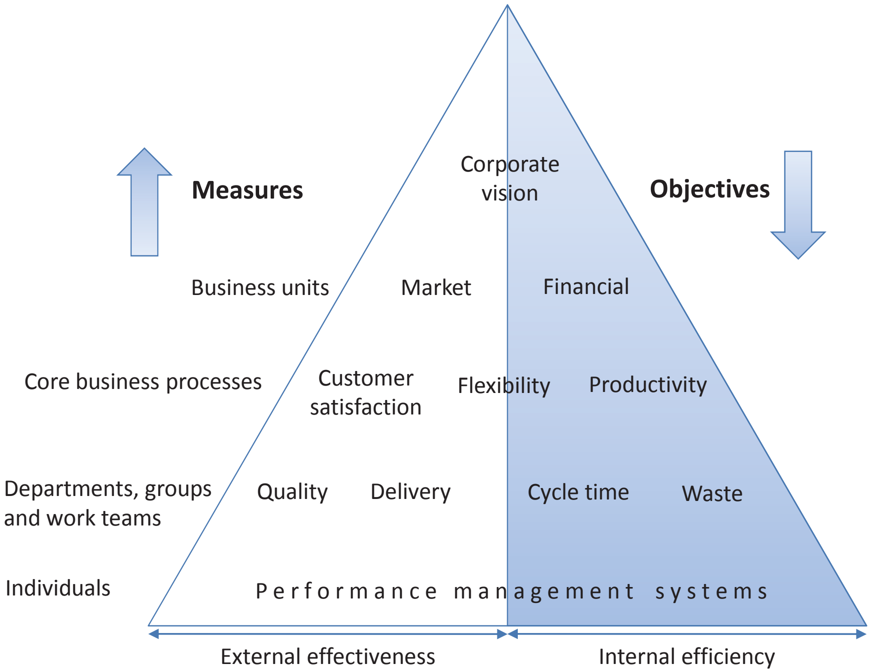

Figure 7. The SMART pyramid

One of the first performance-measurement frameworks to reflect on the cause and effect relationship is the result-determinants framework proposed by Fitzgerald et al. (1991). In this framework measurements were classified into results e.g. competitiveness or financial performance and those relating to determinants of those results e.g. innovation, quality, or flexibility. This concept of linking measurements to cause and effect relationships was further developed by Brown (1996) in the *Input-Process-Output-Outcome framework*, shown in Figure 8.

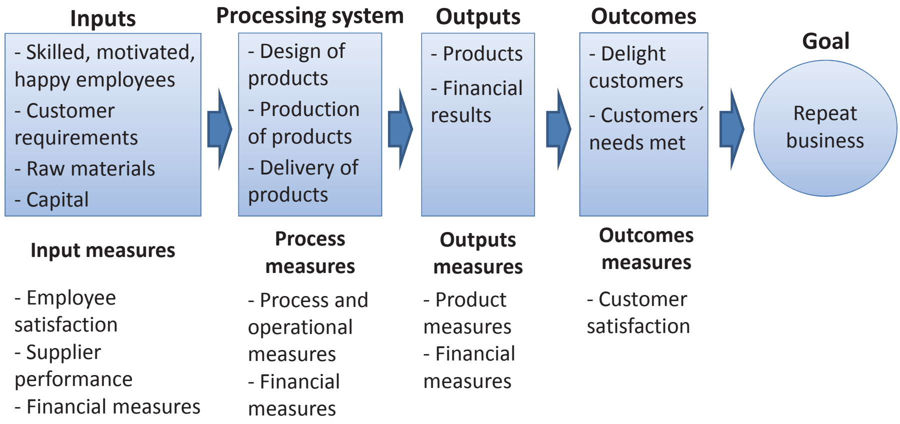

Figure 8. The Input-Process-Outputs-Outcomes framework

Brown's framework assumes a linear set of relationships between inputs, processes, outputs, outcomes and goals, with each previous factor determining the next. The distinction between output and outcome measures has proved particularly popular in the public sector (Neely et al., 2007).

The Balanced Scorecard

The most widespread and cited performance-measurement system is the Balanced Scorecard (Neely, 2005; Paranjape et al., 2006), introduced by Kaplan and Norton (1992). The Balanced Scorecard, presented in Figure 9, identifies and integrates four perspectives of performance: financial, customer, internal business, and innovation and learning (Pun and White, 2005).

Financial measurements alone cannot adequately reflect factors such as quality, customer satisfaction, and employee motivation (Driva et al., 2001). This was the reason behind the development of the Balanced Scorecard, to balance the financial perspective with the perspective of customers, learning and growth, and internal business processes. Balanced measurements are designed to provide a balance by including measures of external success as well as internal performance, together with measurements designed to give an early indication of future business performance as well as a record of what has been achieved in the past (Bourne et al., 2000). It is argued that financial performance, its drivers, customer and internal operation performance, and the drivers of ongoing improvement and future performance should be given equal weighting. In practice however it is difficult to achieve this balance and often the financial perspective given more weight at the expense of the other perspectives.

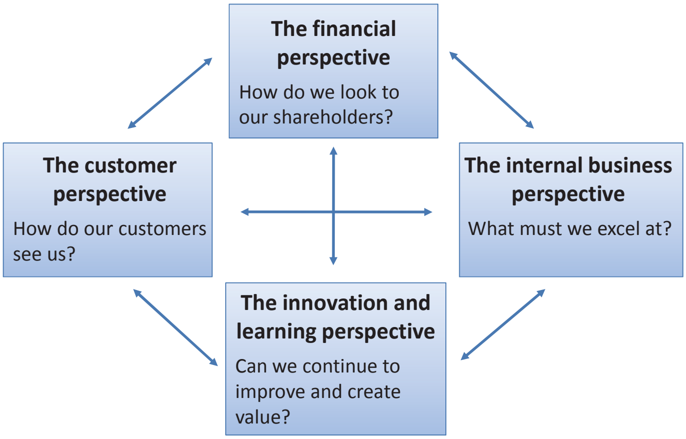

Figure 9. The Balanced Scorecard

The Balanced Scorecard still prevails as the dominant performance-measurement system (Paranjape et al., 2006). By the year 2001 the Balanced Scorecard had been adopted by 44 per cent of organizations worldwide (Neely, 2007). However, successful implementations of the Balance Scorecard are much less prevalent and translating the Balanced Scorecard into concrete action is still problematic. Bremser and Barsky (2004) present a framework to integrate the Balanced Scorecard in R&D management. The Balanced Scorecard has, however, not had the same success within the product-development process as it has within other business processes. One reason for this, as argued by Neufeld et al. (2001), is that performance-measurement frameworks such as the balanced scorecard are too general for reporting to senior product-development managers.

The Performance Prism

Another framework is the Performance Prism (Neely et al., 2001) which emphasizes a more holistic approach to the stakeholder perspective of performance measurements than the Balanced Scorecard. In the Performance Prism the performance-measurement system is organized around five distinct but linked perspectives of performance:

1. *Stakeholder satisfaction* – Which are the stakeholders and what do they want and need? The stakeholder perspective is to be interpreted in a broad sense including investors, customers, employees, regulators, suppliers etc.
2. *Strategies* – What are the strategies we require to satisfy the wants and needs of our stakeholders?
3. *Processes* – What are the processes we have to put in place in order to allow our strategies to be delivered?
4. *Capabilities* – What are the capabilities we require to operate our processes?

5. *Stakeholder contributions* – What do we want and need from stakeholders to maintain and develop those capabilities?

The Performance Prism has a more comprehensive view of different stakeholders than other frameworks. Neely et al. (2001) argue that the common belief that performance measurements should be strictly derived from strategy is incorrect. It is the wants and needs of different stakeholders that must be considered before the strategies can be formulated. One of the strengths of this conceptual framework is that it questions a company's existing strategy before the process of selecting measurements is started. In this way, the Performance Prism ensures that the performance measurements have a strong foundation.

The Earned Value Methodology

The earned value methodology is commonly used within the project management literature to evaluate the performance of project as it moves from project initiation to project closure (PMI, 2004). Earned value analysis is a project monitoring method that combines the schedule performance index with the cost performance index to address questions such as "how much value did we get from the effort we spent?" (Ebert and Dumke, 2007). It is used to measure work accomplished, to quantify the impact of known issues and to use this data to forecast estimates at completion. However, the earned value is not based on customer value. It is more of earned cost, since the activities are valued according to the planned cost of producing the result. Also, without a measure of the quality and value of these outputs, as well as the quantity, the measurement system will drive the wrong behavior. As Brown and Svensson (1988) point out, an R&D organization can be extremely productive when measured by the quantity of outputs produced, but still not do much to further the organization's business goals.

2.4.5 Measuring Performance in Product Development

Research within performance measurements in product development is still in its infancy, but researchers and practitioners are beginning to understand the criticality of an effective performance-measurement system to overall product-development effectiveness (Tatikonda, 2008). In general, few performance-measurement systems, except the Balanced Scorecard, have had any wide spread acceptance in practice. This is even more evident within product development, since not even the Balance Scorecard has reached any wide acceptance. However, there are some performance-measurement frameworks that have been developed with product development in mind.

One of the most cited frameworks in the literature is the performance measurement categorization by Griffin and Page (1996) shown in Figure 10. This categorization consists of customer acceptance, financial success, product and project success, and firm level success. This categorization illustrates that measurements are heavily lagging or result oriented and the perspectives of process or leading indicators are missing.

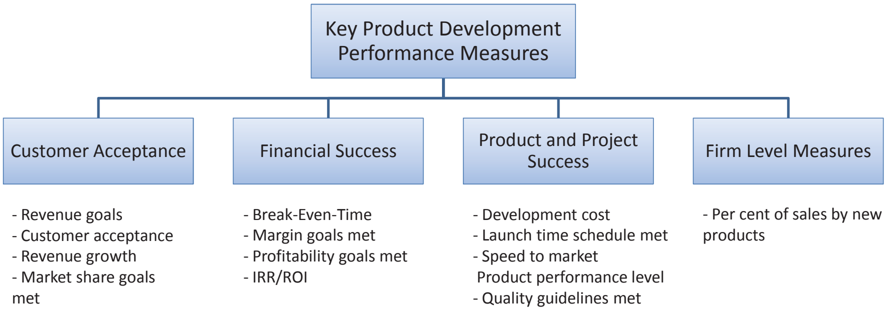

Figure 10. Categorization of performance measures

Godener and Söderquist (2004) have further developed and extended this categorization proposed by Griffin and Page into seven different areas of performance measurement:

- *Financial performance measurements*, where performance is defined as maximizing the quantitatively measured return on product-development investment. Further, financial ratios that compare budgeted and actual expenditures, and costs and investments relative to every product-development project are essential in order to maintain development projects on the right financial track (Werner and Souder, 1997).
- *Customer satisfaction measurements*, where high performance is seen as exceeding or at least satisfying customer expectations (Hultink et al., 1997). This perspective originated in the need to evaluate market expectations of a new product, but also to evaluate market success after introduction by measuring parameters such as the conformances to specifications, the product's appreciation by customers, market share, market penetration, brand image, and relate these measurements to the product-development activities (Hauser and Zettelmeyer, 1997).
- *Process management measurements*, where high performance concomitant with optimizing quality, lead time and cost, and ensuring project progress according to process related goals (Werner and Souder, 1997). Measurements include development lead-time, engineering productivity, total product quality, the effectiveness of communication, and motivational and behavioral factors such as commitment, initiative, and leadership of human resources in the product-development process (Brown and Svenson, 1988).

- *Innovation measurements*, where high performance is considered as the successful transformation of research efforts into new products. In this perspective, performance measurement mostly focuses on outputs such as number of patents generated, the pace of product development and launch, and the percent of new technology content in new products (Kerssens-van Drongelen and Cook, 1997).
- *Strategic measurements*, where high performance means goal satisfaction, how product-development activities contribute to the overall business strategy. The metrics in this area evaluate e.g. the compatibility between product development and business strategy (Hauser and Zettelmeyer, 1997), and, the ability of product development to shape and even initiate new strategic orientations.
- *Technology management measurements*, where high performance is understood as the efficient management of product technology for generating a continuous stream of new competitive products. This area of measurement differs from the others by its focus on the coupling between product and process technology, through the important concept of product platforms (Robertson and Ulrich, 1998). Its purpose is to focus management attention on the technical and commercial effectiveness of product development on a product family basis. This is achieved by considering the dynamics of evolving product lines, the renewal of their underlying technical architectures (or platforms), and the leverage that architectures provide in generating derivative products and improve manufacturing flexibility.
- *Knowledge management measurements*, where high performance corresponds to a qualitative return on product-development investment in terms of knowledge creation, knowledge transfer, and knowledge exploitation resulting in enhanced product-development capabilities and intellectual assets. There is strong evidence that enlarging the knowledge base and improving its use can contribute significantly to product-development performance (Lynn, 1998).

Godener and Soderquist (2004) concluded in their exploratory multiple case studies within the electronics industry that measurements within the technology and knowledge management are scarcely used and thus question the usefulness of these perspectives. The three companies studied, are among the top ten companies in the electronics industry in France and two are global players applying world-class management systems. Moreover, the same authors propose that the usefulness of these measurement areas could be informed by comparing performance outcomes in other areas among companies using and not using the technology and knowledge management in performance measurement.

In the literature there are few performance-measurement systems that focus explicitly on the development of complex products. One exception is the extensive study within the electronics industry performed by Loch et al. (1996), intended to assess the overall contribution of product development to a company's business performance. The authors combine firm and project level views of performance and distinguish between performance in development process, performance of the output of the process, and eventual business success. Moreover, Loch et al. (1996) argue that process performance influences output performance through the operational management of the development projects. The framework is shown in Figure 11.

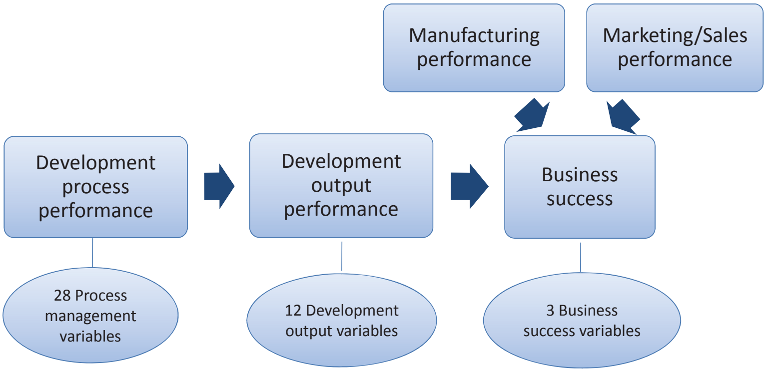

Figure 11. A framework for product-development performance

The framework in Figure 11 has received some critics, e.g. O'Donnell and Duffy (2002a) argue that two of the output variables had no significant relationship to any of the process variables. However, this framework is still important since it is one of few studies with an explicit focus on more complex product development.

Brown and Svensson (1988) emphasize a systems perspective for performance in product development. This system perspective on performance, shown in Figure 12, includes: inputs, processing system, outputs, receiving system, outcomes, in-process measurement and feedback, output measurement, and outcome measurement. Inputs are the raw material or stimuli the system receives and processes, e.g. ideas, equipment, people, information etc. The processing system is the R&D lab which turns input to output testing hypotheses, conducting research and so on. Typical outputs include patents, new products or processes, new knowledge etc. The receiving system comprises the various consumers of the R&D outputs; these usually include marketing, manufacturing, buyers and aftermarket or other departments. Outcomes are the achievements that have a value for the organization e.g. sales improvements, new products, product improvements, cost reduction, and market share. In-process measurements and feedback occur within the processing system as the R&D lab measures itself and feeds this information back to its personnel. Outputs are usually measured in terms of quality, quantity, and cost, however, simply measuring outputs is not sufficient; outcome must also be measured and fed back to the system. It is only through measuring the outcome that the real value of product development can be assessed.

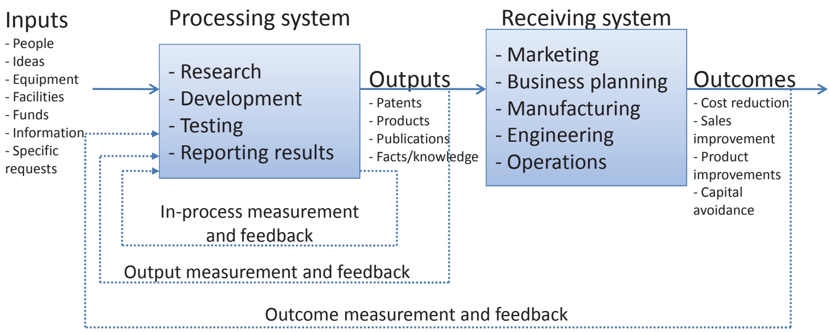

Figure 12. The product-development process as a system

A systems perspective, as modeled by the product-development process, is of value in increasing the understanding of why performance measurement fails. Brown and Svenson (1988) argue that focus is too much on internal measurements. Instead, it is important to analyze the product-development process from a system point of view and design the performance measurement accordingly.

Financial measurements are important as outcomes measurements, but it is also generally agreed that they are most useful at higher levels of management, where they can reflect the success of the strategies pursued (Kerssens-van Drongelen et al., 2000). Furthermore, the financial outcome in terms of revenues related to product-development investment is not usually apparent until several years after the investment decision has been made. Hence, a conceptual holistic system model may be especially important within product development.

In a recent study, Chiesa et al. (2009a) identified 72 different performance measurements used in 15 technology-intensive firms in Italy. The most commonly used performance measurements, number of interactions with customers during the project, per cent of projects respecting costs and budget, and agreed milestones/objectives met, was only used by 6 out of 15 firms. This implies that there is a variety of ways of measuring performance in product development and there seem to be no shortage of measurements to choose from.

2.4.6 What are the Key Gaps and Conclusions?

The key gaps and conclusion in the literature related to performance measurements in product development can be summarized as:

- Performance measurements tend to focus on the result rather what affects the process. This may be explained by the fact that what affect the process tends to be context dependent thus difficult to generalize. In contrast, evaluating e.g. the economical result is not context dependent, hence easier to generalise. This is the same for input measurements that can be measured in economical turns such as percentage of revenues invested in product development and the engineer head count.
- Performance measurements should be aligned with the strategies of the organization. This is one of few generally accepted findings in the performance-measurement literature.
- The body of literature related to performance measurements is vast, but diverse and the common body of knowledge is small.
- The Balance Scorecard, the most widely spread performance-measurement framework has not been as successful when applied in product development. However, the idea of having a balanced set of measurements is argued to be just as valid within product development.
- There are many models and frameworks in the literature. A general difficulty seems to be to transform the information generated by these frameworks into actions. This is not a measurement problem per se but rather a performance management challenge.
- There exists a plethora of extant measures, obviating the need to develop new measures. Instead, the focus should be on determining how to use them in a beneficial way. A systems perspective as presented in Figure 12 may be useful but it is apparent that further research is needed that can assist managers and decision-makers in this task.
- In particular a value perspective is missing during the development of a new product. Earned value is used within project management but it is more earned cost rather than earned value, since the value is based on cost.

2.5 Concluding Discussion

The research area of performance measurement in product development is still relatively young in an academic perspective, with scientists from many different functional backgrounds performing research, making the common body of knowledge limited, even though there is a vast amount of literature. This issue has been highlighted in recent years and the first steps in extending the common body of knowledge have been taken. Still, as concluded in this review the terminology is unclear. Marchand and Raymond (2008) point out that research is more problematic when the basic concepts and definitions that underlie a research area lack clarity, precision, and uniformity. The conceptual and definitional imprecision also makes it more difficult to import knowledge from other disciplines or fields. As Marchand and Raymond (2008) point out, accumulating and integrating research results into a coherent body of knowledge is more difficult, as the lack of a common language makes different studies less comparable.

When reviewing the literature, few studies are found focusing on performance measurements in complex product development. The existing research studies performed within a product-development context often focus on the development project, not on evaluating the performance from a holistic product-development perspective, as described in Section 2.1.1. However, it is not surprising to find most research studies focusing on the development project, since it is a common way to organize product-development activities. However, looking back at the proposed definition of product development, the value creation is mainly decided on before the project scope is fixed and the project is set to be initiated. From a value perspective, to focus only on the product development project neglects the importance of maximizing the possible value. Instead it is easy to limit the perception of performance to a project realization efficiency dimension, which can be relatively easy evaluated using the iron triangle of performance, i.e. time, cost, and quality.

In this research, it is argued in line with the arguments by Gharajedaghi (2006), that an effective evaluation system needs to deal iteratively with both performance criteria and performance measurements. Performance measurements are important as an aid in determining the priorities to be given different activities, and as means of guiding teams by indicating how they are performing and where improvements would be most beneficial. However, performance measurement must be kept in perspective; it must support the product-development process and goal attainment (Nixon, 1997), based on the business strategy. Linking the strategy pursued to a few explicit measurements is a fundamental rule within the performance-measurements literature (Davila et al., 2006). This also implies the importance of continuously evaluating the performance-measurement system.

Leading indicators of performance are important for product development since it usually takes several years before the end result can be measured in economical turns. However, large quantitative research studies focusing on product development tend to view product development independently of the products being developed (e.g. Barczak et al., 2009). Hence, it may not be representative for all types of products suggesting that here is a need for studies focusing explicitly on the development of complex products. A recent study by Blindenbach-Driessen and van den Ende (2010) indicates that best practices for developing products are firm-dependent. This also implies that leading indicators of performance may not be as generally applicable as outcome-oriented measurements. Since the needs vary between organizations, the focus should instead be on developing general methods and models that can be used to derive context-specific indicators of performance.

Chapter 3 Research Questions

The literature pertinent to this field of research, outlined in Chapter 2, has provided an overall frame of reference during the preparation of this thesis. The questions which the research addresses are motivated by the identification of gaps in both the literature reviewed and in industrial practices within the companies participating in the industrial reference group meetings as described in Section 4.3.7.

Yin (2009) argues that the determination of the research questions is a major component in a research design. Defining the research questions may even be the most important step in a research study. The research questions indicate where the research aims at contributing to knowledge (Karlsson, 2009). This research on which this thesis is based is intended to contribute to knowledge within two main research areas. The first research question may be described as exploratory in nature and the second research question is more prescriptive. The two questions with the related sub questions are presented in the following sections.

3.1 Research Question 1

Research question 1: What challenges in evaluating performance can be identified in the context of the development of complex products?

As pointed out by Griffin and Page (1996) success is not just elusive; it is also multifaceted and difficult to measure. The various definitions of performance in Table 2, effectiveness in Table 3 and of efficiency in Table 4 illustrate that performance is multifaceted. To this, the limitations of the Swedish language in not distinguishing between the terms efficiency and effectiveness, must be added. Moreover, the finding reported in Section 2.1.3 that there appears to be a mismatch between the definitions of product development and the development models used in practice, particularly the fuzzy front end, is not generally understood.

The objective of the first research question is to improve the limited understanding of what the challenges are, which makes performance difficult to evaluate in practice, from the point of view of managers and decision makers actively working with the development of complex products. Despite the large volume of published research related to the evaluation of performance in product development, there are still challenges to be overcome, before it can be performed in a satisfactory way, as concluded in Chapter 2.

Research question 1 is to be viewed as a main question with three specific sub-questions that further detail and limit the area of study. These sub-questions are used in this research as leading questions and also to limit and focus the main question. In order to answer research question 1 it is argued that it is important to be able to conceptually analyze and evaluate performance in a complex product-development context. For this, a holistic framework for performance measurements is needed. The sub-questions related to the first research question are:

Rq 1.1 How is performance in the development of complex products perceived by managers and decision makers?

Rq 1.2 How is performance measured in the development of complex products?

Rq 1.3 How is the performance-measurement system perceived by managers and decision makers in the development of complex products?

It is important to be able to evaluate the performance-measurement system to be able to identify the challenges related to evaluating performance. When a performance-measurement system is to be evaluated, it is important to address *what* is to be measured and *when* it is to be measured. The motivation for a particular measurement, the *why*, is a central issue in the process of evaluating a performance-measurement system, especially since the performance of every measurement involves a cost.

3.2 Research Question 2

Research question 2: How can the performance of the activities related to the development of complex products be evaluated from a management and decision-making point of view?

In view of the findings from research question 1, the natural next step is to determine how some of these challenges can be addressed in practice. Research question 2 takes another perspective and being based on the literature and the knowledge gained in this research project it is more solution-oriented in nature. In the same ways as the first research question, the second research question is also further detailed into two sub-questions as follows:

Rq 2.1 How can performance criteria be modelled in the development of complex products?

Rq 2.2 How can performance measurements be designed in order to support managers and decision makers in deploying proactive activities *during* the development of a new product?

An effective performance-measurement system is required to iteratively deal with both performance criteria and performance indicators (Gharajedaghi, 2006). However, in the literature, there is little support for the development of performance criteria in general, even less for the development of complex products. To be able to answer these sub-questions requires the ability to evaluate performance during the development of the new product, from the point of view of managers and decision makers.

However, as concluded in Section 2.4.6., performance measurements tend to focus on the result rather than what affects the process. What is special with complex products is that they involve many stakeholders and are typically developed in large organizations. It is also of great importance that the development is performed in a manner both effective and efficient. Therefore, it is important for managers and decision makers to be able to use the performance measurements during the development in order to improve this process.

3.3 Mapping of the Research Questions to the Chapters of the Thesis

Table 6 illustrates how the research questions are handled in the subsequent result chapters of the thesis.

Table 6. How the research questions map to the result chapters.

	Chapter 5	**Chapter 6**	**Chapter 7**	**Chapter 8**	**Chapter 9**	**Chapter 10**
RQ 1	X	X	X			
RQ 1.1		X				
RQ 1.2		X	X			
RQ 1.3		X				
RQ 2				X	X	X
RQ 2.1				X	X	
RQ 2.2					X	X

Chapter 4 Research Methodology

The main research methodology applied in preparing this research is presented in this chapter. Its outline is as follows. The various approaches to research are discussed first, this discussion being followed by the motivation for the choice of research methods. The chapter continues with an overview of the progress research during the four years leading up to this thesis, this is being followed by more detailed descriptions of the main research studies pursued. The chapter concludes with a discussion of the quality and the limitations of this research.

Research can be described as an organized, systematic, data-based, critical, scientific inquiry or investigation into a specific problem, undertaken with the objective of finding a solution or answer (Sekaran, 1992). Leedy and Ormrod (2005), describe formal research as a systematic process of collecting, analyzing, and interpreting information in which we intentionally set out to enhance our understanding of a phenomenon and expect to communicate what we discover to the larger scientific community. What distinguishes scientists from non-scientist is not *what* they study but *how* they study (Thomas, 2006). Hence, the research method is important when conducting research. This is in line with the arguments by Karlsson (2009) that since the role of research has been described as the creation and development of new knowledge, it needs to be carried out in a proper fashion. This is in contrast to studying, the aim of which is to contribute to one's own knowledge.

4.1 Research Approaches

The term paradigm, originally from Kuhn (1970), is used to describe the world view and mind set of researchers. The thought pattern in any scientific discipline is often referred to as belonging to a specific paradigm. A paradigm often becomes more apparent when there is a shift away from the currently dominant paradigm. This is especially true in research areas that appear more stable, e.g. in the natural sciences. An illustrative example is the change occurring in physics at the end of the 19th century. At that time, physics seemed to be a discipline filling in the last few details of a largely worked-out system. This was clearly illustrated in the year 1900, with Lord Kelvin famously stating:

> There is nothing new to be discovered in physics now. All that remains is more and more precise measurements.

A few years later, Albert Einstein published his paper on special relativity, which challenged the very simple set of rules laid down by Newtonian mechanics.

The current worldview and the way we work is deeply influenced by the thinking that originated in the seventeenth century (Maani and Cavana, 2007). As an engineer it is easy to view the world in accordance with Newton´s physics (Ackhof, 1999), meaning that:

1) A complete understanding of the universe is possible;
2) The world can be understood through analysis i.e. breaking the whole into pieces and examining the parts separately;
3) All relationships can be described through linear cause-and-effect.

In contrast with the natural sciences, within the social sciences there is often not one existing paradigm but several competing paradigms. Two such classical competing paradigms are the positivistic and hermeneutic paradigms. The positivistic tradition denies the existence of a fundamental difference between natural and social science, in contrast with the hermeneutic paradigm in which the world is viewed as a social construct. According to the positivistic approaches to research, the world can be described by laws and this philosophy argues that the world is the sum of its parts. Hence, the world could be understood by studying one part at the time and then summarize this knowledge.

Systems thinking argue, in contrast to the positivistic paradigm, that the whole differs from the sum of the parts. This is due to the fact that the components constituting the system are mutually dependent and therefore may influence each other (Lawson, 2010). The process of developing complex products very much depends on a set of components and the performance of the system is never better than that permitted by the weakest link. When focusing on evaluating performance in the development of complex products, it is appropriate to adopt a system perspective view of the product-development process because of the complex relationships between input and output.

In systems thinking, that can be positioned in between the positivistic and hermeneutic paradigm there are four levels of thinking: events, patterns, systemic structures, and mental models. The deepest level of thinking that hardly ever comes to surface is the mental model of individuals and organizations that influence why things work as they do (Maani and Cavana, 2007). Mental models are, however, difficult to discuss and some researchers even argue that they are impossible to discuss. Still, by thinking in terms of mental models of an individual or organization, and trying to understand and acknowledge them, it may be possible to introduce and contribute to sustainable changes. At the same time increasing complexity stresses the need for models that can be used by teams to develop a shared understanding (Katz and Kahn, 1978).

The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity (Senge, 1990). It is argued in this research, in line with systems thinking, that there is a need to adopt a holistic view as emphasized in systems thinking. Knowledge is obtained by acknowledging, not only cause and effect relations as in the positivistic paradigm, but also through the interaction of human beings and their values and beliefs within a system.

Most research within the area of performance measurements can be classified as belonging to a positivistic paradigm. Typically, quotations like “you are what you measure”, “what you cannot measure you cannot improve” etc. support this classification. Despite the fact that the researcher has a background within engineering, we try to move away from a strict positivistic thinking and instead acknowledge the ideas of and is inspired in thinking in terms of systems. However, the ideas underlying cause and effect within the positivistic paradigm are appealing, even if they are not always applicable within the development of complex products.

4.1.1 The Importance of Language

To understand any complex human activity we must first grasp the language of the individuals who pursue it (Kerlinger, 1986). Language is indeed fundamental to any form of investigative enterprise (Thomas, 2006). In this research this has been approached in two parts. The first part involves the related work in which a special focus has been on identifying and discussing definitions of the terminology used as was presented in Chapter 2. The second part is to investigate the use of the terminology in practice. One conclusion from the review of the literature in Chapter 2 was that it contains no common definition of performance in product development. This makes the topic important to investigate, but at the same time more challenging.

A further difficulty for this research is the limitations in the Swedish language in comparison with the English. One typical example of this difficulty is that there is no direct translation of the terms efficiency and effectiveness. Recently the terms internal and external performance to describe efficiency and effectiveness have been adopted but are not commonly known in practice. Another example is the term “performance” in itself that is often used without a clear meaning of what is meant. It is often used in a general sense to describe a general change of something into something that is better, without specifying what is really meant. For a researcher this makes survey research in particular more difficult to pursue, while case research and especially semi-structured interviews with more open questions collecting qualitative data, might be more suitable.

4.2 Research Methods

Within social science there have mainly been two basic categories of research methods, *qualitative* and *quantitative*, categorized according to the type of data collected. An important decision in regards to the research method is whether to pursue a qualitative or quantitative data oriented research method. When the purpose of the research is to explain and predict, confirm and validate, or to test theory, a method that leads to quantitative data is suitable. In the past, research methods that lead to quantitative data have dominated management research. Easterby-Smith et al. (2002) conclude that much attention have been given to describing, coding, and counting events, often at the expense of studying why things are happening. If the purpose on the other hand is to describe and explain, or explore and interpret, or to build theory, a research method that involves collecting qualitative data may be more suitable. The most central characteristic of qualitative, in contrast with quantitative research is that it begins with the perspective and actions of the subjects being studied, while it is the investigator's ideas of what should be the central focus which is typically the case within quantitative research methods (Bryman, 1989). Hence, qualitative research methods are most appropriate in this research.

Methods for collecting qualitative data might concentrate on exploring in greater depth the nature and origin of people's viewpoints, or the reasons for, and consequences of, the choice of performance criteria (Easterby-Smith et al., 2002). Another advantage of a qualitative data approach is the possibility of considering the entirety in a way that may not be possible with a quantitative approach. In the category of qualitative data collection research, many methods and approaches such as case studies, participatory inquiry, interviewing, participant observation, visual methods, and interpretive analysis are available (Denzin and Lincoln, 2003).

Scientists adopting qualitative research methods rarely try to simplify what they observe. Instead, they recognize that the issue they are studying has many dimensions and layers, hence they try to portray the issue in its multifaceted form (Leedy and Ormrod, 2005). Since this research involves exploring how performance is perceived and how performance measurements are being used within product development, it was decided to pursue a more qualitative oriented data collection approach. It is argued that by pursuing a qualitative approach there are more possibilities of capturing and evaluating the complexities present in evaluating performance when developing complex products. The limitation in language and lack of a common terminology also makes a quantitative oriented data approach unsuitable for this research.

Few studies of performance seem to pursue qualitative data collection methods, enabling more in depth studies, in order to increase the understanding in a product-development context. In the academic literature several studies focus on large quantitative studies with the aim of developing best practice systems by identifying what top performing companies do. Typical examples in this stream of research are the research projects carried out by PDMA (Product Development Management Association), see e.g. (Griffin, 1997b; Griffin, 2002; Griffin and Page, 1993; Griffin and Page, 1996; Kahn, 2005; Kahn et al., 2006; Page, 1993), and the studies by APQC (America Productivity and Quality Center), see e.g. (Cooper et al., 2002a; Cooper et al., 2002b; Cooper et al., 2004a; Cooper et al., 2004b; Cooper et al., 2004c). In a review of 16 years of product-development research, Page and Schirr (2008) found that the dominant form of quantitative empirical research, the single-informant, cross-sectional survey in which the data came primarily from recall, remains subject to memory and survivor bias.

Instead, an exploratory case study approach may be especially suitable for learning more about a little known or poorly understood situation (Leedy and Ormrod, 2005), as is the situation in this research. Yin (2009) describes different research strategies i.e. experiment, survey, archival analysis, and case study. A case study is defined by Yin (2009) as:

> … an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.

Meredith (1998) cites three outstanding strengths of case research put forward by Benbasat et al. (1987):

1) The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing actual practice.
2) The case method allows the questions of why, what and how, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon.
3) The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

The research journey which included several different research studies and the motivations for pursuing them is presented in the following section.

4.3 The Research Journey

The research questions presented in Chapter 3 may be categorized into two sets of research questions. The first set, research question 1 and the related sub questions may be described as explorative, in the sense that it sets out to identify challenges related to evaluating performance in complex product development. The second set, research questions 2 and the related sub questions, is prescriptive in the sense that it aims at developing and verifying tools that may assist managers and decision makers, with some of the challenges identified from the first set of research question.

This doctoral thesis is the result of a research journey that due to the character of the two sets of research questions involves both exploratory research and the first steps towards more prescriptive research aiming at influencing practice. Complex research contexts often require a methodology which consists of various techniques rather than a methodology relying on a single method. An overview of the research journey is shown in Figure 13.

Eisenhardt (1989) argues that it is important when entering an under-researched area in an exploratory manner, that the research needs to be guided by emergent empirical findings. Performance measurements may not be an under-researched area, but as the review of the literature in Chapter 2 concludes, there is no common way of evaluating performance in the development of complex products. Hence, this research has been guided by the intermediate findings. The final result, as reported in this thesis, is the result of pursuing a number of research studies in order to answer the research questions presented in Chapter 3.

The research process has hardly been as linear and structured as appears in Figure 13. Instead, all the studies are heavily interlinked especially the literature review and the industrial reference group meetings (presented in Section 4.3.7) that have iteratively treated the findings from the conducted studies.

Table 7 presents an overview of how the research questions map to the research studies pursued, as illustrated in Figure 13. As Table 7 indicates, the main focus of the first part relates to the first set of research questions, while the second part of the research journey is more focused toward the second set of research questions. The exception is the survey that was conducted in order to further validate some of the findings related to the multiple exploratory case studies in the first part.

Table 7. How the research questions map to the pursued studies.

	RQ 1	RQ 1.1	RQ 1.2	RQ 1.3	RQ 2	RQ 2.1	RQ 2.2
Focused Group Interview	X		X				
Exploratory Case Studies	X	X	X	X			
Industrial Reference Group Meetings	X	X	X	X	X	X	X
Literature review	X	X	X	X	X	X	X
Performance Measurement Design Methodology					X	X	X
Survey	X		X				
Value Study					X		X

4.3.1 Part One of the Research Journey

The first part of this research journey focused on the first set of research questions i.e. to identify the challenges related to evaluating performance; how performance and the performance-measurement system is perceived by managers and decision makers; and investigate how performance is measured within the development of complex products.

A review of the relevant literature, to identify the research gap and position this research in the existing literature was initiated when the first part of this research journey began. The literature review process is further presented in Section 4.3.3. On the basis of the diverse findings reported regarding the evaluation of performance, within the domain of developing complex products, an inductive research approach was decided on. It was decided to use initial semi-structured focused group interviews in order to efficiently determine what managers identify as important for a high performance product-development process. The semi-structured focused group interview was set-up together with the senior managers in the industrial reference group, in order to identify what they perceive as important success factors for complex product development. This group interview together with an initial literature review is the foundation for the categorization of performance in complex product development as presented in Chapter 5.

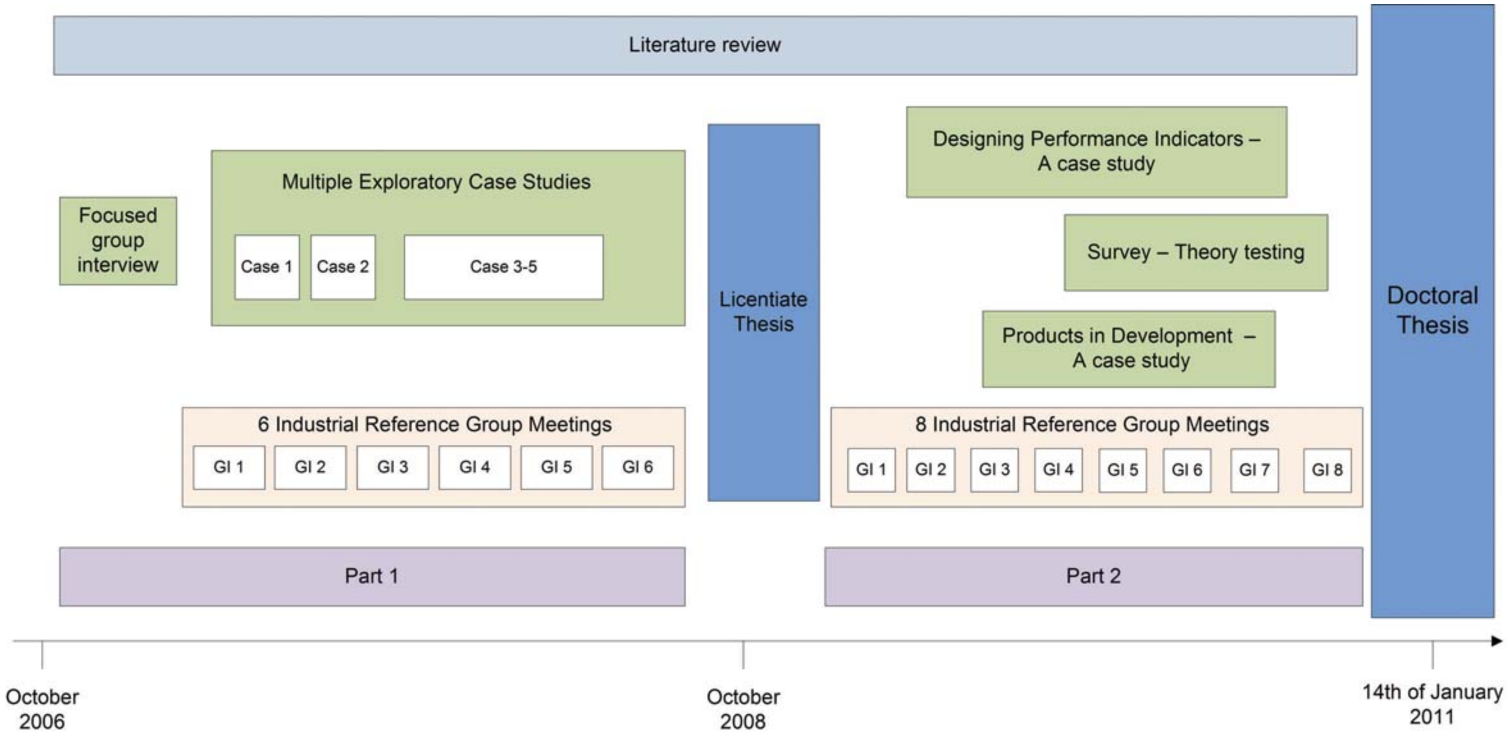

Figure 13. An overview of the research journey that eventuated in this doctoral thesis

The results from this group interview became the initial foundation for designing the multiple exploratory case studies. Through these case studies a deeper understanding of the challenges related to evaluating performance in complex product development was obtained. Moreover, the framework for performance in complex product development presented in Chapter 5 was developed into a conceptual tool that can be used to evaluate what is and what is not measured by a performance-measurement system. The result is the Performance Measurement Evaluation Matrix (PMEX) that is presented in Chapter 7.

Since there is a lack of research focusing on how to measure performance in complex product development, it has been beneficial to base the research in the first part on induction. In this way pre-understanding has been limited and the focus has been to establish a substantial understanding of what is important, from an industrial point of view, whit respect to performance and performance measurements in complex product development.

4.3.2 Part Two of the Research Journey

The second part of the research journey relates mainly to the second set of research questions, hence aims at being more prescriptive in character. The research questions addressed in this part relates to how performance may be evaluated during the development in order to support managers and decision makers.

The overall findings from the first part resulted in the identification of a number of challenges and limitations regarding measuring performance in complex product development. In particular the missing link between success factors and the performance-measurement system, identified in the exploratory case studies is validated in the second part using a survey. Hence, a triangulation of various research methods, as well as data sources, has been possible in order to add strength to this conclusion.

Moreover, the link between success factors is further elaborated in the second part of this research. This resulted in the development of a performance-measurement design methodology, based on the IDEF0 model of an activity. The IDEF0 has been used to model the relevant performance criteria, hence is an important aspect when designing new measurements. The proposed performance-measurement design methodology is further detailed and tested in Chapter 9.

From the literature review in Chapter 2 it was concluded that a value perspective is lacking during the development of a new product. Because of the absence of value as a measure of performance during the development, a model based on perceived customer value has been developed. A case study was performed to test the method in practice, the results being reported in Chapter 10.

The value study and the performance-measurement design study are similar in character in the sense that they were designed to test the applicability of a proposed theory in practice. Common to both studies is that they have been developed on the basis of knowledge gained and needs identified in the first part of this research. These models have been verified in a first case study, aimed at verifying their applicability and continuing their development. The specific details regarding the research approach pursued for the performance-measurement design study are given in Chapter 9 and for the value study the research approach is further detailed in Chapter 10.

4.3.3 Literature Review

An important part of all scientific work is to search for, gather, and review the previous research literature. Research involves contributing to knowledge and the literature review serves an important purpose in identifying the existing knowledge (Karlsson, 2009). The literature review is also important as a tool to obtain a better understanding of the research problem, and to how any other attempts to solve the problem have been performed. It is important, however, that the role of the literature review in research remains a means to an end, not an end in itself (Tangen, 2004). As is illustrated in Figure 13 a continuous literature review has been performed during the entire research process. This has been important since the field is extensive and diverse, with a limited core of knowledge relevant to the specific topic, making it difficult to perform a single exhaustive systematic literature review. Instead the literature has been scanned and reviewed continuously throughout the research journey.

Yin (2003) argues that more experienced researchers usually review previous research in order to develop more insightful and relevant questions about a topic. This has been the ambition of the present researcher but the research questions have also been prompted by emergent empirical findings in line with the arguments by Eisenhardt (1989). This approach has naturally had effects on the performance of the review of the literature, needs appearing during the research requiring it to be continues. Findings from the multiple exploratory case studies, empirical data and discussions in the industrial reference group meetings are example of this influence.

The literature relating to performance measurement and product development is vast. As concluded in Section 2.5 this is a broad, not well defined, research area with a limited common body of knowledge. However, some authors argue that there are some indications of the beginning of the development of such a body of knowledge (Page and Schirr, 2008). The main sources of relevant literature were previously the marketing and operations management-oriented journals e.g. Journal of Product Innovation Management, R&D Management, Research Technology Management, and International Journal of Operations & Production Management. These journals were identified by using keywords such as product development, performance, and performance measurement. However, since the literature search during the research journey was conducted longitudinally, there have been a number of different key words, dependent on the motive of the specific search, have been used. The literature reviewed also included books, often identified in the reference list of the journal articles.

4.3.4 Focused Group Interview

The focus of this research is on the domain of complex product development, but most studies of success factors in product development relate to more general domains, it was therefore decided to use focused group interviews (Patton, 2002) to determine the factors managers identify as important for success, these also being a cost-effective way to gather empirical data (Robson, 2002). Focused group interviews have several further advantages (Patton, 2002), they were chosen here because the interaction between participants enhances the data quality and it is relatively easy to evaluate the consistency of the data obtained.

The focused group interview was performed with senior managers of product development from eight companies. The managers participating were selected on the basis of their experience in developing industrial products. They represented global companies, with the exception of one national management consultancy firm, all being active in Sweden. They all have extensive experience in developing industrial complex products within transportation, telecommunications, automation, and the automotive industry. The participating companies are not competing in each other's markets and have different products in their portfolio. However, they share similar difficulties and challenges in achieving a high-performance product-development function and being able to measure its performance.

The focused group interview was carefully planned and began with a presentation of an initial differentiation of product development into planning and implementation activities, as is further described in Chapter 5. This was followed by dividing the participants into smaller groups to discuss, based on their experience, what is important for success in each of the two categories. Each group presented and discussed their results in the larger group, resulting in a list of important factors. This list of success factors was then analyzed and categorized by the authors. The resulting initial framework of success factors (see Table 9, Table 10, and Table 11) was then presented and discussed at a seminar with the participants in the focused group interviews. The results were also compared with the findings from the literature (see Table 12).

Focused group interviews tend to work well when the participants, though sharing similar backgrounds, are strangers to each other (Patton, 2002), as was the case in this case. The atmosphere of the group interview was constructive, in the sense that the participants openly wanted to share and learn from each other's experiences. Data collection is generally difficult in groups, and the findings were therefore recorded during the interviews in such a way that all participants could see the data collected and acknowledge its validity.

Focused group interviews are often used in conjunction with other methods for obtaining information such as individual interviews (Robson, 2002) and thus an appropriate preparation prior to the multiple exploratory case studies. The framework of success factors developed from the focused group interview was used as an input to the exploratory case studies in order to find out what measurements are used and how the performance and the performance-measurement system are perceived in practice.

4.3.5 Exploratory Multiple Case Study

The major part of the first section of this research project consists of multiple exploratory case studies, conducted at five different case companies developing complex products. The use of multiple case studies was important in order to get information from a representative of large organizations developing complex products. Moreover, the first set of research questions is explorative in nature, making case studies appropriate. This is in line with the arguments of (Yin, 2003), that case study research is particularly advantageous when answering *how* questions. The objective of the multiple explorative case studies, other than developing answers to the answering the research questions posed, was to get a broad understanding of the needs and difficulties of measuring the performance of the product-development process within the participating companies.

The explorative multiple case studies were performed in accordance with the approach presented by Yin (2003). A case study research strategy focuses on understanding the dynamics present within a single setting (Eisenhardt, 1989) and is therefore suitable for exploring the perception and measurements of performance in complex product development. The unit of analysis in this research is the development of a new complex product within the product-development organization. The aim of the multiple exploratory case studies was to obtain a deeper understanding of how performance in product development is perceived by managers and how it is measured. The planning and implementation processes within products development were also studied. This broad understanding will then serve as a foundation for further research.

Presentation of the Case Companies

Access to the real world is often cited as a problematic issue in management studies (Thomas, 2004). In this research, such access, including access to detailed and sensitive information, has not been a problem since relevant case companies were already actively involved, and the cases were selected from the operations of this group of participating companies. The criteria for selecting cases included large organizations, product companies, complex products, and research and development activities within the organizations.

Table 8 presents an overview of the five case companies. They all develop products within commercial vehicles, automation solutions, and the telecommunication industry. They have all in common that they provide solutions involving both mechanical, electrical, and software in a business-to-business environment. Moreover, the development activities are often distributed within different organizations both inside and outside the firm often in an international setting.

Table 8. Overview of the five case companies

	Company A	**Company B**	**Company C**	**Company D**	**Company E**
Part of a corporate group	Yes	Yes	Yes	Yes	Yes
Type of industry	Industrial automation	Commercial vehicles	Commercial vehicles	Telecom-munication	Industrial automation
Type of product	Final product	Final product	Technical platform	Technical platform	Technical platform
Number of employees in the product development organization	~150	>500	>500	>500	>200
Global distributed development organization	Yes	No	Yes	Yes	Yes
Own production	Yes	Yes	Yes	Yes	No

Two of the case companies develop products that are sold to an external end customer outside the corporate group. The other three case companies develop products that are more technical platform products that are customized by internal customers, i.e. within the corporate group, before being sold to an external customer. This technical platform is often delivered to another division within the same corporate group, adding an application specific solution in order to deliver a specific solution to the end customer. The products often have a long life times and the development work is more evolutionary than radical. It is often a new part or a new function to be integrated into one or several products. Completely new products are also developed; typically when a new generation of the platform has appears.

The case companies are all global companies developing complex products in Sweden. All the five case companies are divisions within a larger corporate group, and all of these corporate groups belonged to the global Fortune 500 list in July 2007 (CNNMoney.com, 2007), hence they are all well established firms with success in their particular market.

Data Collection and Analysis

An overview of the explorative case study design applied to each of the five case companies is presented in Figure 14.

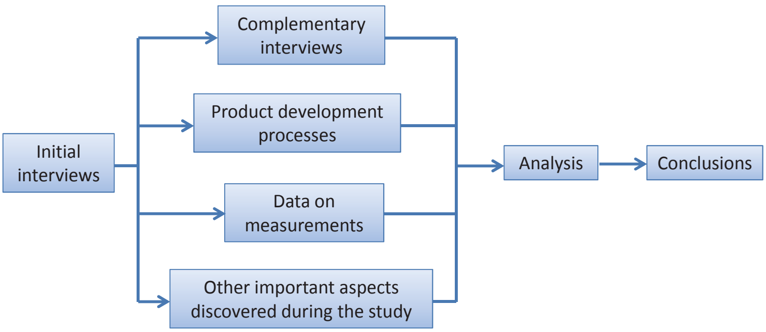

Figure 14. Explorative case study research design overview

The major source of data collection was through interviews as illustrated in Figure 14. The data collection was also performed by reading e.g. internal documents, organizations charts, and data from the performance measurement system currently used. An important aspect of this case study design is the *other important aspects discovered during the studies* (see Figure 14) depending on the case company. Explorative case studies, compared with most quantitative research methods, make it possible to have an initial general research design, but also to customize some parts of the study according to discoveries made during the progress of the research.

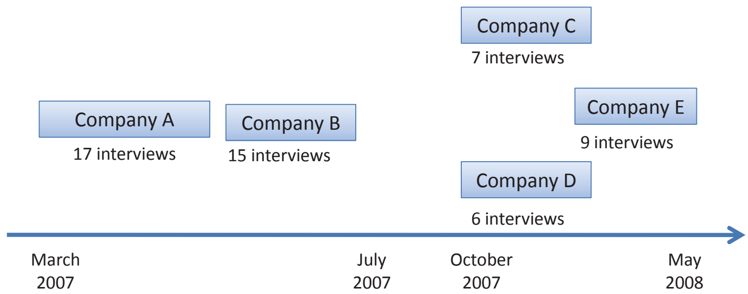

Figure 15. An overview of the multiple exploratory case studies

A total of 54 semi-structured interviews have been held at the five case companies. An overview and timeline of the perused case studies performed are given in Figure 15. The questions asked during the interviews were open and stated in such a way, that the respondents were encouraged to talk about what they thought important from their point of view. Open questions are important in order not to ask leading questions. The respondents were all managers and decision makers at different levels of responsibility within the organization. The interviews lasted between 50 minutes and 2 hours. As shown in Figure 14, some of the interviews were performed during the initial interview phase and others, when necessary, during the complementary interview phase. At first an initial set of respondents were chosen and supplemented with the senior manager representing the company in the steering committee. During these interviews snowball sampling has been used i.e. additional respondents were identified and interviewed when necessary.

During the first two case company interviews, the interviews were recorded and the transcriptions sent to the respondents in order to verify that nothing had been misunderstood or omitted from the interview. The use of a recorder was accepted by all respondents, except at one interview at the first case company. Only two respondents had any complaints about the transcription and some small changes were adopted accordingly. At case company 3-5 the interviews were conducted by two researchers, one taking notes and the other asking questions. This interview method proved successful in several ways. It became possible to discuss the overall impressions from the interview afterwards, thereby improving the quality of the analysis of each interview, of the overall analysis of the case company and of the analysis of cross case comparisons. Additionally the time consuming process of transcribing from tape was shortened.

An important aspect of the interviews was the inclusion of respondents with different roles within the product-development process. A project manager and a product manager could have very different ideas of what is important, since they view the product-development process from different points of view. The study was initially performed in a sequential manner, one case at the time. This process was advantageous initially but became very time-consuming because of the difficulty of finding time for the interviews. The main difficulty with the interviews was finding time for the interviews; all of the respondents having important roles within the organization, with tight schedules. It was therefore decided to conduct the subsequent cases in parallel.

As pointed out by Robson (2002) analysis is necessary and important because data in its raw form does not speak for itself. The analysis of the interviews began with data reduction into common categories related to the questions posed during the interviews. Qualitative analysis is guided not by hypothesis but by questions, issues and a search for patterns (Patton, 2002). By separating the data into different categories one complete document with the different answers to the different questions related to the category was assembled. Hence, it was possible to survey the results from each case company and compare the different analyses. There was little difference between the uses of performance measurements in the different companies. When a draft of the analysis was completed, the groups identified and interpretations performed were discussed with the other members of the research group and the industrial reference group. On this as a basis, adjustments were made to the suggested groupings and interpretations.

4.3.6 The Survey

The first part of this research, in particular the exploratory case studies, generated a number of challenges related to evaluating performance in the development of complex products. One key challenge that limits the use of the currently used performance-measurement systems is the difference between what managers and decision makers perceive as important success factors and what is measured by the performance measurement system. In order to validate this finding, a research survey approach was decided on.

The survey was designed in order to validate the hypothesis that there is a weak link between success factors for product development and what is measured by the performance-measurement system. In order to test this hypothesis, the success factors from a recent meta-review of success factors presented in the Journal of Operation Management by Chen et al. (2010), was selected. It was decided to use this meta-review of success factors, because they were accepted as success factors in the literature. However, the architecture identified as an important success factor for complex product development in Chapter 5, was also included. A complete list of the success factors can be found in Table 5. For each of the 13 success factor every respondent was asked if the success factor was perceived as a success factor both from a company perspective and from the individual's perspective. The follow-up question was if the success factor is evaluated by the performance-measurement system. This set of questions was repeated for each of the 13 success factors.

The respondents selected for the survey were all managers and decision-makers working in the development of complex products. Theoretical sampling was used to identify and select the respondents. The survey was distributed to the network of managers and decision-makers involved in this research asking them to complete the survey and distribute it to five additional persons. As a result 36 surveys were completed. A more detailed presentation of the result of the survey is given in Section 6.3.1. A complete list of questions asked in the survey is available in Appendix 1.

4.3.7 Industrial Reference Group Meetings

During this research project, a total of 15 industrial reference group meetings in order to report on and discuss the progress made have been held. The duration of each of these meetings has been between three and four hours. The aim of these meetings has been to present and validate early emerging research results, in order to keep the research relevant. On some occasions, these meetings have been of a workshop character and on others, more focused on communicating and discussing results. Using these meetings for discussions of findings and proposals has been a good way to triangulating the research findings.

Having several companies actively participating in this research through these industrial reference group meetings has been important, since this research is of inductive nature and the industrial reference group meetings have been a vital part of the empirical nature of the research.

4.4 Research Quality

Most academic researchers agree that the evaluation of qualitative research is important and necessary, but there is little consensus about what the evaluation should consist of (Corbin and Strauss, 2008). One issue related to this is the concept of validity, generalization, and reliability, initially developed within the context of traditionally fixed research designs, used to collect quantitative data. The applicability of these criteria for validity for more flexible designs with qualitative data has therefore been questioned (Robson, 2002). In contrast to these criteria for research quality, Thomas (2004) argues for the following criteria when evaluating case study research:

1) Justification - Why was the strategy adopted? Is it appropriate to the problem? Was the intention to describe, explain or both?
2) Selection - How many cases were used? How were they selected? Why these cases? If access to a site was required, how was this obtained?
3) Ethics - Was it necessary to disguise the identity of the cases? Were there any other ethical difficulties?
4) Data - What data were obtained, from what resources and by what methods?
5) Analysis - How were the data organized and summarized? Was cross-case analysis possible?
6) Presentation – Has a coherent and convincing account of the study been written? How has the presentation been organized?

Another attempt to evaluate the quality of research involving qualitative data is to use words such as credibility, dependability, confirmability, verification, and transferability should be used instead of validation (Leedy and Ormrod, 2005). The adoption of four dimensions of validity; descriptive, interpretative, theoretical and generalizable validity recommended by Ghauri and Groenhaug (2005) is in line with this suggestion.

This research, especially for the exploratory multiple case studies, follows Yin (2003). Hence despite the arguments of e.g. (Thomas, 2004; Leedy and Ormrod, 2005; Ghauri and Groenhaug, 2005), being acknowledged by this research an evaluation approach based on the four dimensions of research quality argued for by Robson (2002) and Yin (2003); construct validity, internal validity, external validity, and reliability.

4.4.1 Validity Concerns

In case research there are three types of validity: construct, internal and external validity, which are established during different phases of the research (Voss et al., 2002).

Construct Validity

The construct validity is about ensuring that the construction of the interviews actually relates to the problem to be discussed and that the chosen sources of information are relevant. In this research, multiple sources of information have been used, i.e. in accordance with the case study design shown in Figure 14. The interviewees have been selected in consultation with the senior manager in the industrial reference group representing the company. The selection of the respondents in this way and the search for further respondents from the initial interviews has ensured that the interviews have related to the right problem. Also, by using numerous and highly knowledgeable interviewees who view performance measurements in complex product development from diverse perspectives bias in the data collected is limited (2007).

To strengthen the construct validity, the questions asked during each interview were posed in an open way to minimize the possibility of the answer of the interviewees being influenced unduly. By approaching the interviews in this way, the interviewees could discuss what they think is important. Moreover, the interviewees, in the multiple explorative case studies, have reviewed the interview material to further ensure the construct validity.

Internal Validity

Internal validity is when the conclusions drawn arrived at are true. As an example, a conclusion might be that X causes Y when it in fact is the unknown factor Z that actually causes Y. Internal validation is a difficult task and no guarantees can ever be made. In the interviews related to case company 3-5, two researchers were present during the interviews. This made it possible to review and discuss the analysis, thereby increasing the degree of the internal validity. The number of respondents was not decided beforehand but was in accordance with the needs of each case company. All the conclusions drawn are based on data from at least two interviews, often combined with other sources of data e.g. internal documents. Hence, the internal validity is based on triangulation between different sources of data.

Other ways of increasing the degree of the internal validity of this research have been to triangulate not only the data but also the methods used, and to perform a quantitative survey focused primarily on the conclusion that there is missing link between success factors and that which is measured by the performance measurement system. The contributions of the industrial reference group together with seminars at the case companies have improved the internal validity.

External Validity

The external validity or generalizability is related to the generalization of the research results. Are the conclusions made valid for other areas than the one studied i.e. are results from one case company also valid at other case companies and in a general context? This can either be assured by theory or by replication of case studies at other companies in different areas. Yin (2003) proposes the use of analytical generalization for case studies, meaning that the result should be compared with existing theory. Proposed findings can be supported or not by comparison with established theory. This has been applied in this research and is one reason why the literature review has been conducted continuously during its progress.

This research has involved several different organizations, this adding further to strengthen the external validity. For example the companies participating in the industrial reference group are active in different domains within complex products. The only single case studies that have been conducted are those intended to test and initially verify the performance-indicator design and the value study. However, these studies represent the first steps in validating the findings and the method needs further work before a more thorough validation can be performed.

In common with all research studies based on qualitative data, this research has its limitations, especially with respect to generalizability. It may be difficult to draw any conclusions outside the area of developing complex products. However the main ideas behind this research could easily be applied within other domains. The tools and frameworks developed as part of this research are conceptual, hence general in their nature in order to be able to adapt them according to different contexts. These conceptual tools can therefore only be validated by being proven in practice. As yet this has not been investigated further within the scope of this research.

4.4.2 Reliability

The reliability or conclusion validity concerns the ability of other drawing the same conclusions when analyzing the case study and the interview material. Reliability is closely related to the trustworthiness of the research and if the research could be repeated with the same result. One way of ensuring this is to use proper documentation of the study. Every interview has been documented in a way that makes it impossible to identify the respondent, which may make it a degree more difficult to reach exactly the same conclusions. Also, all information available during an interview can be difficult to document e.g. because of the degree of the openness of the respondent, the tone of the interview etc. Factors such as these may influence how the findings are interpreted.

The far from linear and straightforward research approach adopted adds to the reliability of this research. The use of triangulation (Easterby-Smith et al., 2002) in terms of e.g. related literature and other documentations from the case companies may be easier to replicate, but the industrial reference group meetings have not been extensively documented, beyond the Power Point slides prepared for each meeting, and may therefore be difficult to use for replication purposes. This is clearly a limitation. When researching case company 3-5 two researchers were present during each interview, one asking the questions, the other taking notes. The discussions, when analyzing the material after an interview has been beneficial since on some occasions we have not agreed completely about the findings. This way of analyzing the interviews has increased the internal validity, but since this analysis process is only partly documented, it could have a negative effect on the reliability of the research presented. All the collected empirical data is however stored, which permits replication and thus increases the reliability.

Chapter 5 Evaluating Performance in Product Development

In this research it is argued that in order to analyze and evaluate performance in product development, especially in large industrial companies, a holistic framework is needed. In this chapter such a research framework is presented, starting by introducing our view on product development based on the definitions presented in the frame of reference (see Section 2.1). The proposed framework is based on success factors for the development of complex products. A system perspective of performance in complex product development makes explicit the need for different competences and understandings of the different phases of the product-development process.

The outline of this chapter is as follows: the research framework used in this research is presented first and this is followed by a description of the research approach used when identifying success factors for the development of complex products. The chapter continues with a discussion and an analysis of the findings and how they relate to the existing literature. The chapter ends with some general conclusions regarding performance and value creation in product development.

This chapter is based on the following publications: Journal paper 1, Book chapter 1, and Conference papers 9 and 13, as listed in Section 1.7.

5.1 Research Framework

The review of performance in product development in Section 2.2 concludes that many articles focus on the result of the process, i.e. the characteristics of successful products, and not on what results in successful products. However, an increasing number of articles acknowledge that the early activities in the process are important in order to achieve success. This is especially relevant and important today, when an enterprise is expected to develop a continuous stream of successful new products.

The definition of product development adopted in this research, presented in section 2.1.1, promotes a holistic view of the activities related to product development. The early activities of the product-development process certainly determine the success of a new product, since it is during the early activities that it is decided what to develop i.e. what customer needs are to be satisfied with a new product. The success of a new product can never be judged until it has been delivered to the customers. From a performance evaluation point of view, it is argued in this research that the activities related to product development may be divided into three different categories. We categorize the activities in the product-development process as: Planning, Implementation, and Sales and Delivery, see Figure 16. Each of the three categories requires specific objectives and competences for its successful execution and there are different criteria for evaluating the performance of the different categories.

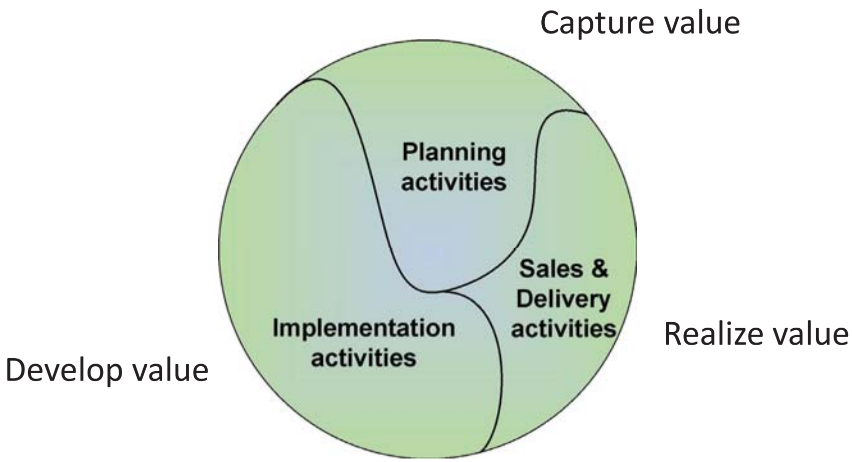

Figure 16. The proposed categorization of the activities in the product-development process

The Planning activities typically include decisions regarding what product to develop, and the planning and concept development of the generic phases of the product-development process (see Figure 2). The Implementation activities are more operational and include the designing of the product, typically involving system-level and detail design, test and refinement, and the production ramp-up (see Figure 2). The final part, Sales and Delivery activities are important in ensuring the completeness of the product-development process and its overall success by communicating the benefits of the product to the customer.

The proposed categorization of the product-development process may give the impression of a linear process i.e. first planning activities are conducted, and then the implementation activities, followed by sales and delivery activities. Instead this proposed categorization of the product-development activities is to be viewed as a framework permitting a holistic evaluation of the performance of the activities according to the specific needs. The task of evaluating the activities in a market environment analysis is very different from the task of software programming. At the same time it is important to acknowledge the importance of how the different activity categories contribute to the overall performance of product development. In practice there may be an iteration of planning and implementation activities, or the product development may be begun by selling the product to the customer, prior to the planning of implementation activities. The latter case is particularly common in the development of complex products, due to customized development or incremental development to products already installed.

The concept of successful product development may be difficult to describe without a conceptualization of the product-development activities. From a value perspective the planning activities may be viewed as the activities capturing value; the implementation activities may then be interpreted as developing the value captured in the planning activities; while sales and delivery activities are where the value is realized in monetary terms. A high performance product-development process, based on the proposed categorization, may be described as the result of successful planning, implementation, and sales and delivery activities.

5.2 Research Approach

This research began with a review of the literature in order to identify success factors for the particular planning and implementation activities in the proposed framework. Normally, success factors are identified either at the business unit level or at the product level by comparing a successful business unit or product with one less successful. Research studies regarding success factors in product development tend to focus on a general, rather than specific, product in mind. As concluded in Section 2.3, there are few studies of success factors focusing on the development of complex products. Since the focus of this research is in the domain of complex product development, and most studies of success factors relate to more general domains where complex products may just be a small part of the complete sample, it was decided to use a focused group interview (Patton, 2002) in order to determine the factors managers identify as important for success. The focused group interview is presented further in Section 4.3.4.

The resulting framework, populated with perceived success factors, was presented and discussed at a seminar with the participants from the focused group interview. The success factors from the focused group interview were compared with the findings in the literature, in order to determine if the success factors for developing complex products agree with the more general findings in the literature.

5.3 Success Factors for Complex Product Development

The results and analysis of the success factors collected from the focused group interview are presented in the following sections.

5.3.1 Product Development Planning Success Factors

Product-development planning is the first category of activities in the proposed research framework. The planning activities may be the most important, as they include deciding if a new product should be developed or not. The overall objective of the product-development planning activities is to determine customer needs and transform them into a product that utilizes the company's resources in an optimum way, thereby maximizing future cash flow. It could also be argued that it is during the planning activities that the upper boundary for the overall success and profitability of the product development is set.

The result from the focused group interview for the planning activities was categorized in subcategories in order to group and relate the various important factors for further analysis. From this analysis two main subcategories emerged, based on an overall description of the groups of success factors, as two sets of questions to be answered during product-development planning. The first set of question is w*hat* to develop and *why*, the second set of question is *how* and *when* it is to be developed. *What* and *why* are vital questions, since they set the boundaries for both the technical specification and the targeted market. From a value-creation perspective; once a company has decided *why* a product should be developed and *what* needs the product should satisfy, the future value of the product-development investment is limited, since the technical solution and targeted market are decided on. This is an important aspect of the product-development process that should be considered to make optimum use of the resources available.

Table 9 shows the result from the focused group interview, what managers in global companies developing complex products consider most important during the planning activities:

Table 9. Important factors for the successful planning activities (without mutual ranking)

What and Why		How and When	
Market environment analysis	Involves different aspects: technology, competitors, the customers' future business and processes, market knowledge etc.	Technology Road map	Develop the technology needed to support the product roadmaps.
Customer Needs and Wants	The ability to fully understand the customer needs and wants.	Metrics	Different metrics assisting the decision making
Business Case	Clearly specify what kind of profit this product generates and why.	Organization	It should have clear responsibility, mandate, culture, competence and roles to support the planning
Product Roadmaps	A clear plan of how the product will evolve in the future.	Ownership from Top Management	It is important that the CEO understands how the innovative product-development process will generate future revenues and profit
Risk Management	The ability to assess risks and to work actively with them.	Planning Competence	Understanding all the aspects: technical, market, economic, production, purchase etc. needs and addressing them.

5.3.2 Product Development Implementation Success Factors

Product-development implementation activities constitute the realization of the objectives decided on by the planning activities. The ultimate success for product-development implementation is to create exactly what is specified, on time, with the specified quality and within the budget. If key requirements cannot be met or the business case is jeopardized, it may be necessary to kill the project (Cooper, 2005), and focus the limited resources on other development activities. Hence, it is important to have a front-loaded product-development process in order to achieve an efficient and predictable implementation. Front-loaded development is to be viewed, in the proposed research framework, as the successful balancing act between the planning and implementation activities considering the customer needs to be satisfied and the resources and capabilities available for realizing the intended product. In practise this often means committing additional resources to and spending more time in the planning activities, i.e. hence front-loading the product development.

The results from the focused group interview were categorized in subcategories, in order to group and relate the various important factors for further analysis. From this analysis four subcategories emerged as important during the product-development implementation: Process, People, Management, and Technology. Table 10 and Table 11 present the four subcategories including the various factors relevant to each subcategory. Our findings are that these factors may affect the performance of the product-development implementation activities in the development of complex products.

Table 10. Important factors for successful implementation activities: Processes and Management (without mutual ranking).

Processes		Management	
Process Quality	The maturity of the processes	Professional Project Implementation	Important to have skilled project leaders for effective project execution.
Clear Development Process	In the sense that everyone in the organization understands and is able to execute the processes in use.	Multi-project / Portfolio management	The company must be able to handle multiple projects and maintain effective project execution.
Tools	Updated tools that support the innovative product development work the best way possible.	Risk Management	All risks must be identified and assessed.
Industrial Structure	Meaning that the right support systems are in place and can be used by the projects.	Handle Dependencies	Dependencies could involve business, resources, technical issues and projects.
Clear Metrics	The use of metrics will improve the understanding of the performance of the process.	Global and Local Development	Find the right setting for what should be developed where.
Requirement Management	A structured way of handling requirements	Clear Objectives / Requirements	Management must be clear about what is expected from the people involved in the project.
		Supplier / Partners	The ability to handle suppliers and partners during the development.

Table 11. Important factors for successful implementation activities: Technology and People (without mutual ranking).

People		**Technology**	
Feedback	Feedback to the people involved in the project to further develop their competence.	Technical Platform / Architecture	Makes it possible to share technology and thereby development cost between projects /applications.
Culture / Attitude	In the global world of today it is important to have all involved working together as a team.	Pre-development of Technology	Should support the implementation to improve time-to-market and quality.
Organization	Important that the organization evolves with the changes that occur in the firm and thereby support projects the best way possible.		
Resources	Important to have the right amount of motivated personnel available for the project.		
Competence	Involves securing a diverse and excellent competence in the company		
Incentives	Could be in the form of bonuses and other carrots.		

5.3.3 Product Development Sales and Delivery Activities

The third activity category of the proposed framework consists of the product-development sales and delivery activities. It is during these activities that an enterprise capitalizes on the value of its developed products, since the activities in this category are directly related to the revenues and profits. These give a clear indication of the success not just of the product-development sales and delivery activities, but also of the total product-development performance. It is important to understand that the sales and delivery activities are not necessarily conducted as part of a new product development. It is often the case with complex products that a tender procedure it conducted before the actual development is initiated. This tender procedure may include not only sales activities, but also planning activities. There may also be implementation activities if e.g. a prototype or demonstrator must be developed in order to demonstrate the product or solution tendered. This chapter will not discuss product-development sales and delivery activities further, since there are already well-established theories in the literature (e.g. Kotler, 1996; Slack et al., 2007), but this category is important as an essential part of the proposed holistic product-development framework.

5.4 Discussion and Analysis

In the following sections the result is discussed and analysed in relation to the literature.

5.4.1 Product Development Planning

The most important determinant of profitability is the development of a unique, superior product with real value for the customer (Cooper, 1995; Luecke, 2003). It is in the planning activities of the product-development framework that this issue should be addressed and it is vital for the performance of the product-development process that they are performed successfully. The market environment analysis is the main activity that serves as the foundation for the information input to the company. It is important that the analysis covers all aspects of the intended customer and market segment e.g. technology, competitors, the customer's future business and process, market and more. The market environment analysis activity is important since the sources of innovation are typically found among users, manufacturers, suppliers and others (Hippel, 1988).

On average, 70 percent of the product cost is fixed after the specification and design process (Christensen and Raynor, 2003). The best way to achieve this is to have front-loaded projects with adequate competence present when the important early decisions are made in the project (Morgan and Liker, 2006). Success comes from improving the understanding and cooperation between different departments in a company, especially between product development and marketing (Griffin and Hauser, 1996).

In contrast to *what and why*, the *how and when* questions are more focused on utilizing a company's resources in an optimal way, with efficient project execution as the most important objective. A key success factor for *how and when* is not to initiate implementation activities if key resources are unavailable. If a new development project is started in an already fully utilized organization it will only slow the other projects down (Seider, 2006). This may lead to a decrease of the overall performance. Companies tend to initiate project after project, believing performance is increased, without securing the key competence and resources first (Goldense and Power, 2005). Moreover, technology planning that supports and speeds up product implementation activities is a vital success factor (Wheelright and Clark, 1992). The planning ends and the implementation begins when the firm decides to execute the product-development project, i.e. by implementing the planned product.

5.4.2 Product Development Implementation

The product-development implementation activities can be compared with a manufacturing process, since the best possible performance is to deliver what is specified and planned for, by the product-development planning activities. However, for that to be a good comparison an essential factor is that the *Technology* supports the project with pre-development and re-use. This will increase the predictability of the implementation by decreasing the inherent risk associated with technology development activities. It is also vital, for product-development implementation activities, that the *People* involved understand what is required of them, in order to create and realize what has been decided in the planning activities.

In the implementation category the ultimate success is to achieve the specified time-to-market with sufficient quality and cost. In order for *Management* to make *People* motivated and productive it is essential that the project members find their assignments professionally challenging, and leading to accomplishments, recognition, and professional growth (Kahn, 2005). A study by Koehler and Weissbarth (2004) reveals that most new products, from automobiles to washing machines, are over-engineered, because the customer needs are not communicated and managed properly. It is important for managers and decision makers, during the implementation activities, to continuously update and communicate organizational goals and project objectives decided on in the planning activities. It is also important to make known for the personnel the relationship and contribution of individual activities to the overall product development and business case (Kahn, 2005).

An illustrative metaphor to describe the product-development implementation activity categories is to relate them to the systems needed for railway transportation. It may be possible to run a train with bad tracks, but it will be a lot smoother ride, enabling a higher speed of the train, if the tracks are maintained and well functioning and it is the same thing with the *Processes* category of the product-development implementation, in the sense that they will disable or enable high performance. The train operator is responsible not just for the train running from A to B but also for meeting the timetable, similar to the responsibilities of the *Management* category.

To be able to transport passengers the operator uses trains, which represents the *Technology* and it is important that the train is able to keep to the specified timetable. The train operator uses the signaling system to enable safe train rides and the possibility exists to run multiple trains, similar to handling multiple projects and the function of a performance-measurement system. To be successful, the train operator must have skilled personnel who understand the passengers' needs. Skilled People who understand the customers' needs and requirements are needed in the development of a product.

Success for the train company depends on the system components functioning together. When the train is moving in the right direction and the customers are sitting comfortably in the railway car, they want to stay on the train and they will use the train again, since it fulfills their needs and expectations.

5.4.3 Comparison with Success Factors in the Literature

It is difficult to directly compare success factors in the literature with those identified in our research because they are defined at different levels of abstractions. An example to illustrate this issue is strategy, identified in Ernst (2002) and in Cooper and Kleinschmidt (2007) as an important success factor. In our framework this strategy is sorted into the *why*, *what*, *how*, and *when* subcategories. In this analytical validation of the success factors identified in our research, the main objective is not to emphasize detailed variations but rather highlight major differences in comparison with the literature. With this in mind, an analysis of the mapping in Table 12 indicates that the technology category is not explicitly addressed by any of the other studies found in the literature. This is an important finding that might be explained by the fact that they focus on a wider set of companies and products, while this research explicitly focuses on the development of complex products. In the context studied, technology is per definition one important aspect of product-development performance. The technology category involves, for instance, platforms or product-line architectures that are used across a set of related products, making it possible to share and re-use technology and thereby share both development and product costs between different products and applications.

Pre-development of technology, as support for the product-development implementation activities, is another factor that will affect important aspects such as time-to-market and the quality of the developed product. Moreover, the technological infrastructure, e.g. the architecture of a system, can have both positive and negative effects on the product-development performance of an enterprise. The architecture may exhibit different levels of quality attributes such as evolvability, flexibility, and testability which have an effect on performance when evolving a long-lived system. Christensen (2003) has conducted a thorough study within the disk drive industry, highlighting the importance of this issue.

Table 12. Illustrates how the categorization of success factors identified in this research, maps to the success factors identified in the literature.

	(Tang et al., 2005)	**(Ernst, 2002; Cooper and Kleinschmidt, 2007)**	**(Adams et al., 2006)**	**(Bessant and Tidd, 2007)**	**(Chen et al., 2010)**
What	Product strategy	Customer integration, Strategy	Portfolio management, Innovation strategy, Commercialization	Market knowledge, Clear product definition, Product advantage	Goal clarity
Why	Product strategy	Strategy	Portfolio management, Innovation strategy, Commercialization	Market knowledge, Clear product definition, Product advantage	Goal clarity
How	Product strategy	Strategy		Market knowledge, Clear product definition	Goal clarity
When	Product strategy	Strategy	Portfolio management, Commercialization	Market knowledge	Goal clarity
Technology					
Management	Leadership, Organizational culture, Information, Human resources	Organization, Role and commitment of senior management, Culture	Innovation strategy, Knowledge management, Project management, Organizational structure	Project organization, Top management support	Top management support, Team leadership, Team empowerment
Process	Project execution, Information, Product delivery, Results	Product-development process	Input management, Knowledge management, Project management	Risk assessment, Proficiency in execution	Process formalization, Process concurrency, Iteration, Internal integration, External integration
People	Information	Organization, Culture	Organizational culture, Input management	Project resources, Proficiency in execution	Learning, Team experience

Both the rate of improvement of a technology's performance and the rate at which the technology is adopted by the market have repeatedly been shown to conform to an s-shaped curve (Schilling, 2006; Cetindamar et al., 2009). The ability to assess when the currently used technology has reached the end of such an s-curve, and hence is in need of, for example, improved inner qualities in the architecture, would clearly be beneficial especially for the efficiency dimension of product-development performance.

Moreover, the *how* and *when* questions in the product-development planning are less emphasized in comparison with the questions of *what* and *why*. The aspect *when* is important since the product-development portfolio is commonly overloaded in the search for higher efficiency. However, such an overload often results in an increased product-development project lead time (Seider, 2006). From the point-of-view of a product-development manager the success of the overall portfolio is of greater importance than the performance of an individual product-development project. Studies focusing on the success of an individual product-development project, are likely to miss out on the importance of the *when* aspect of the product-development portfolio performance. During the product-development implementation activities it is *management* that is highlighted as the most important success factor; this result being in line with all of the studies included in Table 12.

5.5 Conclusion

Peter Drucker made the following famous observation: "Because the purpose of business is to create a customer, the business enterprise has two and only two basic functions: marketing and innovation. Marketing and innovation produce results; all the rest are costs." (Drucker, 1985). Today, when top management is surveyed in the US, their priorities in order are: finance, sales, production, management, legal, and people (Trout, 2006). Missing from the list are marketing and innovation. With this in mind, this chapter has proposed a holistic framework for evaluating the performance of the product-development activities by categorizing them as planning, implementation, and sales and delivery activities. The three categorize all require unique specific competences and objectives.

In a performance-measurement perspective it is vital to differentiate between Planning and Implementation activities, since their objectives differ. Product development is a complicated process and it is therefore essential to adopt a holistic framework to be able to understand the different factors required for success, because the product-development process can never be stronger than its weakest parts. The product-development process cannot be considered successful until the targeted customer needs are fulfilled and the new product generates profit. High performance is the result of having efficiency and effectiveness in all the activities in each of the three categories.

The role of the product-development framework should be viewed as a conceptual tool not only to evaluate and analyze performance but also as ground for improving the ability of an organization to successfully develop and bring new profitable products to the market. In our opinion a competitive advantage arises when an organization understands its strengths and weaknesses in the product-development framework. The greatest increase in overall performance of any system is achieved by strengthening its weakest parts.

Chapter 6 Challenges in Evaluating Performance

This chapter focuses on issues related to evaluating performance, as identified in the multiple exploratory case studies, in the context of developing complex products in large organizations. The outline of this chapter is as follows; it begins with an overview of the specific literature connected to challenges in evaluating performance in product development; a presentation of the research approach and the findings related to the multiple exploratory case studies follows; the chapter concludes with a discussion of reasons for, and implications of the findings. This chapter is based on conference paper 3, as listed in Section 1.7.

As outlined in the Section 1.1, today's focus on product-development performance originated from performance revolutions within downstream activities of supply management and production. For downstream activities such as production and supply-chain management there are well established methods for evaluating performance. For example, in manufacturing, inventory turnover and gross margin percentage may be used as measurements of the performance of the manufacturing process (McGrath and Romeri, 1994).

In contrast, when Rubinstein (2004) examined the trends in the field of engineering and technology management, he concluded that the methods used for evaluating projects have not been improved much during the last 50 years. One explanation for this situation may be found in the arguments of Adams et al. (2006). They argue, on the basis of an extensive review of measurements in innovation, that the literature regarding measurements in product development is characterized by a diversity of approaches, prescriptions, and practices that can be confusing and even contradictory. However, today's market is more competitive than ever, as described in Section 2.1, making the demand for the product-development process to continuously deliver new products greater than ever. Hence, it is of great interest to explore how performance measurement is handled in practice, since there seems to be limited support from theory, as concluded in Section 2.4.

By nature and definition, product development has a long term effect, is often subjective in its value to the organization and is frequently intangible. However, the obsession with quarterly earnings requires managers to choose between short-term results and the long-term well-being of the organization (Koller et al., 2005). A short-term cost focus may affect more long-term results or vice-versa. Cooper and Edgett (2008) argue, in line with these findings, that companies today are preoccupied with minor modifications, product tweaks, and minor responses to salespeople's requests, while true product development has taken a back seat. This is evident in the development of complex products, since these products often are long-lived with new features added during their lifetime. Product-development activities are thus incremental rather than radical in character, except when a new architecture is developed that from a company point of view can be considered to be a radical development.

Performance in product development is, in relation to other business processes, not a well defined concept in the literature. This is illustrated by Table 2 in Chapter 2. Existing models of performance in product development are almost exclusively focused on the artifact instead of the performance of the activities required for its development (O'Donnell and Duffy, 2002b). One explanation why many studies focus on the artifact instead of the process may be found in the arguments by Stainer and Nixon (1997); they argue that the nature and definition of product development makes the traditional performance-based measurements inappropriate. With this in mind it is important to explore how performance is perceived and evaluated in practice within companies developing complex products.

Performance measurements are important. They may be used as an aid to determine priorities, e.g. within different activities, and as means of providing direction to teams by highlighting their performance and indicating where improvements would be most beneficial. However, performance measurements must be kept in perspective; they must support the product-development process and goal attainment (Nixon, 1997) based on the business strategy. Since performance measurements are powerful it is important to align the measurement system with the strategic priorities of the organization (Neely et al., 2005). Performance measurements may function as the primary strategic deployment tool. A goal-focused measurement system is the best vehicle for institutionalizing targeted changes in the management process and galvanizing management action (Stainer and Nixon, 1997).

A more detailed presentation of performance measurements in product development is given in Section 2.4. Finding the right measurements to effectively monitor and evaluate product-development performance is critical; failure to select and implement the right measures can mean missed opportunities, misallocated resources and poor decision-making.

6.1 Research Approach

As the reviews of the literature indicate, performance in the product-development process is an ambiguous concept and could mean different things in different contexts. Moreover, Gharajedaghi (2006) argues that effective performance measurements need to be grounded in relevant performance criteria. It is therefore of great interest to investigate the perception of performance and its affect on what performance measurements are used in order to evaluate the particular perception of performance. An important aspect is to understand how performance is perceived and to determine if there is a link to the measurement system. In this chapter the three sub-research questions related to research question 1 in Chapter 3 are studied.

Rq 1.1 How is performance in the development of complex products perceived by managers and decision makers?

Rq 1.2 How is performance measured in the development of complex products?

Rq 1.3 How is the performance-measurement system perceived by managers and decision makers in the development of complex products?

It was decided to use multiple exploratory case studies, as described in Section 4.3, since they are particularly beneficial when the variables are still unknown and the phenomenon is still not understood (Meredith, 1998). The case studies mainly involve semi-structured interviews (Robson, 2002) and analyses of the documentation of the performance-measurement system concerned. This approach has been complemented with seminars and discussions of the results in both academia and industry. Additionally, a survey has been conducted to strengthen the validity of the finding that there is a weak link between what is perceived as a success factor and what is measured by the performance-measurement system. By adopting several data sources, triangulations of the findings are possible. A detailed presentation of the research approach is found in Chapter 4.

6.2 How is Performance Perceived?

The perception of performance was discussed in all of the 54 semi-structured interviews. All interviewees were asked how they perceive performance in product development, based on their role in their organization. Some of the typical views on performance in product development are outlined below. The first general impression is that there seems to be one definition for every interviewee, all of the definitions given where somewhat different. However, some factors were common to the various perceptions of performance i.e. the dimensions of cost, time, and quality. Some of the statements of how performance is perceived follow[1]:

> **Project manager at Case Company E:** "Performance in product development is to develop the requirements with as low development cost, product cost, to as low price, in as short time, with the highest quality possible."

> **Manager product planning at Case Company B**: "Performance can be measured both in time and in cost. It relates to delivering solutions that are cost effective."

> **Line manager at Case Company C**: "Performance depends on what you want to achieve with the product-development activities, there are three important parameters time, cost, and quality and it is important to succeed with all three."

> **Sales manager at Case Company A**: "Performance is if it took three years to develop a product a couple of years ago, then I want it to take 6 months today."

> **Manager at Case Company B**: "I do not know what performance in product development really is I do not think that we as an organization know either."

> **Business unit manager at Case Company A**: "Performance is to shorten the cycle times, deliver on time and reduce time to market. If you look at the business case and the cash flow it is cash in and cash out, normal NPV calculations, it is easy to see that it is important to have a positive cash flow as quickly as possible. That is equivalent to have short cycle times. Quality is also important we have high costs related to everything delivered to a customer that does not work properly."

> **Site manager at Case Company E**: "Performance is the ability to break down and estimate the time for implementing the requirements and to know what is needed and then be able to fulfill the time plan and the budget that is available."

> **Project manager at Case Company C**: "Performance for top management is not to increase the output but instead have the same output but decrease the resources."

> **Product development manager at Case Company D**: "Performance is to create the largest possible ROI, this can be measured by growth, gross margin, and how well we fulfill what we want to achieve in terms of, cost, quality and time."

[1] The statements of performance are direct translation from Swedish

> **Technical product manager at Case Company E**: “Performance in product development is about creating realistic goals that can be used to motivate because it is possible to overview what is needed.”

> **Product development manager at Case Company C**: “Performance in product development is about evaluating the value. Within software development you can measure lines of code per hour. If you implement right you are efficient, the number a faults should be as low as possible. It can be everything from a faulty interpretation of the customer requirements to a fault in the implementation or manufacturing process. It depends on making the right decision in the right often early moment. Today instead of measuring the performance it is the gut feeling that is important. It depends on the difficulty of finding ways of measuring the performance.”

One of the findings from an analysis of the perceptions of performance is that there was no difference between the different case companies. The difference was more on an individual level rather than organization-dependent. In none of the five case companies could a common organization-specific definition of performance be identified in terms of what is important for success. One possible explanation of this result is that in all of the organizations, several development projects are executed in parallel and the factors of importance may vary in different projects. In some development projects, the development speed may be most important in order to meet a specific delivery date. In another project, the product cost may be the most important in order to be competitive in the market. This might be explained by this exploratory research not focusing on specific projects, but rather on the development function within the organizations studied. At one case company, however, there was a difference in how performance was perceived by the product management function and by the project management part of the organization. Product management emphasized from a financing point of view that it was important to have predictability in the planning of the project. In contrast, project management stressed the importance of improving efficiency in the execution of projects.

6.3 How is Performance Measured?

The second research question posed in this research study relates to how performance is measured in practice. In contrast to how performance is perceived within the case companies, there were several similarities between the case companies approach to measuring product development. Four of the five case companies had a limited set of performance measurements in use for product development. Only one of the five case companies (case Company D) differed in this respect from the others. Case Company D measured a lot of different activities, as one process manager stated:

> We measure everything we can, even if there is no clear need for it.

Moreover, what distinguished case company D from to the others was that they had an articulated process for their measurements, based on the ISO/IEC standard 15939 (IEEE 15939, 2009), something not used in the other four case companies. Instead, in the absence of a measurement process, the use of measurements was more individual and differed depending on the responsible manager.

In line with how performance is perceived, the bulk of the measurements utilized by the case companies involve the traditional dimensions of time, cost, and quality, often in a lagging result perspective. Typical measurements related to these dimensions are product cost, project cost, time delays in the project plan etc. Besides those important, but limited measurements, other measurements include for example the earned value methodology. The earned value methodology is presented in Chapter 2.4. Within case company C the earned value methodology was used by the development projects with a positive result. However, as one of the managers put it:

> Earned value only tells us how well the plan is executed and cannot be used as a way of measuring performance.

Another interviewee explained that:

> New earned value curves are calculated every week and it is a good way of visualizing for an outsider how well we are performing according to plan, over or under the curve. Still, if the planning process is not enabling high performance there will never be high performance, no matter what the schedule and cost performance index curves are showing.

The earned value methodology is used in varies forms in four of the five case companies.

Other ways of evaluating performance may be to use measurements based on the formula X / product-development unit, e.g. features / development hour. How many development hours do you get for one million SEK? The amount of development hours you get from an engineer is one aspect of internal performance. In case Company B the following example was discussed. In total there is about 1750h each year available for each engineer. The target is that 1540h should be spent in direct activities in the projects; the remaining hours can be spent on activity development, education, departmental meetings, or absence due to illness. This is a measurement of the availability and operating hours. It is one way of measuring the performance of the organization, i.e. time utilization effectiveness.

Table 13. Summary of the findings related to performance measurements

Findings related to performance measurements	Case companies where the findings were identified
1) Performance measurements are of lagging character	A, B, C, D, and E
2) The focus of the performance-measurement system is to report project progress	A, B, C, D, and E
3) Performance measurements are mainly focused on the later phases of the development	A, B, C, D, and E
4) Measurements of value creation are missing	A, B, C, D and E
5) Productivity measurements are missing	A, B, C, and E
6) The technology or architecture is not evaluated by the measurement system	A, B, C, and E
7) Quality measurements are typically focused on the artifact not on the process	A, B, C, D, and E
8) The fiscal year budget is stronger than the development project budget	A, B, C, D, and E
9) The financial reporting systems do not focus on the development activities	A, B, C, D, and E
10) The business dimension is not evaluated	A, B, C, and E
11) What is important for high performance and what is measured differs	A, B, C, D, and E

Table 13 presents a summary of the findings related to how performance is measured within the five case companies. Below is a summary of the findings in Table 13 regarding performance measurements as identified in this exploratory research:

Performance measurements are of lagging character - No structured way of using leading measurements of performance was identified. At the same time, the predictability was low and overruns were common at all of the case companies. Overruns in a development project usually have higher priority as compared with projects not started. Hence projects costing too much continue at the expense of new projects. As one manager at case Company E characteristically expressed it regarding the focus on cost:

> We know how much we have spent on the development of new products but we do not know how much we have gained for these spending.

It is also common for the development costs to be underestimated at the beginning and the focus is then transferred to the changes to these predictions and not on the value created by the project and how this will change during the development time.

The focus of the performance-measurement system is to report project progress - The stakeholders primarily focused on by the performance-measurement system are upper management in order to report the progress. As one manager at case Company C expressed it:

> The performance measurements focus on the project manager and not on what enables high performance.

Performance measurements are mainly focused on the later phases of the development - Few measurements are made in the early phases of the product development. However, during the focused group interview, the early phases of the product-development process were stressed as important in order to enable an effective and efficient implementation in the later phases. This finding is in line with the finding that most measurements are lagging in character.

Measurements of value creation are missing - No measurements of value created or value to be created were identified. When asked about value creation a typical response was that it is difficult to demonstrate the value of a new product that is the incremental development and replacement of a product already in the market. All of the five case companies do have a structured process to develop a clear business case in order to initiate a development project. This information is used in order to gather internal funding for the project.

Productivity measurements are missing - The concept of productivity as input divided by output is not measured. Instead the focus of the measurement system is mainly on the cost and time perspective i.e. the denominator not on the numerator of productivity. There are no productivity measurements in use; instead there is a focus on the denominator of the productivity calculations i.e. the resource consumption part while the gain or the result of the effort is missing in the measurements. A typical response when asked about productivity is that it would be interesting to have productivity measurements, in order to balance the perspective of cost, time, and quality, with the value created.

The technology or architecture is not evaluated by the measurement system - The technology or architecture used in the products is not part of the performance-measurement system, even though it affects the performance. Only case Company D had measurements related to their technology and how it affects the performance. However, in the focused group interview, as presented in Chapter 5, the technology factors such as the product architecture was stressed as one important factor for both the effectiveness and the efficiency in the development of complex products.

Quality measurements are typically focused on the artifact and not on the process - Quality is typically measured through MTBF, quality deficiency costs, error reports from the field etc. One internal study within case company E concluded that all the faults identified in the testing and verification process could have been found in the previous step of the development process. The measurement system in use had a clear focus on reporting what had already happened i.e. had a lagging perspective.

The fiscal year budget is stronger than the development project budget - On a senior management level the fiscal year reporting has a higher priority since it reflects the organization to its external stakeholders. One of the managers within accounting in case company B highlighted as an issue that the reporting of the organization follows a calendar year and is designed to also fit in with reporting to the stock market while the financial reporting is very much dependent on where it is in the development project lifecycle.

The financial reporting systems do not focus on the development activities - The reporting systems for the development projects have different objectives and the most common is an external reporting perspective and not for continued improvements of performance. It is difficult, for example, to see the activities performed in specific phases of the development; the focus is on monitoring the costs and other consumptions of resources on the project.

The business dimension is not evaluated - Almost no development projects are terminated once they have been initiated. Even though all the case companies have some kind of Stage-Gate model in use, projects were never or almost never terminated. When it occurred, the project was postponed due to budget cuts or similar and conducted at a later time. A development project started is a project completed. Hence, as the technical and market uncertainty decreases, the business side of the projects is not always reevaluated during the progress of the project.

What is important for high performance and what is measured differs – What is measured is lagging indicators, and what is important is leading indicators. Through the focused group interview a number of factors enabling high performance in the development of complex products were identified. A presentation of the findings related to that study is given in Chapter 5. An interesting finding was that what managers say is important and what is actually measured differs. In the following section, this relation is further researched using a survey.

6.3.1 The Weak Link between Success Factors and Performance Measurements

A survey was designed to further research the link between success factors and what is measured. The hypothesis for the survey is that there is a weak link between what is perceived as success factors and what is measured by the performance-measurement system within the development of complex products. Section 4.3.6 presents the methodological aspects of the survey.

To test the hypothesis, the success factors identified by Chen et al. (2010) were selected with the addition of architecture that was identified in Chapter 5 as an important success factor within complex product development. The questions asked in the survey were arranged in three steps that were repeated for each of the 13 success factors.

1. How important is Success Factor X for successful product development in your organization according to your opinion?

   [1= Not at all - 7 = Most important]

2. How important is Success Factor X for successful product development in your organization according to the organizations opinion?

   [1= Not at all - 7 = Most important]

3. To what extent does your organization systematically evaluate Success Factor X through a measurement system?

   [1 = Not at all - 7 = Fully]

Table 14 shows the mapping of the success factors used in the survey and the question numbers as used in Figure 17 where the result of the survey is presented. As an example, the questions for goal clarity are shown:

201. How important is *Goal clarity* for successful product development in your organization according to your opinion?

[1= Not at all - 7 = Most important]

202. How important is *Goal clarity* for successful product development in your organization according to the organizations opinion?

[1= Not at all - 7 = Most important]

203. To what extent does your organization systematically evaluate *Goal clarity* through a measurement system?

[1 = Not at all - 7 = Fully]

On the basis of the findings in Figure 17, it is concluded that what are perceived as important success factors are not measured by the measurement system within the development of complex products. All of the factors in Table 14 were regarded as success factors by the respondents. In general, the respondents perceive the success factors as more important compared to the organization in general. This is an indication that all the respondents are interested in performance in product development.

Table 14. Overview of the success factors investigated in the survey.

Success factor	**Numbers in Figure 17**
Top management support	101-103
Goal clarity	201-203
Process formalization	301-303
Process concurrency	401-403
Iteration	501-503
Learning	601-603
Team leadership	701-703
Team experience	801-803
Team dedication	901-903
Internal integration	1001-1003
External integration	1101-1103
Team empowerment	1201-1203
Architecture	1301-1303

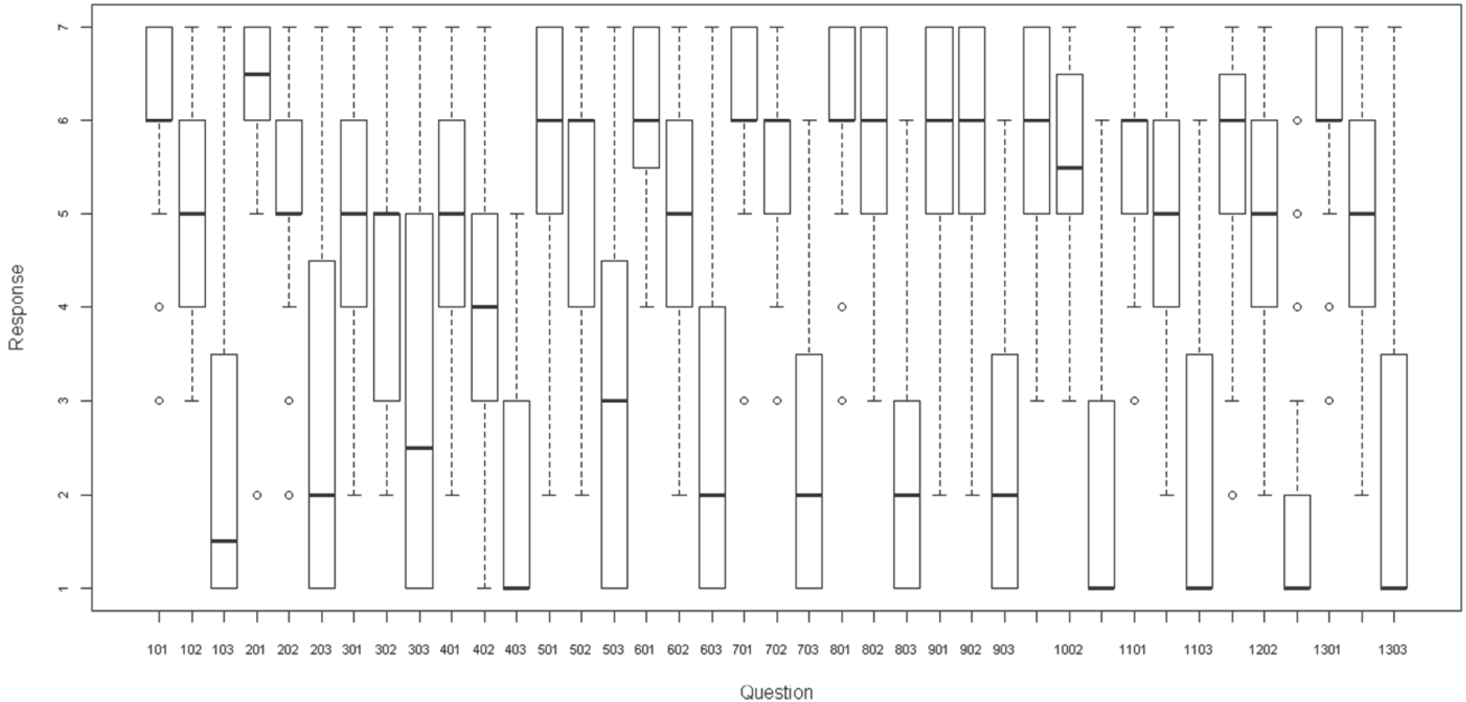

Figure 17. The result from the survey visualized as Box-and-Whisker Plots

6.4 How is the Performance Measurement System Perceived?

The third research question in this chapter is how the performance-measurement system is perceived within the organization. Table 15 presents an overview of the findings related to how the performance-measurement system is perceived.

Table 15. Summary of the findings related to how the performance-measurement system is perceived.

Findings related to the perception of the performance-measurement system	Case companies where the findings were identified
Performance measurements are important	A, B, C, D, and E
There is a need to improve how performance is measured	A, B, C, D, and E
A performance measurement process is missing	A, B, C, and E
No mental/abstract models of performance exist	A, B, C, D, and E
A learning perspective is missing	A, B, C, and E

A summary of the findings related to the perceptions of performance-measurement systems presented in Table 15 is given below.

Performance measurements are important – 53 of 54 interviewees acknowledged that it is important to have a good performance-measurement system in their organization. Even in the organizations where there were few measurements an explicit need for having performance measurements was expressed. According to one manager at case company A:

> Measurements show how the reality is and it creates incentives for improvements. What cannot be measured cannot be improved.

There is a need to improve how performance is measured - A strong will to improve the performance-measurement system was clearly identified in the semi-structured interviews in all of the case companies. A majority of the interviewees argued that the performance-measurement system needs to be improved if it is to reflect the performance of the organization. 52 of 54 interviewees were positive to improvements of their capabilities within this area. It seems to be common knowledge that the performance measurements are not evaluating the real performance in a holistic supporting manner. However, no ideas of how to improve the current state were identified in the interviews. Instead two of the 54 interviewees expressed the opinion that performance in product development is impossible to measure.

A performance measurement process is missing – Out of the five case companies, only case Company D had a clearly defined process for managing the performance measurements. This case company was using a process based on the ISO/IEC standard 15939 (IEEE 15939, 2009), a software engineering and software measurement process. In the other four case companies more ad hoc processes were used, very much dependent on the individual manager. As one manager at case Company A expressed it:

> We have improved our measurements a lot during the last five years; we measure things like MTBF, delays, time adherence, project cost, product quality etc. They are fairly good measurements but the difficult thing is what to do with the information. Quotes like what gets measured gets done are not always true. It is often easy to explain the difference and variance in the measurements. The difficult thing is to make sure that it will not be repeated by improving our way of developing products.

The result of the performance-measurement system is not common knowledge - The information gained from the performance-measurement system is not common knowledge in the organization. What is measured is typically not spread in the organization. Usually there is a structured way of setting the target for each performance measurement and there might even be a special place on the intranet, but it seems that most measurements are never presented or spread in the organization and therefore not discussed outside the management group.

No mental/abstract models of performance exist - There were no explicit or mental models in use, at any of the case companies, to help managers to reason and discuss performance. However, one process manager at company C compared the performance-measurement system with the role of a regulator for a technical system. Similarly, a line manager at company A discussed the similarities with sports.

> In handball, if you want to measure the performance of your team you should measure the number of goals you score and concede. If the team is not performing as expected it does not matter how good you are at measuring the number of goals, it does not help your team to excel. Instead you should focus on e.g. completed passes, fitness level, to have the right player in the right position etc.

However, examples such as these were the only ones and they were never elaborated into something that could be used in a more structured way in the organization.

A learning perspective is missing - There are many measurements made during a development project, especially at the later phases, often involving time and cost. Measurements of the early phases and the outcome of the development project are missing. Only case company D of the participating companies has a structured post-launch review process. The other firms focus on the evaluation of the project once it has been completed in terms of project execution proficiency, but not in terms of value created. The learning perspective is not associated with measuring performance in the product development.

6.5 Discussion and Analysis

One of the findings from the literature review, in Chapter 2 is that there is no common perception of performance and this finding was also identified in all of the five case companies. There seems to be one definition of performance for every interviewee. However, cost, time, and quality are common elements in the various definitions of performance, while value creation was only mentioned by three of the 54 respondents. This might be explained by the difficulty of measuring and putting a quantitative value on the output, especially during the development. Also, no unified perception exists of what is most important, in terms of cost, time and quality, within the case companies.

One explanation for this may be the result of having various stakeholders, thus diversity in the aspirations. A clear strategy for what is important to prioritize within the organizations seems to be needed. At the same time, there are no mental models of performance. Such a model is needed in consideration of the behavioral complexity that characterizes the extent to which there is diversity in the aspirations, and values of decision makers (Roth and Senge, 1996). Behavioral complexity is characterized by a conflict in assumptions, beliefs, and perspectives. This might explain why the prioritization of cost, time, and quality differ, depending on the interviewee. Under conditions of high behavioral complexity, it is difficult to get people to agree on what should be done because they see the world differently and because they have different preferences and goals (Roth and Senge, 1996). Hence, a performance-measurement system supporting the strategies and action within the organization might clearly be beneficial in terms of communication of priorities and what is to be achieved.

In line with the findings in the literature review, no measurements of value created or value to be created were identified. Measurements of productivity were also missing. The focus of the measurements systems was instead on cost, time, and quality. This might explain, as argued by Cooper and Edgett (2008), why companies today are preoccupied with minor modifications, product tweaks, and minor responses to sales people's requests. This may also be the direct result of not having value or productivity measurements in place. Another explanation for this issue might be the fact that investment in product development is still considered as a cost. The available budget is often expressed as a percentage of the turnover, not on a pull basis depending on the ideas and the value creation possibilities. Add to this the arguments of Slack et al. (2007) that the common idea of performance measurement is as the process of quantifying action. This limited scope of performance measurements easily end up in strategies to measure what can be measured, instead of what would be important to measure. A typical case illustrating this issue is the measurements of quality that are typically focused on the product and not the process. The product is more tangible than the process. Measurements such as MTBF, quality deficiency cost, error reports from the field etc. are all lagging measurements of the product-development performance. As one internal study within company E concluded, all the faults identified in the testing and verification process could have been found in the previous step of the process. This limitation is supported by O'Donnell and Duffy (2002b) in their conclusion that most of the research focus on performance goals of the product and not on the process. Moreover, performance-measurements systems have traditionally been designed and managed by lag-oriented accounting and finance functions (Bourne et al., 2000). This cements the view of product-development activities as something that should be measured in terms of resource consumption rather than value created. Add to this the stock market obsession with quarterly earnings (Koller et al., 2005), which further motivates the cost focus of the performance measurements. In this chapter it is therefore argued that it is vital to adopt a more holistic perspective of performance evaluation where performance measurements are one way of evaluating the performance. By limiting the focus on quantifying actions, a reduced and limited scope of the performance evaluation system is obtained.

With this in mind, it is not surprising to find that there is no relation between what managers identify as important and what is measured by the performance-measurement system. Examples of this issue are the early phases of the product development and the technology i.e. the architecture used in the products. Both are important factors for a high performance development function of complex products. However, there are no or very few measurements relating to these factors in the five case companies. This finding is also acknowledged by e.g. Bremser and Barsky (2004) in their findings that technology is very important, that many firms depend on it for its competitive advantage, but that it is not easily measured by traditional financial metrics. This can explain why there are few measurements related to the technology and architecture. It may be the result of limiting the scope of the performance evaluation system to something that is used to report to external stakeholders. Of the motivations for performance measurements indentified by Chiesa et al. (2009a), only the diagnostic activity is supported in this study. The important perspectives of learning, communication and coordination, risk and uncertainty management, and performance improvement are absent. It was also concluded that overall, there is a need for extending the scope of the performance-measurements system to also include measurements of internal stakeholders i.e. the ones directly involved in the development activities where the objective would be to improve the performance of the product-development process.

An important finding is that the performance measurements employed by the case companies, strongly relate to what managers perceive as performance in product development. It is argued in this research that performance measurements affect the perception of performance, instead of the other way around. This finding is supported by Chapman and Ward (1997) in their finding that performance is perceived primarily in terms of the dimensions that can be measured, such as time and cost, or particular aspects of quality. Still, there is a clearly articulated need to improve the way the case companies currently evaluate performance. A strong genuine will to improve the performance-measurement system was identified, but there have been no or few attempts in order to do so. Overall, there seems to be a need for performance evaluation even though there are no articulated performance criteria to derive measurements from and evaluate against. All of the 54 interviewees were positive to improvements in the organizations' capabilities within this area. The similar findings of Driva et al. (2001) are that without exception, all of the case companies wanted to improve their performance measurements.

There seems to be no integration of the performance-measurement system with strategies and actions. No clear link between the strategy, the actions, and the measurements considered to be vital by Dixon et al. (1990) was identified. This is clearly seen in comments such as "we do not know what to do with the information the performance-measurement system gives us". Only one of the companies had a structured measurement process based on a standard (IEEE 15939, 2009). Since it is unclear who the customer and user of the performance-measurement system is such a process could prove to be very useful.

The basic function of any performance-measurement system lies in its integration into operative processes and in its actual use in prompting improvements leading to improved performance in the area targeted (Godener and Soderquist, 2004).

6.6 Conclusion

In this chapter performance evaluation from the point of view of managers and decision makers involved in the development of complex products is investigated. The literature reveals that the area of performance measurements in product development is a diverse field of research. This is seen in both the literature, where no commonly adopted ways of defining performance or evaluating performance exists, and in practice where no consensus in perception of performance exists, even if cost, time, and quality dominates both the perception of performance and its measurements. It is concluded in this research that the performance-measurement system has affected, thus limited the perception of performance in product development. This might explain why value creation and learning is not associated with measurements of performance. At the same time managers are dissatisfied with the current performance evaluation systems, without having any ideas of how to improve the situation. It is argued in this research that a change in the performance-measurement system should begin with the criteria for performance and how the performance evaluation system is used, not by focusing on what is easy to quantify in measurements. For this to become a reality a change in the way performance is perceived by managers and other stakeholders involved in product development is needed.

On the other hand, when asking managers about what is important for success, a completely different set of factors are discovered. Factors that have more of the character of a leading performance indicator, i.e. factors affecting the process. It is therefore argued in this research that managers today need to change their focus from performance measurements to what is important in order to be successful and determine relevant measurements accordingly. It is also important that not every measurement needs necessarily to be easily quantifiable, as long as there is something that can be used to improve the process. The important thing is that the evaluating system fulfills its purpose.

Traditionally, performance-measurements systems have been designed and managed by lag-oriented accounting and finance functions (Bourne et al., 2000). According to the findings from this study within complex product development, this is clearly evident. Hence there is a need to complement this limited application of the performance-measurement system, to also support continuous improvements, learning, etc. For this to become a reality much work must be performed to change the culture and perception of performance, since an effective measurement system must be grounded in its performance criteria. Future research should focus on the relevant performance criteria for product development, i.e. on what characterizes high performance in a particular project or organization. This changes focus to leading indicators of performance that can be used by managers and decision-makers during the development in improving the performance of the product-development process.

The basic aim of operations management research is to create scientific knowledge. At the same time, this field of research is practically oriented and practicing managers are among the major consumers of the knowledge created (Handfield and Melnyk, 1998). In this research the need for more holistic studies with a system perspective of performance evaluation in product development has been argued for by highlighting some of its challenges. More research is needed with a more cross-functional perspective in order to address these issues that are important for managers. There is a need for review articles and conceptual papers, integrating various fields of research such as marketing, operations management, engineering design, decision making, software engineering, and systems engineering in order to advance the state of knowledge in this field. It is also suggested that a future research opportunity would be to make use of the literature on success factors and performance measurements to permit the design of a measurement system based on what is important in order to achieve success.

Chapter 7 The Performance Measurement Evaluation Matrix

This chapter outlines a framework for evaluating a performance-measurement system, in relation to what is important for success. The chapter is arranged as follows, the literature specific to evaluating a performance-measurement system is presented first; this is followed by a description of the proposed framework i.e. the PMEX (Performance Measurement Evaluation Matrix) this being verified in three different case studies. The results of using the PMEX are then discussed and some general conclusions are drawn.

This chapter is based on the following publications: Journal paper 1 and 2, Book chapter 1, and Conference papers 6, 7, and 9, as listed in Section 1.7.

7.1 Evaluating the Performance Measurement System

A vast amount of research is available within the field of performance measurement (Neely, 2007), mainly focusing on the design and the implementation of new performance-measurement systems. However, the development and implementation of a new performance-measurement system is a time-consuming and costly process. In a recent survey, only 35 percent of executives were satisfied with their company's current measurements related to the development of new products (Andrew et al., 2008). Unfortunately, this survey did not investigate further what the executives were dissatisfied with. This may be explained by the problem of keeping measurements relevant to today's changing business and organizational context; "old" measurements are often not discarded and new measurements merely add to the confusion (Paranjape et al., 2006).

Poh (2001) presents a comparative study of different R&D evaluation methods using the Analytical Hierarchy Process method. However, the focus is here on a portfolio level rather than a project level.

Hudson et al. (2001) developed an evaluation typology that synthesizes current performance-measurement theory to evaluate strategic performance-measurement approaches found in the literature. The typology proposed by Hudson et al. (2001), as depicted in Table 16, consists of three sets of evaluation criteria addressing: (1) dimensions of performance, (2) performance-measurement characteristics, and (3) specifications and requirements for performance-measurement development.

Table 16. An evaluation typology of strategic performance-measurement systems

Dimensions of performance	**Performance measure characteristics**	**Specifications and requirements for performance-measurement development**
Quality	Derived from strategy	Need evaluation / existing PM audit
Flexibility	Clearly defined/ explicit purpose	Periodic maintenance structure
Time	Relevant and easy to maintain	Top management support
Finance	Simple to understand and use	Performance measure development
Customer satisfaction	Stimulate continuous improvement	Full employee support
Human resources	Provide fast, accurate feed-back	Set timescales
	Link operations to strategic goals	Clear and explicit objectives
		Strategic objective identification
		Key user involvement

The typology developed by Hudson et al. (2001) was developed to evaluate approaches to performance-measurement in the literature in order to evaluate their applicability for small and medium enterprises, not for evaluating the performance-measurement systems actually used. Few typologies of this kind appear in the literature, none relating to the development of complex products. Similarly, merely half of the ten reviewed performance-measurement design frameworks, by Pun and White (2005), included any kind of evaluation of the currently used performance-measurement system before a new system was designed.

The first step in developing an effective performance-measurement system is to obtain relevant performance criteria and define the performance measurements accordingly (Gharajedaghi, 2006). However, the performance criteria change according to the needs of the market as well as the pursued objectives of the organization. For complex products, the needs may change when developing a new product for a new market, as compared with the needs when a product is in maintenance and there is a new release of the product being developed. Hence, there is a need to evaluate the performance-measurement system in order to ensure that the current goals and needs of the organization are supported.

On the basis of the literature review conducted in this research, it is concluded that few research studies focus on the evaluation of performance-measurement systems and missing for the measurement systems in current use by companies. To address this issue, this chapter proposes a tool for holistically evaluating performance measurements within the development of complex products.

7.2 Research Framework

This section outlines the proposed Performance Measurement Evaluation Matrix (PMEX). The underlying assumption behind the PMEX is to evaluate performance measurements in relation to what is important to be successful. Hence, the framework of success factors presented in Chapter 5 is used in the PMEX. When a performance-measurement system is to be evaluated, it is argued that it is important to address *what* is to be measured and *when* it is to be measured. The motivation for a particular measurement, the *why*, is also a central issue in the process of evaluating a performance-measurement system, especially since every measurement involves a cost.

To address *what* is to be measured, the success factors of complex product development presented in the Chapter 5 are adopted in this chapter. An effective performance-measurement system is derived from performance criteria and this information should be used in defining the measurements accordingly (Gharajedaghi, 2006). In this research the Stage-gate model is proposed as a means of addressing the *when* to measure *what*. The Stage-Gate model is presented in more detail in Section 2.1.2. Since the Stage-Gate model represents the different phases of a product-development project it is useful to study the timeline of when a performance measurement is sampled. The PMEX, see Figure 18, has the different phases of the Stage-Gate model as one dimension of the matrix and the categorization of important success factors for developing complex products as the other dimension. The categorization of success factors included in the PMEX represents what is important to manage in order to obtain a high performance product-development process.

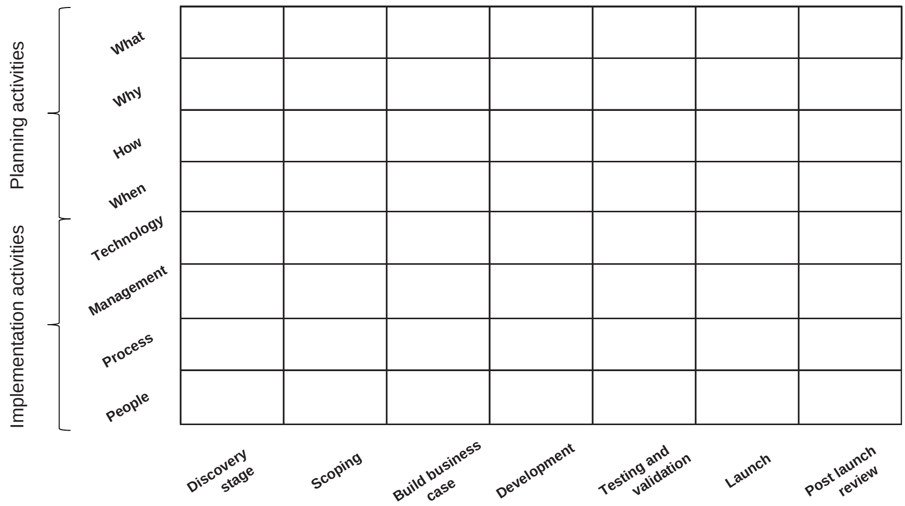

Figure 18. The PMEX.

It may be tempting to design a performance-measurement system that covers every square of the PMEX. This is not the intent of the PMEX and even if it is achieved, it would probably be difficult to make use of all the information provided. Instead, the PMEX should be viewed as a conceptual framework for product-development managers and decision makers in considering the performance-measurement system, in the sense of what needs to be measured, why it should be measured, and when it should be measured.

7.3 Research Approach

The research gap has been identified through a review of the literature. On the basis of the limited focus on evaluating performance-measurement systems, within the domain of complex products in particular, an inductive research approach was decided on. The review of the success factor literature concluded that there are few studies focusing on the development of complex products. Since the focus of this research is on the domain of complex product development, and most studies of success factors relate to more general domains, it was decided to adopt the success factors in this study.

The PMEX has been verified in practice through three case studies, as part of the multiple exploratory case studies presented in Chapter 4.3, intended to analyse the use of performance measurements in practise. The case companies i.e. Company A, B, and E presented in Section 4.3.5 were selected from the five companies participating in the multiple exploratory case studies. The three organizations develop complex products in the fields of industrial automation and commercial vehicles. Within these three case companies a total of 41 semi-structured interviews were held in order to identify how performance is measured at different levels of the organizations. As a part of these case studies the different performance measurements of the three organizations were identified and mapped into the PMEX. Measurements were identified through case company specific documents describing their performance-measurement system. The measurements were mapped into the PMEX by the researcher and verified in the supervisory group. The findings and conclusions reached were presented and discussed at seminars at each of the three companies.

7.4 Applying the PMEX in Practice

The first observation made when applying the PMEX in case Company A was that time, cost, and quality were common areas of measurement. The PMEX, however, lacked explicit areas for time, cost, and quality. It was therefore decided to extend the initial framework of success factors to include these categories. Not because they are success factors in the product-development process, but rather as the result of succeeding with the success factors. Also, many measurements involve time, cost, and quality. It is surprising that time, cost, and quality were never mentioned in the focused group interview when the success factors where elicited and analysed by the senior managers participating in our study. One interpretation may be that success factors can be related to leading indicators, while time, cost and, quality are lagging indicators of performance. Hence, when the focus is on performance criteria, time, cost, and quality are not considered. Case Company B and E did not require any changes in the framework, but added to knowledge of how performance measurements were used.

The updated version of the proposed PMEX, with an indication of what is measured by the three case companies, is shown in Figure 19. The performance measurements from the three case companies were all successfully structured into the PMEX.

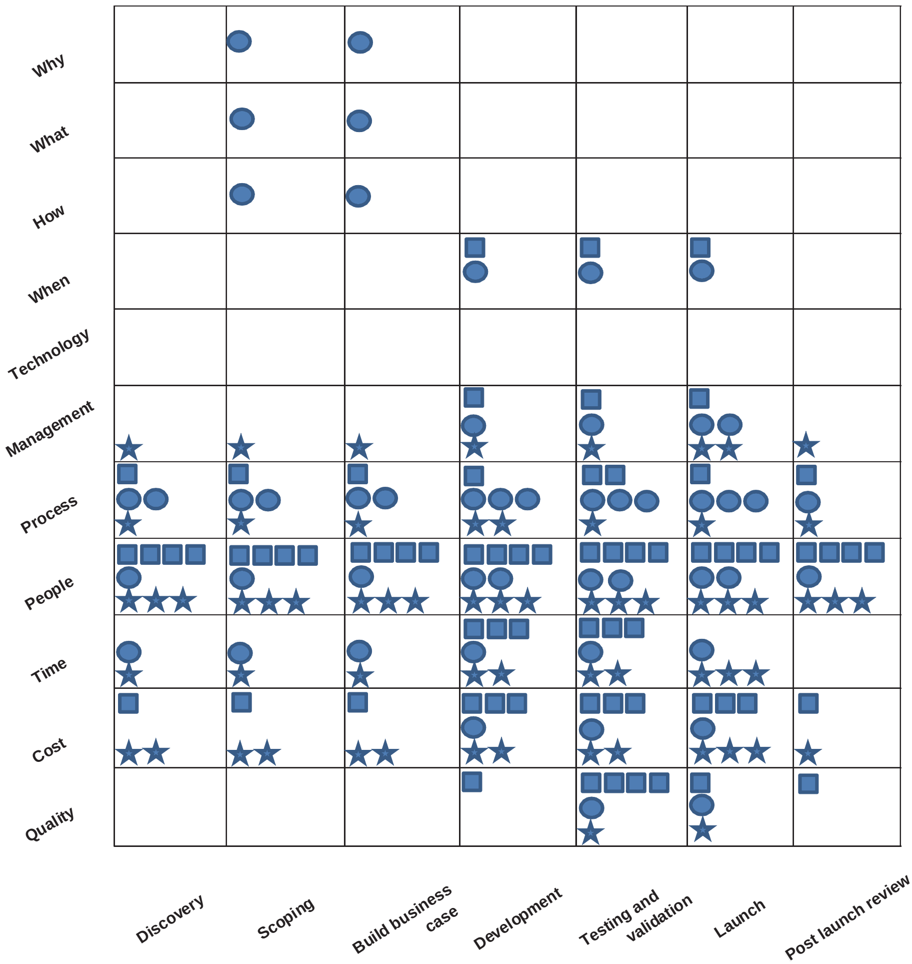

Figure 19. The PMEX applied to the three companies.

The stars in Figure 19 represent the measurements used by case Company A; the circles represent the measurements used by case Company B; the squares represent the measurements used by case Company C. It was decided to map the performance measurements into the matrix as stars, circles and squares, in order to emphasize the presentation and usage of the PMEX as an evaluation method, rather than to focus on the specific metrics used by these three case companies. Moreover, it should be noted that a star, a circle or a square does not represent a unique measurement. It could be that the same measurement is used in a number of squares of the PMEX. An example of this is that the circle in the why, what, and how lines, measured during the scoping and build business case stages, is the same measurement. It is a measurement of how the prescriptive process of early stages in the product-development process is followed. Multiple entries of stars, circles or squares represent multiple measurements applied in the same area.

A further result of the analysis is that the three case companies seem to measure what is easy to measure and not what managers consider to be important. If the measurement of fulfillment of the early stages of the product-development process is disregarded, there are hardly any measurements within the planning activities (why, what, how and when) of the product-development process. This may be negative in the important effectiveness perspective of the product-development process. It may be the result of companies focusing on the efficiency and not the effectiveness of product development. Another important finding is that none of the three case companies measure the aspects related to technology, despite the potentially large influence it may have on, in particular, product-development efficiency.

7.5 Experiences from Using the PMEX

The PMEX has been verified at case Companies A, B, and E and within these the PMEX has been received as a useful way of evaluating the current performance-measurement system. In all the cases studied the PMEX clearly illustrate what is and what is not measured. The main idea of the PMEX is to holistically evaluate the performance-measurement system and use it as a conceptual tool when performance measurements are discussed. Managers and decision makers within product development are often aware that they are using a less than optimal measurement system but are unable to pinpoint explicitly its advantages and disadvantages.

Moreover, the three case companies have a clear potential to further develop their performance-measurement system since the success factors identified by the participating companies are disregarded to a great degree, especially the planning activities. This finding is supported by the literature e.g. in a study by Hertenstein and Platt (2000) they conclude that companies seldom reflect their strategies in their performance-measurement system.

Furthermore, the findings that technology is not explicitly perceived as an important success factor in the product-development literature and at the same time is disregarded by the performance-measurement system are both important. This is particularly so since most of the product development within companies developing complex products is incremental development of long-living systems rather than development of completely new products. Product-line architectures or platforms are often used and shared between products. It is our experience that the important inner quality of such architectures declines over time if quality is not actively managed by the product-development organization. Reasons for this include poor communication of important architectural decisions and constructs leading to architectural disintegration when new features are implemented in ways that violate the rules set by the architecture, the introduction of new features incompatible with the current architecture, changes in business context not supported by the current architecture, turn-over of engineers resulting in the loss of knowledge. For a company developing complex products it is therefore a clearly competitive advantage to have its technology evolve parallel with the business context, thereby supporting an efficient and effective implementation of new features and applications.

Since all the companies studied are successful, and have an interest in increasing their product-development performance, it could be that this information is managed as tacit knowledge. Tacit knowledge, as opposed to formal or explicit knowledge, is defined as knowledge that cannot be articulated or verbalized (Foos et al., 2006); it is knowledge that resides in an intuitive realm. Since the subject of tacit knowledge transfer, content and process, is poorly understood (Foos et al., 2006) it may be a substantial risk to treat the technology and planning aspects of the product-development process in this way. If that is the case, it may be difficult to manage the planning activities as a process and thereby enable continued improvement. This has not been the focus of this research but it is an opportunity for further research.

7.6 Conclusions

In this chapter, the Performance Measurement Evaluation Matrix (PMEX), a tool for evaluating the performance-measurement system of a company's product-development function from a product-development manager's perspective, has been proposed. An effective performance-measurement system is based on relevant performance criteria. Hence, the PMEX has the success factors within the development of complex products as one dimension and the phases of the Stage-Gate model, representing the timeline, as the other dimension. One benefit of the PMEX is the possibility, for a product-development manager, to holistically evaluate what is measured and maybe more importantly, what is not measured. The PMEX may also be used as a conceptual tool to evaluate and analyze the performance-measurement system, making it possible to initiate discussions of *what* is measured, but also *why*, and *when* something is measured. Furthermore, as the PMEX also illustrates what is not measured, it can be used when changes or new measurements are to be added, in order to ensure a performance-measurement system that measures what is important in a product-development manager's perspective.

Another conclusion based on the result of using the PMEX, is that the technology aspect of the product-development process is not measured by any of the three case companies. This is surprising since they acknowledge technology as an important success factor. The implications of not measuring the technology aspect are difficult to assess. However, it can affect performance both short and long term. Further research is needed, focusing on possible success factors and measurements that can be used to address the technology aspects within the development of industrial products.

Overall, it seems that the explicit link between what managers identify as important success factors and what is measured is weak. One interpretation is that success factors may be regarded as leading indicators, thus more difficult to quantify in measurements when compared with lagging indicators such as time, cost, and quality.

A key conclusion within the performance-measurement literature is that it is advantageous to link the strategy pursued by an organization with its measurement system (Davila et al., 2006), but important strategic factors such as the product-development planning and the technology aspects were not emphasized in existing performance-measurement systems. Instead, an overall conclusion from the case studies is that there seems to be a tendency to measure something because it is possible to measure, rather than because it is important to measure. As a result there are areas in the PMEX, see Figure 19, which are covered by up to four different measurements. This is far from cost effective but by means of PMEX this phenomenon can be detected.

Moreover, more research is needed in order to address the weaknesses in the performance-measurement system identified through applying the PMEX in practise. The problem of how to design performance measurements remains. There is a need to focus on developing performance criteria relevant to e.g. technology and planning activities, since an effective performance-measurement system iteratively needs to deal with both performance criteria and performance measurements (Gharajedaghi, 2006).

Chapter 8 A Performance Criteria Reference Model

Performance in product development is, as identified in this research, an ambiguous concept. In the literature reviewed in Chapter 2, it was concluded that there is little or no support for managers to conceptually analyze performance in product development. Also, in Chapter 6 it was concluded that performance is mainly perceived in the limited terms of time, cost, and quality. This chapter presents a conceptual model, to assist managers and decision makers in discussing and analyzing performance criteria in product development.

The outline of this chapter is as follows: the literature related to defining performance in product development is briefly summarized and a conceptual model of performance criteria in product development is derived. The applicability of the model is demonstrated in three root case analyses. Finally, the chapter is concluded with a discussion regarding the general conclusions from applying the model in practice. This chapter is based on the following publications: Journal paper 2 and Conference papers 5, 7, 10, and 11, as listed in Section 1.7.

In Chapter 6 it was concluded that there are several different interpretations of performance when developing complex products. An effective performance-measurement system should be grounded in performance criteria relevant to the organization (Gharajedaghi, 2006). It is argued in this chapter that without performance criteria that adopt a system perspective, performance-measurement system may be unbalanced and fail to perform as intended. This may be especially evident when there are strong external factors affecting an organization. The stock market's obsession with quarterly earnings, forcing companies to minimize cost and time to market, often at the expense of value creation (Koller et al., 2005), is an example of this. As a result, performance measurements tend to focus on cost and time delays rather than value progress as concluded in Chapter 7. This may also explain why performance is often equated with efficiency and why project managers focus on finishing the project within the budget, and not necessarily developing the right product. At the same time are the early phases of product development frequently mistreated because of fire fighting activities within old projects (Repenning, 2001).

8.1 Research Approach

This research is from the viewpoint of a product-development manager, emphasizing a holistic view of performance in the product-development process. It is argued, in line with the arguments of Gharajedaghi (2006), that an effective performance-measurement system should be based on the performance criteria relevant to the organization to achieve its objectives. The literature gives managers little or no support in how they can model performance criteria. Thus, the research question addressed in this chapter is:

Rq 2.1 How can performance criteria be modelled in the development of complex products?

A conceptual product-development model, based on the IDEF0 model of an activity (Colquhoun et al., 1993), involving decision making, uncertainty and performance is presented to address this question. The proposed Performance Criteria Reference Model (PCRM) can be used as a tool for further research. It may also be employed as a conceptual model for product-development managers when analyzing and evaluating performance. This is important, since increased complexity stresses the need for models that may be used for teams to develop a shared understanding (Katz and Kahn, 1978). Also, as argued by Senge (1990) the real leverage in most management situations lies in understanding dynamic complexity, not detail complexity.

To test and illustrate the applicability of the PCRM model it has been applied to three problem areas at case company A identified during the case study as part of the exploratory multiple case studies (see Section 4.3).

A further aim of this chapter is to develop a general syntax within product-development performance that allows companies to define their own performance measurements according to specific needs.

8.2 Different Aspects of Product Development

With the definition of product development, defined and discussed in Section 2.1.1, in mind the product-development process can be viewed as three generic levels of activity: product strategy, project management, and development activities. These three generic levels of activities may be compared to a strategic, tactical and operational level of control within an enterprise. The strategic level is more long term and long range planning driving to a planned end result. As concluded in Chapter 2 it is important that the performance-measurement system is derived from and supports the strategy of the organization. In contrast, the tactical level is more short term and short range involving skill and agility. The operational control is where the day-to-day activities are handled.

The product strategy, project management, and development activities are activities that require different organizational capabilities in order to be successful. Extensive research has taken place within each of these generic levels of activity. Yet, instead of bringing them closer together in a system view of the complete product-development process, it is argued that it is common to divide and separate them from each other in research studies. In the following sections, the literature related to product strategy, project management, and development activities are briefly reviewed.

8.2.1 Product Strategy in Product Development

The basis for a product-development strategy should be the business strategy. Aligning especially the product strategy with the business strategy is important for a successful product-development process (Ernst, 2002). A business model is defined by Zott and Amit (2008) as a structural template of how a specific firm transacts with customers, partners, and vendors. Missing from this definition is a value perspective. A commonly used description of a business model is that it is the description of the rationale of how an organization creates, delivers, and captures value. Hence, in practise the business model captures the pattern of the firm’s boundary-spanning connections with product markets and other factors. A central aspect is to acknowledge that the purpose of a business is external in creating and satisfying customer needs (Koch, 2006).

By aligning the strategy of product development with the business strategy, it may be easier to get senior management support. Such support has been identified by many authors as an important success factor in product development (e.g. Ernst, 2002). Moreover, Zott and Amit (2008) describe product strategy as the pattern of managerial actions that explain how a firm achieves and maintains a competitive advantage through positioning in product markets. It could be argued that the role of a product strategy is to guide the identification of the needs of the chosen market and to decide which products to develop in order to satisfy them. According to Krishnan and Ulrich (2001), there are five generic questions at the product strategy level:

1. What is the market and product strategy to maximize probability of economic success?
2. What portfolio of product opportunities will be pursued?
3. What is the timing of product-development projects?
4. What assets (e.g. architectures or platforms), if any, will be shared across which products?
5. Which technologies will be employed in the product(s)?

An example of a strategic decision within product development is that of adopting a first mover or a fast follower advantage. A first mover to the market may face considerable uncertainty, compared with fast followers, about what product features customers will ultimately desire and how much they will be willing to pay for them (Schilling, 2006). Mechanisms that promote first mover advantages include proprietary learning effects, patents, the pre-emption of input factors and locations, and the development of buyer switching costs (Lieberman and Montgomery, 1988). This strategic decision relates to what Porter (1996) describes as strategic positioning, i.e. performing activities not performed by rivals or similar activities in different ways, and operational effectiveness, i.e. performing similar activities more efficiently.

The product-development portfolio should have a strategic focus that gives an overall direction to individual product-development projects (Ernst, 2002). In Cooper and Kleinschmidt's (1995) study, the construct of 'new product strategy' is the second most important success factor for the product-development program; a high-quality new product process being the first. Firms that include an explicit strategy step in their product-development process are more likely to produce successful new products (Griffin, 1997b). Further, it is essential to keep the product strategy updated, to balance the tendency to focus solely on finishing the current active product-development projects. This phenomenon is acknowledged by several researchers as their focus turns from the project level to a more strategic view. An example of this is the research team behind the Stage Gate model, that changed focus to emphasize instead the importance of strategic buckets, in order to achieve a balanced product-development portfolio (Cooper, 2001).

8.2.2 Project Management in Product Development

Requirements and product complexity are increasing, product-development schedules are shrinking, and the competitive environment among customers and suppliers is stiffening. As a result, development projects become more advanced. Consequently, more is demanded of the performers of projects, both internally and externally. In essence, project management is simply the process by which a project is completed successfully. But there are many other aspects of project management to consider. In order to understand project management, it is first important to understand what a project is. Several definitions of a project exist. The PMBOK (2004) defines a project as a temporary endeavor undertaken to create a unique product, service, or result. A definition frequently referenced to is the one Turner (1993) argue for:

> A project is an endeavour in which human, material and financial resources are organized in a novel way, to undertake a unique scope of work, of given specification, within constraints of cost and time, so as to deliver beneficial change defined by quantitative and qualitative objectives.

The definition includes some concepts that need further explanation. First, the project is organized in a novel way, thereby implying that a project is not part of the original organizational setting. The project is set up for the limited period of time necessary to achieve the set objectives of the project. Second, the scope is stated to be unique. This is understood to mean that one project is not easily compared to another. The scope of a project is determined by the objectives to be met. Furthermore, because the project is unique, it involves a level of uncertainty. Finally, the project should deliver beneficial change. Here, a clear distinction is made between the temporary project and more standard operations. We undertake projects because we cannot produce, or achieve, the benefits defined, by performing routine activities, and the expected benefits from executing the project outweigh the risk (Turner, 1993).

8.2.3 Product Development Activities

When studying product-development activities, the analysis is often focused on engineering design and those activities that directly impact on the design of the product. While there are great numbers of product-development activity models (e.g. Pahl and Beitz, 2007; Ulrich and Eppinger, 2008), these models vary their approaches depending on what is being developed. Other authors champion the importance of different aspects of product development, e.g. the integration of work procedures, information management, and support tools, such that the complexity of product development can be managed in an effective and efficient way (Norell, 1992).

However, design is not the only activity within product-development activities that adds value to the overall performance of a product-development organization. In a product-development project, there are several aspects that contribute to the success of a product in achieving its overall goals e.g. revenues and market share. These aspects are affected by decisions being made on a product activity level. Hansen and Andreasen (2004) argue for the aspects of use process, project tractability, product, business, and product life cycle. These aspects cannot be separately handled from the project management and product strategy level, and must be viewed holistically when making decisions in order not to sub-optimize. A more detailed review of the literature is found in Chapter 2.

8.3 Perceptions of Performance in Product Development

In organizations, various performance metrics are measured and acted on. Since some activities are far too complex to be measured, processes, models and other simplifications provide the possibility to evaluate performance. Often, performance is perceived primarily in terms of the dimensions that can be measured, such as time and cost, or particular aspects of quality (Chapman and Ward, 1997).

Nowadays, many companies have identified a number of key processes to ensure success in achieving project objectives. Project management involves several processes utilized to achieve the best possible management of a project. There are differences in the possibility of measuring the performance of different processes, both transactional e.g. strategy processes, risk and opportunity management and operational e.g. manufacturing, in achieving their objectives. Although most processes have some type of metric which permits measurements of their performance, their impact on the overall product-development performance is difficult to measure. The basis of the process view is embodied in the following principle: for organizations to be more efficient and effective, the various functional areas need to work together towards a common goal (Sandhu, 2004).

Since both transactional and operational processes interact and support the project management process, there are several sources of uncertainty that can influence the project outcome. The successful business will be the one that manages its projects most effectively, maximizing competitive benefits while minimizing the inevitable uncertainty (Hillson, 2003). The outcome of these processes depends on their ability to appreciate the presence of uncertainty. Measurements of the performance of a product-development process are associated with some implications. This is mainly due to the reason that uncertainty itself cannot easily be measured against a business-related value, i.e. the presence of uncertainty cannot easily be defined in terms of time, cost, and quality.

As identified in Chapter 2, in line with the findings by O'Donnell and Duffy (2002a), performance in product development is seldom defined and there is no consensus about what performance is. Within product development, effectiveness and efficiency are often common denominators in the various definitions of performance. Sink and Tuttle (1989) describe effectiveness as doing the right things at the right time, with the right quality. Similarly, efficiency is described as doing things correctly, often expressed as a ratio between resources expected to be consumed to resources actually consumed. The process of measuring performance has triggered a substantial amount of research attention. A more extensive review of the literature is provided in Chapter 2.

One of the findings from this review is the design performance model developed by O’Donnell and Duffy (2002b), which is an attempt to clarify the performance syntax. Their model is based on the IDEF0 model of a general activity (Colquhoun et al., 1993). The IDEF0 model of a general activity with the definitions of efficiency and effectiveness as proposed by O'Donnell and Duffy (2002a) is shown in Figure 20.

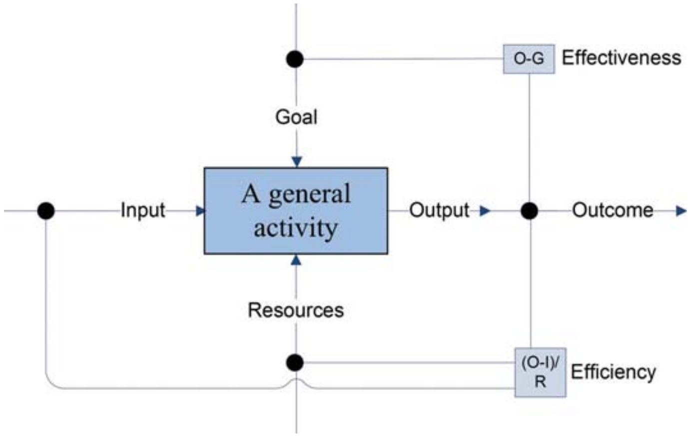

Figure 20. The IDEF0 model of a general activity including the definitions of efficiency and effectiveness.

An activity uses resources to transform input to output under the direction of goals and/or constraints (O'Donnell and Duffy, 2002a). The input refers to the initial state of knowledge prior to the activity, while the output is the final state of the performed activity. Resources encompass more than the people involved in the activity; they include items like computer tools, materials, techniques and information sources. Goals are specific elements of knowledge that direct the change in the state of the activity from the initial input to the final output state. Further, O’Donnell and Duffy (2002b) use the model of an activity to define efficiency and effectiveness.

8.3.1 The Knowledge Gap in Product Development

It is apparent that uncertainty exists in everyday life, in organizations and in projects. Uncertainty in a business situation is often expressed verbally in terms such as "it is likely", "it is probable", "the chances are", "possibly", etc. Several attempts to classify uncertainty exist. Hillson and Murray-Webster (2005) assert that the two aspects of uncertainty are variability and ambiguity. Here, there is a state of variability when a measurable factor can have one of a range of possible values. The event is defined, but the outcome is uncertain because it is variable. Ambiguity, on the other hand, is defined as uncertainty of meaning. It can be applied to determine whether a particular event will happen at all, or whether something else unforeseen might occur. Hillson (2004) attempts to link risk with uncertainty in the following couplet:

> Risk is measurable uncertainty; Uncertainty is immeasurable risk.

This implies that an uncertainty is to be considered a risk when measurable. However, Hillson considers risk as having both positive and negative consequences on project objectives. This also follows Lefley (1997), who argues that although risk results from uncertainty, risk and uncertainty are theoretically not synonymous. Risk involves situations where the probability of outcome is known. Uncertainty is when the probability of outcome is unknown. It is obvious that different opinions exist regarding what to consider as uncertainty, risk and opportunity.

In this research, risk and opportunity are to be viewed as being derived from uncertainty. Moreover, it is important to acknowledge that risk and uncertainty are inherent in product development. By definition, developing a new product means developing something new. The degree of newness can be translated to a knowledge gap that needs to be managed in order for the product to become reality. The development process can be viewed in one way as the filling of a gap in knowledge between what is known today and what is a desired future state of knowledge, and to break down that knowledge gap into different areas and levels in the product-development organization. The knowledge gap in a product-development context thus involves both uncertainty and risk. However, the specific degrees of risk and uncertainty may vary depending on e.g. the project being radical or incremental in character.

It is proposed in this research to define the knowledge gap, using the IDEF0 model of an activity, as the difference between the goal and the input i.e. a measure of the new knowledge required by the activity to produce the intended output.

8.4 The Performance Criteria Reference Model

In this section, the Performance Criteria Reference Model (PCRM) is introduced. The PCRM is a holistic model based on three generic levels of activities in product development: product strategy, project management, and development activities. Each of these generic levels can be modelled as an activity according to the IDEF0 (Colquhoun et al., 1993) and related to each other as shown in Figure 21.

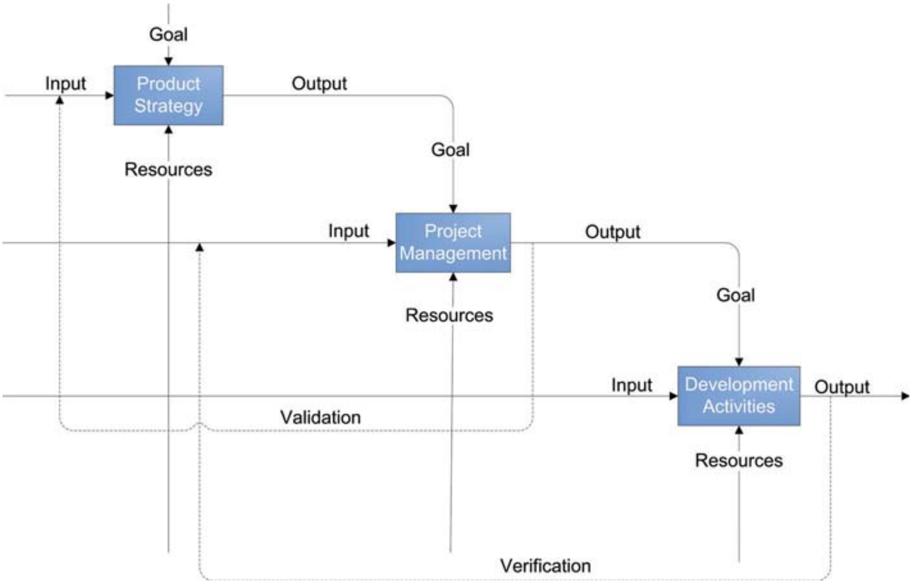

Figure 21. The Performance Criteria Reference Model

Each of the three generic levels of activities uses resources, even though different resources, to transform input to output in achieving a series of goals while subject to constraints. In the product strategy, it is decided what product to develop and why and a product-development project is initiated, realizing the selected customer needs. The project management activity then translates the selected customer needs into a product specification. This serves as a goal for the development activities, in which the product is created according to the specification. As for every activity, it is important to acknowledge the associated uncertainty. The Performance Criteria Reference Model appreciates the inherent uncertainty in product development, as well as the uncertainty in activity input and in the decisions on output. In Section 8.4.1, this model will be further detailed as it relates to the different generic levels of activities. We will also show how performance, including the knowledge gap, can be modeled in the Performance Criteria Reference Model.

8.4.1 Three Views on the Performance Criteria Reference Model

The Performance Criteria Reference model is based on three generic levels of activity, product strategy, project management and development activities, identified in the product-development process. These activities as viewed in this research are described in the following subsections.

Product Strategy View

Within military theory, it is common knowledge that a strategy and its objectives (i.e. output) only survive until the first enemy contact. This reasoning and understanding stems from experiences gained in warfare. This phenomenon illustrates that although a comprehensive and, at the time, accurate plan is developed, the knowledge gap, in terms of uncertainty, affects the strategic planning and cannot be disregarded. In the same manner, the effect of the knowledge gap in product-development performance must be appreciated in setting the goals and in determining the input needed to enable efficient and effective output.

In this research, product strategy is viewed as a pattern of decisions and actions performed today to ensure future success. The product strategy activity with the definitions of goal, input, resources and outputs are further discussed below.

Product strategy goal: The primary objective of the product strategy activity is to fulfil the business strategy. It is important that the product strategy is aligned with the business strategy, since it is the path chosen for overall company success. The goal of product strategy is to implement the business strategy. By having a clear link to the business strategy, it will be easier for senior management to be more active in the product-development process.

Product strategy input: This is the initial knowledge about the business strategy's targeted market needs. These needs can be divided into unsatisfied needs and needs fulfilled poorly by today's solutions. Knowledge about new technology development, both within and outside the company, is an important factor in deciding what product should be developed.

Product strategy resources: The main resource and responsibility for this activity is the product manager. In many companies, a steering committee assists the product manager with this activity. Normally, senior management from marketing, sales, manufacturing, finance, and so on are involved in the product strategy.

Product strategy output: The chosen market needs are the output from the product strategy. These serve as the goals for the project management activity. Hence, the output functions as a specification of what to develop in addition to budget and time-plan for market introduction.

The product strategy is a complex and important activity in the product-development process. In this chapter, the Performance Criteria Reference Model is simplified by applying to the design of one product through one project (i.e. having a single-product and project perspective). It is important to acknowledge that the product strategy activity is not completed when a product-development project is initiated. Once a new project is started, product management should confirm that the right product is developed and monitor that the targeted customer needs are still relevant. Both of these tasks are important in securing a successful product-development process.

Project Management View

When the product strategy activity output is decided, a product-development project is initiated to ensure that the selected customer needs are realized in an efficient and effective way. The responsibility of managing the development belongs to the project management activity. The activities at the project management are the product manager's direct interface to the project. The Stage Gate model is a tool, commonly used by product managers to supervise and make sure that the right products are developed (Cooper, 2001). The role of the project manager is to act as a catalyst between the output from the product strategy and the resources involved in the development activities. The project management activity should be performed in an iterative way, in close interaction with the development activities.

The essential purpose of managing the knowledge gap is to improve project performance via the systematic identification, appraisal, and management of project-related uncertainty (Chapman and Ward, 1997). After all, the management of the knowledge gap does not in itself, as a process, bring value to the project; rather, it assists other processes to bring value to the product-development process. The input, goal, resources and output of the project management activity, as modelled in Figure 21, are further discussed below.

Project management goal: The goal is derived from the chosen customer needs and what type of product should be developed (e.g. the output from the product strategy activity). There is a budget and when the product should be realized by the project is to be fixed in a schedule. One important task for the project management is to agree to, and clarify the goal of the initiated product-development project with the product manager. There should be an agreement between product managers and project managers on the product-development project's objective in the beginning of the project.

Project management input: The previous knowledge of project management and newly developed products serve as input to this activity. Also, previous knowledge of the project management processes serves as input. Companies developing advanced systems often use some type of platform or architecture that can be used by the project. Knowledge about the relevant limitations and possibilities is also an important input for the project management activity. The s-curve is argued to be useful as a tool for predicting when a technology reaches its limit and when to move to a more appropriate (Foster, 1986).

Project management resources: For smaller projects, it is common to only include the project manager. In more advanced product-development projects, a project core team often exists to assist the project manager in managing the project.

Project management output: This is a project requirement specification with concrete activities that will function as a goal for the development activity. It is important that the specification is complete, since it will function as the goal of the project management activity. There should also be a project plan, including a schedule for activities that will be performed in the development activities.

The project management activity serves as a bridge between the product strategy and the development activities. To do this successfully, it is important that the project manager understands and is able to communicate the requirement specification. If this is not performed in an effective way, there is a risk of designing an unsuitable product.

Development Activities View

The product is designed during the development activities. The development activities include all activities requested by the project management. The role of the development activities is to solve and realize the initiated activities as efficiently and effectively as possible. The development activities should be performed in close cooperation with the project management since it is an iterative process.

As was the case previously, the development activities, as modelled in Figure 21, with a goal, input, resources and outputs are discussed below.

Development goal: The objective of the development activities is to fulfil the requirement specification developed in the project management activity.

Development input: This includes, for example, knowledge about previous projects and development activities, development processes and working tools. A new product is usually not based on a previous product or architecture, seldom developed from a blank sheet of paper. It is therefore important that the people involved in the development activities are familiar with this previous knowledge.

Development resources: All resources used by the development activities are included. This involves the personnel primarily. However, computer tools, materials, techniques, and information sources are also included.

Development output: The finished product plus the deliverables, specified in the product requirement specification. Together they make up the product. The finished product normally involves different parts integrated into a final product.

Within a product-development project, it is important that the goals from the project management activity are broken down into well-defined activities that can be realized in an efficient and effective way. To be successful in the development activity, it is important that all activities are performed in close cooperation with the project management activity. This is especially important for two reasons. The first involves ensuring that the right product is developed. The second is to monitor the progress to make sure that the budget and schedule are kept. It is important to become aware of them early on to be able to permit their correction.

8.4.2 Three Dimensions of Performance in the Performance Criteria Reference Model

The proposed Performance Criteria Reference Model makes it possible to define efficiency, effectiveness and knowledge gap within the three generic levels of activity as presented in Figure 22.

Performance and Product Strategy

Product strategy effectiveness (E_{PS}) is defined as how the output meets the goal. In this case, the goal is to fulfil the business strategy. Thus, it is important that the output is clearly linked to the business strategy. To do so, ownership from upper management is encouraged; it is, as previously stated, an important success factor. By achieving effectiveness in the product strategy, a foundation for successful product development is established.

Product strategy efficiency (e_{PS}) is defined as the difference between output and input divided by the resources used (in other words, the cost of realizing the output). The output of the product strategy is the market needs the new product satisfies. The input is the initial knowledge prior to the activity. It is therefore, important that the difference is not too great and can be managed by the resources (i.e. product management) involved in the product strategy. The efficiency of the product strategy is often forgotten and not explicitly measured.

Product strategy knowledge gap (K_{PS}) is defined as the difference between the goal and the input. This means that the knowledge gap in product strategy is a measure of the new knowledge required in the product-development project. This knowledge gap measure could be used in the portfolio evaluation to make sure there is a mix between incremental and more radical product-development projects. Within the product-development portfolio, there should be a mix of projects with different levels of knowledge gaps, i.e. incremental as well as more radical ones, in order to balance a short term focus with a long term growth perspective. Moreover, the knowledge gap is related to the required resources needed to bridge the knowledge gap when developing the intended product. In a portfolio management perspective it is desirable to identify or create customer needs with a large leverage between knowledge gap and resources used.

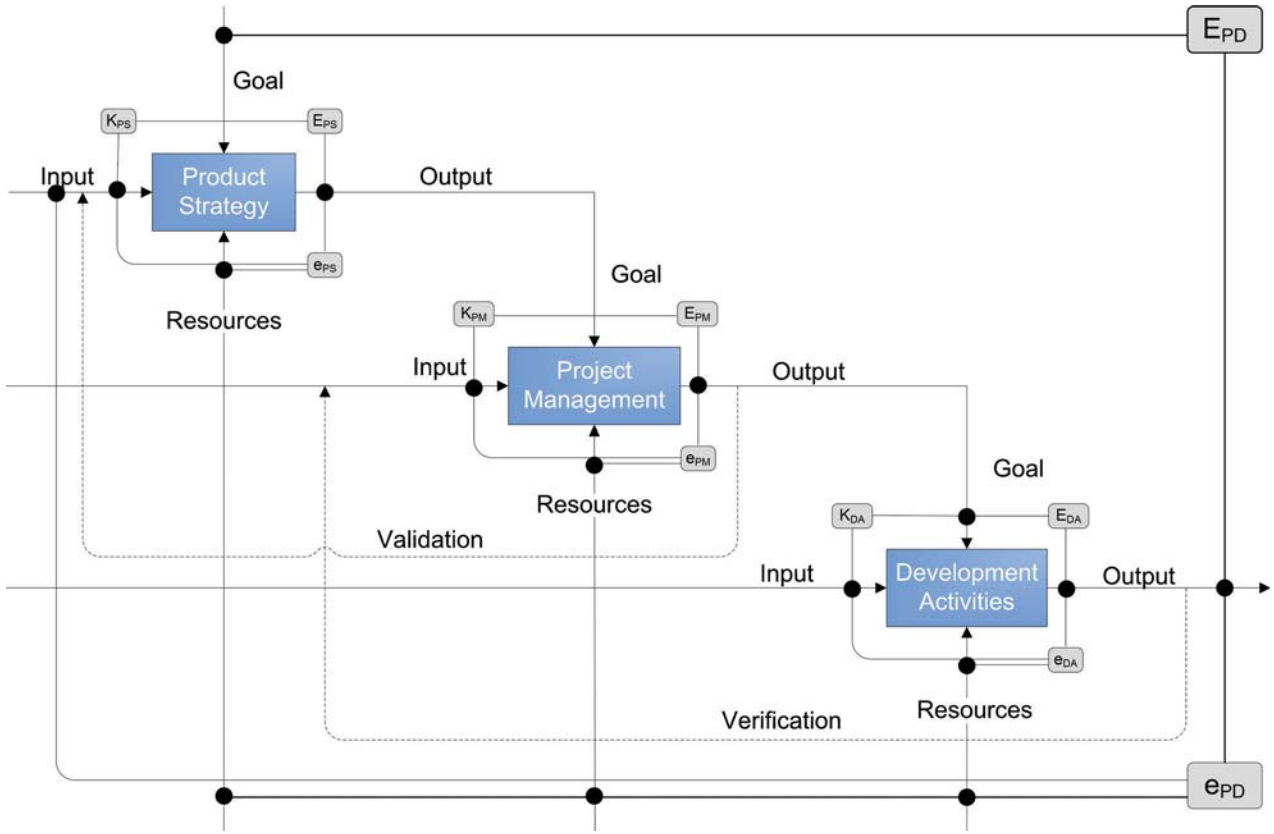

Figure 22. The Performance Criteria Reference Model with efficiency (e), effectiveness (E) and knowledge gap (K).

Performance and Project Management

Project management effectiveness (E_{PM}) is defined as how the output meets the goal e.g. how the selected customer needs, output from the product strategy, are transformed into a product specification. Effectiveness within the project management is, therefore, a measure of how the project realizes the scope and objectives of the project. Effectiveness is achieved when all the selected needs from the product strategy have been fulfilled. Hence, it is important for the project management to act as a bridge between the product strategy and the development activities.

Project management efficiency (e_{PM}) is defined as the difference between output and input divided by the resources used to realize the output. Efficiency is closely related to the project planning. If there are problems with the efficiency in the project management activity, these are reflected in budget and time overruns (as a result of development activities with high level of complexity resulting in additional unplanned activities). Project managers tend to focus on finishing the specified activities on schedule and within the budget (i.e., the efficiency aspect). It is, therefore, important to remember that if the effectiveness of the project management activity cannot be achieved, everything else is of minor importance.

Finally, project management knowledge gap (K_{PM}) is defined as the difference between the goal and the input. Hence, it is a measure of what has to be created by the product-development project. If much new knowledge is needed in the project, the development activities tend to be complex. Thus, the knowledge gap will affect both efficiency and effectiveness of the project management activities. If the knowledge gap related to project management can be evaluated it may be used as a leading indicator of effectiveness and efficiency. Moreover, the relation between the knowledge gap and the resources needed to achieve the project scope and objectives, are crucial for making informed trade-off decisions during project execution.

Performance and Development Activities

Development activities effectiveness (E_{DA}) is defined as how the output, i.e., the realization of the activity, meets the activity’s goal. This is an important measure. The focus is on the output, and the goal is forgotten. An ultimate failure of the product-development process would be to have development activities managed in an efficient way, on time and within the budget, but not meeting the goal. It is therefore vital that the project management within product development always focuses on securing the effectiveness of the development activities, by communicating a clear and well-defined goal for the activity.

Development activity efficiency (e_{DA}) is prescribed as the difference between output and input divided by the resources used to realize the output. Thus, efficiency in development activities may be used as a measure to make sure that the invested resources are used in the best possible way. Traditionally, development activity efficiency is often the target for measurements when performance in product development is evaluated.

Finally, development activity knowledge gap (K_{DA}) is, defined as the difference between the goal and the input. It is therefore a measure of how complex the development activity is, and, therefore, what types of resources are required for an efficient and effective implementation of the activity. By evaluating the development activity knowledge gap, it is possible to manage the knowledge and to discover potential problems early, when there is still time for changes without risking any substantial costs.

It is argued in this research that performance in the development activity is achieved when knowledge gap, effectiveness and efficiency are being managed as a whole. The objective of increasing performance may be accomplished by identifying weaknesses and addressing them at an early stage in the product-development project.

8.4.3 Product Development Efficiency and Effectiveness

Product-development effectiveness (E_{PD}) is defined as how the output of the product activities meets the goal of the product strategy. In this case, the goal is to fulfill the business strategy, thus, it is important that the output is in line with the business strategy. To do so, ownership by upper management, identified as a success factor in Chapter 5, is encouraged. The effectiveness of the product-development process is the important foundation of a successful development process. However, there is no easy way to measure this and no one factor to manage, in order to improve the product-development effectiveness. Instead, product-development effectiveness should be viewed as the result of having well-functioning product strategy, project management, and product activities that dynamically work together in order to develop successful products. Product-development effectiveness is the aggregated result of the effectiveness for the three activities in the PCRM.

Product-development efficiency (e_{PD}) is defined as the difference between the output of the product activity and the input to the product strategy, divided by the total resources consumed in the product strategy, project management, and the product activities in order to produce the intended output. Moreover, product-development efficiency is important to make sure that the invested resources are used in the best possible way. The product-development efficiency can be improved by increasing the output or decreasing the cost of the resources consumed by the activities.

The success of the product-development process depends on both efficiency and effectiveness in the performed activities. The iron triangle of time, cost, and quality is often used to evaluate projects, thus focus turns to the resources and the output aspect of the product activities. Hence, the effectiveness and value perspectives of what is being developed are neglected or taken for granted.

8.5 Verification and Validation Feedback Loops

Every company seeks to fulfil the customer needs in the targeted market. As a result, the company needs to manage certain market specific constraints in order to be successful. Within the defence industry, for example, there may by a lead time of many years for a new product-development project. This could be compared with, for example, the mobile phone industry, where time to market is a deciding factor for the success of a new product. The time factor within the PCRM is not explicitly shown in the model. However, there is strong time dependence in the PCRM, which is incorporated in the verification and validation loop (see Figure 22). The two feedback loops also represent the learning that can be drawn from each generic level of activity in the product-development process. Validation and verification may be used by product-development management to ensure that the correct activities are being performed and the different outputs match the specified goals.

8.5.1 The Validation Loop

The validation loop represents the feedback from the output of the project management, and is modelled as an input to the product strategy. The validation enables the product manager to monitor the progress of the product-development project. The validation could also be viewed as a representation of the time to market constraint of the chosen customer needs. That the right product is being developed is often taken for granted. Therefore, it is not questioned once a project is started. It is possible that customer needs change during a product-development project, especially when the cycle-time is measured in years. If the customer needs have changed, it is important, if necessary, to terminate the project and focus the scarce recourses on the other projects in the product-development portfolio. The lead-time of the validation loop differs between markets and products. As mentioned, in the defence industry, a lead-time of many years for a product-development project is common, compared to the mobile phone industry where the introduction of a product a week too late, can be the difference between success and failure of a new product. The validation loop influences the verification loop. This is because any changes in the customer needs must be reflected in the product-development activities.

8.5.2 The Verification Loop

The verification loop in the PCRM is modelled as the feedback from the development activity output to the input of the project management activity. Representing it this way shows the possibility for the project manager to view the progress and the output of the development activities. Through verification, it is possible to ensure that the output produced from the development activities is aligned with the goal (e.g. the output of the project management activity). The verification loop can also be viewed as a representation of the lead-time of a company's internal product realization capability. The product realization capability is constrained by the time-frame of the validation loop. If the chosen market expects new products every year, the product-development lead-time within the company must be within that limitation. It is important to monitor the verification loop during the product-development cycle to ensure that the output from the product-development project is aligned with the output from the product strategy. If the selected customer needs have changed, it is important to understand these changes and to act accordingly. The time-frame of the verification loop varies depending on the validation loop, as the verification time-frame is linked to the validation loop. Hence, changes in the market put constraints on the verification loop in order to fulfil the validation time frame.

8.6 Applying the Performance Criteria Reference Model in Practice

In a first attempt to verify and illustrate the applicability of the PCRM, it has been used to analyze some problem areas identified during case study A in the exploratory multiple case studies. The PCRM can be used as a tool for identifying the root cause of problem areas within product development. To verify the PCRM, the following problem areas were selected from the result of the case study:

1) This issue is about the limited use of reuse of components between various products. Complicated solutions are often selected, when a new product is developed, even when there is no obvious reason. This inhibits the reuse of known solutions and standard products. As a result, for example, an unnecessary amount of special cables are used for different products. A discussion regarding reducing the number of components has commenced. However, there is a lack of long-term thinking, as everything is short-term oriented.
2) Development overload is often the result of an organization managed towards increased performance, with the idea that an increase in development projects and work will increase the performance. It is not

unusual to have overload in the product-development process, both in the product-development project and in the project portfolio. As a result, overruns in budget and schedule are a recurring phenomenon. An illustrative quote from one of the interviewees follows:

> In a normal distribution with the expected value of five, it is still possible to get twelve, but over time you still get five. We run the company as if we could get 12 on average.

The effect is that at the end of the product-development project, unfulfilled requirements are cancelled in order to deliver on time. This is a process that is well known within the case company but difficult to change. One interviewee expressed it in the following manner:

> It is like obesity; we know it is not good, but we keep eating anyway.

3) The view of product-development performance is focused on shortening cycle-times, delivering on time, and reducing time to market. When looking at the NPV calculations in the business case, it is clear that reduced cycle-times and time to market are essential ingredients in order to receive a positive cash flow as quickly as possible. Quality is also mentioned together with performance. Case company A has substantial costs related to products delivered to customers that do not work properly, due to poor quality.

8.6.1 Root Cause Analysis of the Three Identified Problem Areas

The first problem area may be related to the product strategy activity in the PCRM (see Figure 22). However, it is not managed as such in the case company. The necessary decisions are avoided and end up in the project management activity. As a result, the decision must be made by the project management activity within each project. The outcome may easily become a product-development project making decisions based on the knowledge and needs of the projects. Sub-optimization in the perspective of the case company may be the result when a product-development project makes decisions without clear, well-defined goals from the product strategy. The lack of long-term product thinking is a natural phenomenon when the product strategy activity does not manage this issue properly. Expressed in terms of the PCRM, the output from the product strategy does not include important strategic information needed to guide the project management activity. Ideally, this would be discovered by the product management through the validation loop.

Project management is involved in the second issue. Overloading the project in the early phases and trying to run the company faster than possible are phenomena that can be analyzed in the validation and verification of the PCRM. The capacity of the resources employed by the product-development project is a vital input for the project planning, within the project management activity. Moreover, overload problems in the product-development pipeline may be solved by analysing and evaluating the validation and verification loops and using the knowledge gained to initiate changes in the output of the product strategy activities. Discussion of the project management knowledge gap may also be useful in order to evaluate and analyze the complexity required by the product-development project. Project overload can be interpreted as the result of failing to manage the product strategy and project management knowledge gap. This is because it represents the new knowledge needed to create the required output from the product strategy.

The third problem area is within product-development performance and the need for a holistic view. To improve performance, the focus should be placed on the product and project management activities and not exclusively on the development activity output. Decreasing cycle-time, delivering on time and shortening time to market are of course important. Nonetheless, when the complete product-development process is managed accordingly, it may lead to incremental updates and product-development projects characterized by a small knowledge gap. The issue of not being able to deliver on time may be the result of overload and poor knowledge, as illustrated in the second issue. Reducing the time to market and cycle-time of product-development projects is easily achieved by focusing on incremental instead of radical updates. An important factor might be to forecast the capabilities of the resources and how they should be managed to achieve optimal potential. The performance of product development, illustrated by this issue, is focused on the efficiency aspect of performance in the project management and development activities of the PCRM. If knowledge gap and effectiveness aspects of these activities were included with performance of the product strategy, the benefit of maximizing the value contribution of the product-development budget could be achieved.

8.7 Discussion and Conclusions

The Performance Criteria Reference Model (PCRM) suggested in this Chapter enables product-development managers to adopt a holistic and common view, and to analyze product development from the points of view of product management, project management, and development activities. The model can be used as a conceptual tool to evaluate and analyze performance, thus making it possible to investigate the performance within each level of the product development. It is argued that by modelling the three generic levels as activities, the often abstract activities in product development are made more explicit. This is done by reasoning about input, goal, and resources, and not just output. This applies particularly to the product strategy and project management activities. Further, the effectiveness, efficiency, and knowledge gap are useful points of view of analyzing performance at each of the three generic activity levels. This may be especially useful in the product strategy and in the project management activity.

In industry, it is common for managers and decision makers to look for simple solutions to boost product-development performance. Hence, focus is often on the efficiency of the development activities in the PCRM in order to improve the overall product-development performance. On the basis of this research, it is suggested that performance in product development is achieved through three steps. The first step is to manage the knowledge gap, since this is the knowledge of what needs to be created to fulfil the goal and what resources are needed. The next step is to secure effectiveness, in order to create the right product. Once the first two steps are established, the third step, the focus on efficiency, becomes important. Performance is attained when knowledge gap, effectiveness and efficiency are managed as a whole in all of the generic levels of activities in the PCRM.

Finally, extensive research is available within each of the generic levels of activities in the PCRM. However, instead of assembling them in a system view of the complete product-development process, there is a tendency to divide and separate them from each other. This may be the reason why the industry is still struggling to make use of all theories available. In this research, it is suggested that the major issue is not the available knowledge on each of the generic levels of activities; but rather, the inability to holistically manage the product-development process. Only by adopting a system perspective is it possible to identify the difficulties and limiting factors present in a company's product-development process without sub-optimizing. By identifying and improving the weakest parts, the highest level of overall performance is achieved. Future research will focus on further verifying and developing the model by case studies within the context of advanced product development.

Chapter 9 A Method for Designing Performance Indicators

In this chapter the Performance Criteria Reference Model (PCRM), presented in Chapter 8, is further developed into a method for designing performance indicators. This chapter begins by motivating why there is a need for a method for designing performance indicators and this is followed by a presentation of the proposed method. The chapter continues with a presentation of the research approach applied when the method was tested in practice. A discussion of experiences and results from applying the design method in a real case concludes this chapter. This chapter is based on the following publications: Conference papers 5, 10, and 11, as listed in Section 1.7.

All functions related to product development are under great pressure to continuously deliver sustainable value to stakeholders, by bringing new products to the market. Performance measurements are of great importance in this context, since without them we cannot answer the most basic questions such as how well are we performing in our projects (Tatikonda, 2008). Even where performance measurements are introduced purely for purposes of information, they are probably interpreted as definitions of the important aspects of that job or activity, hence have important implications for the motivation of behavior (Ridgway, 1956). Thus, there needs to be a relation between what the organization perceives as important, i.e. success factors and the performance-measurement system in order to support improvements of the product-development process.

In a survey of commonly used performance measurements related to the development of new products in the US (Teresko, 2008), the following five metrics were those most commonly used:

1) R&D spending as a percentage of sales
2) Total patents filed/pending/awarded/rejected
3) Total R&D headcount
4) Current-year percentage sales due to new products released in past X years
5) Number of new products released

These metrics are useful on a high aggregated level in a product-development organization, typically at a top executive level. However, these metrics do not support managers in their everyday work of monitoring and managing product-development projects. These metrics are either input or outcome oriented measurements, e.g. the current-year percentage sales due to new products released in the past X years is a measure of the result developed for up to X years ago, and says little about the current development activities. In contrast to those high-level measurements are those focusing on ongoing activities in individual projects, often in terms of development efficiency. Measurements related to efficiency are often focused on deviations from the project plan or budget, once the deviation has occurred.

One conclusion, derived from the literature review in Chapter 2, is that performance is often measured in terms of what is easily quantifiable and not necessarily what is important, in order to support the obtaining of the desired performance results. In Chapter 7 this finding was also found within the case companies studied using the PMEX. One conclusion from Chapter 7 is that the current focus on performance measurements is mainly on the later stages of the implementation phases. Hence, there is a risk that focus is on what is measurable, rather than on the importance of what is measured. The fundamental task here is to avoid McNamara's Fallacy[2]:

> We have to find a way of making the important measurable, instead of making the measurable important.

This is also confirmed in Chapter 6 and Chapter 7 where no link was found between what managers and decision makers perceive as important, i.e. in terms of success factors, and what is measured by the performance-measurement system in complex product development.

This chapter describes the work of investigating how important performance aspects, success factors, can be evaluated during the development of new products in order to support the interactive nature of the product and project management functions. What is important differs between companies due to various circumstances and preferred ways of working. It is argued that a method is needed to support managers' work in developing a context dependent evaluation system based on their specific management needs of success factors. It is argued in this research, based on the review in Chapter 2 and the findings presented in Chapter 6 and Chapter 7, that it is important to focus the performance-measurement system on supporting managers and decision-makers *during* the development activities, in order to increase the likelihood of a successful end result. More specifically the research question guiding this research is:

---

[2] Named after former US Secretary of Defense Robert McNamara.

Rq 2.2 How can performance measurements be designed in order to support managers and decision makers in deploying proactive activities *during* the development of a new product?

Unfortunately there are few research studies describing how to design performance measurements according to the contextual needs of the organization. In a review by Neely (1997) the following guidelines for how to define performance measurements where argued for. The performance measurement record sheet should include: Title, Purpose, Relates to, Target, Formula, Frequency, Who measures?, Source of data, Who acts on the data?, What do they do?, Notes and comments. Furthermore, performance measurements must reflect the objectives for and responsibilities of the person(s) or activities that are being measured. However, these guidelines, even though important, describe a mechanistic view on performance-measurements design. They are more requirements for deploying measurements than for designing them.

In research question 2.2 it is stressed that there is a need for developing measurements that can support managers and decision-makers during the development. Hence, it is leading indicators of performanc that is aimed for according to the classification in Section 2.4.1. Parmenter (2010) defines seven characteristics of leading indicators of performance:

1) They are nonfinancial i.e. not expressed in monetary terms.
2) They are measured frequently
3) They are acted on by the CEO and senior management team
4) They clearly indicate what action is required by staff
5) They are measures that tie responsibility down to a team
6) They have a significant impact e.g. affect one or more of the critical success factors.
7) They encourage appropriate action e.g. have been tested to ensure they have a positive impact on performance, whereas poorly thought-through measures can lead to dysfunctional behavior.

9.1 Research Framework

The foundation for an effective performance-measurement system is that the performance measurements are derived from relevant performance criteria (Gharajedaghi, 2006) and objectives. When performance in product development is defined it is often in terms of efficiency and effectiveness as described in Chapter 2. However, most definitions of efficiency and effectiveness do not support the evaluation of these performance dimensions. In Chapter 8 an attempt was made to clarify the confusion in terminology, by extending the IDEF0 model of an activity, used by O'Donnell & Duffy (2002b) to define efficiency and effectiveness, to also include the knowledge gap, see Figure 23. These dimensions of performance were then defined at a product strategy, project management, and development activity level. The knowledge gap is defined in Chapter 8 as the difference between the goal and the input i.e. a measure of the new knowledge required by the activity, to produce the intended output.

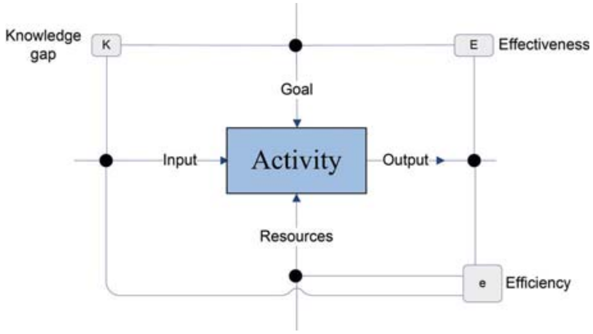

Figure 23. The IDEF0 model of an activity including the definitions of effectiveness (E), efficiency (e), and knowledge gap (K).

In this research, performance in product development is viewed in line with the arguments by Ermolayev and Matzke (2007) who suggest that the term performance is derived from the root concept for intentional action. Hence, performance should be defined as intentional action. This is of central importance as the performance of something is always context dependent. Not all actions are intentional. The notion of intentional action can be contrasted with accidental, as well as with unintentional action. This may be difficult to identify in a performance-measurement system where the focus is often on the output or the outcome of an activity. In this research it is suggested that what is sought of people engaged in product-development activities is goal-directed adaptive behavior, guided by the overall performance objectives set by the organization. This is in line with one of the generally acknowledged findings in the performance-measurement literature that performance measurements should be derived from strategy (e.g. Moxham, 2009).

9.1.1 A Method for Designing Performance Indicators

The key challenge, as argued in this chapter, is not to design new performance indicators. In a review of the literature by Adams et al. (2006) it was concluded that there is already a sufficiency of measurements defined in the literature. Instead the challenge lies in understanding the performance criteria and success factors that are important in order to fulfill the objectives set by the organization or a development project, in order to decide on the "right" measurements.

A method for designing performance indicators (DPI) consisting of three consecutive steps is proposed, as presented in Figure 24. The first step of the DPI method is the performance objective set by the organization that should be reflected in the performance-measurement system. Performance objectives should be interpreted as the objectives to be achieved in order to realize the pursued strategy. Performance criteria and success factors, representing the first steps in the operationalization, are identified in the second step of the DPI method on the basis of the performance objectives selected. An understanding of what is needed and how it is to be executed is developed by iterating the performance criteria and the success factors. In the third step, the important performance criteria and success factors are then translated into appropriate performance indicators that may be used to evaluate the current state of operation. Performance indicators can be identified from the literature or be defined as what is needed in achieving the important performance criteria and success factors.

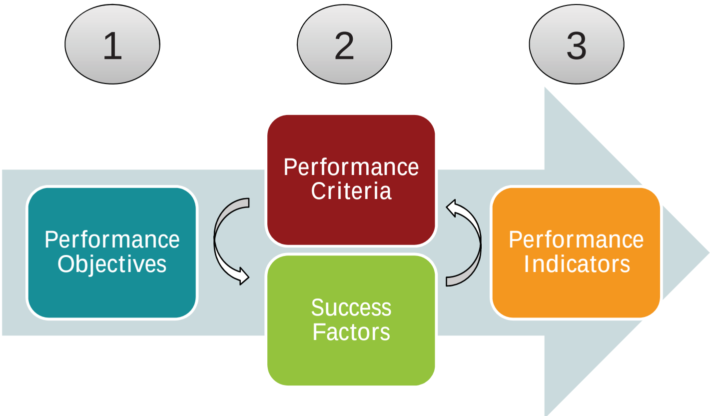

Figure 24. The proposed method for designing performance indicators (DPI).

The GQM paradigm (e.g. Basili et al., 2010; Mashiko and Basili, 1997) is, similar to the DPI method, a three step approach including goals, questions and measurements, developed within the software-engineering literature. One main difference is the inclusion in the second step of the generation of questions to be answered by the measurements in order to achieve the goal. The GQM paradigm has mainly been practiced within the software-engineering literature.

The IDEF0 model of an activity presented in Figure 23 and the PCRM presented in Chapter 8 are central support tools in all of the three steps in the proposed DPI method. The PCRM may be used as a starting point for modeling the organization of product development since it relates the generic levels of product strategy, project management, and development activities. The activity model may also be an important starting point when analyzing and breaking down the performance objectives. Analyzing the important major activities from the point of view of knowledge gap, efficiency, and effectiveness is the first steps in identifying relevant performance criteria and success factors. It is argued that developing measurements using the DPI method will result in new measurements that will support managers in improving performance.

9.2 Research Approach

A case study approach was used to test the proposed DPI method. The case study, presented in this chapter, was conducted at a market-leading company that recently has identified a need within the organization to make the product management function more explicit in order to manage their product portfolio and monitor ongoing development projects more efficiently. The unit of analysis in the case study was the development process related to the development of a new product. A development project was selected and used as a starting point for selecting interviewees. The development project was selected because of its character as a radical development project, mainly because the product is new to both the company and the industry. However, the new product leverages knowledge within the organization from the current product portfolio.

Data collection was mainly conducted through eleven open and semi-structured interviews with ten employees in the case study company, together with company specific documentation of the development project and process. To obtain a holistic picture of the performance-measurement process interviewees were chosen in a systematic way from different departments and functions with personnel on different levels having dissimilar backgrounds and experiences. Typical roles were line managers, technical experts, marketing managers, product managers and project managers. The interviews were conducted with two researchers present. The questions asked were stated in such a way that the interviewees were encouraged to talk about what they thought important for them to be able to perform their work with a high degree of performance. The interviewees were all experienced managers and decision-makers at different levels of responsibility within the organization. Every interview lasted between 1 and 2 hours. In total 10 hours of interviews were recorded and analyzed. All interviews took place at the case company. Several workshops where held at the case company first to present and develop the proposed method and then to present and analyze the findings. The data collection part was concluded by a final workshop in order to verify the findings and results.

The collected data was first analyzed by the two researchers individually and then together by listening to the recorded interviews and categorizing the findings according to the predefined categories in the IDEF0 model in Figure 20; Knowledge gap, Effectiveness, Efficiency, Input, Goal, Resource, and Output. During the case study, the researchers had access to the documents related to the project (e.g. project organization, process descriptions, administrative documentation, and product documentation).

9.2.1 Case company

The case company is a business unit within a Fortune 500 company, being the market-leader in their primary market. There are two main types of development activities within the case company, development of standard products and order specific development projects. In the latter the standard product is tailored to fit the needs of a specific customer. The products developed are complex products, i.e. products built around a platform and/or architecture, reusing components to keep the development costs low, something that is important due to the relative low volumes of these types of products. Further, these products include power electronics, mechanical, electrical and software components, making the need for cross-functional development teams important. In order to manage their product portfolio and to monitor the performance in ongoing projects, senior management has identified the need for a new function within their organization – the product manager. The development project studied in the case study was chosen since it is a technology development project and of great importance for the company's future success in securing new orders from customers.

9.3 Performance Measurements at the Case Company

The main objective of the initial workshops was to develop a common understanding of the aim of this research study and to get an understanding of the current state and use of performance measurements. More specifically one of the workshops aimed at investigating why the case company wanted to measure performance and how they intended to use the information obtained from the performance-measurement system. The result from this workshop was a long list of different reasons and objectives. In order to analyze the result from the workshop the six categories of reasons for an organization wanting to measure performance in R&D identified by Chiesa et al. (2009b) and presented in Section 2.4.2 was used.

Figure 25 shows the result from the first question, why it is important to measure performance in product development, indicating that all of the categories identified by Chiesa et al. are covered. However, the category relating to diagnosis is the single most popular, almost 50 per cent of the different motivations being related to this category. Motivation of personnel and learning was mentioned once only. This is in line with the findings by Chiesa et al. (2009a) that most performance measurements in large organizations developing high tech products can be related to the diagnosis category. A diagnostic approach results mainly in measurement systems including, for examples, project progress-monitoring systems, post project evaluations, and organizational audits (Kerssens-van Drongelen and Cook, 1997), as is the case within the case company.

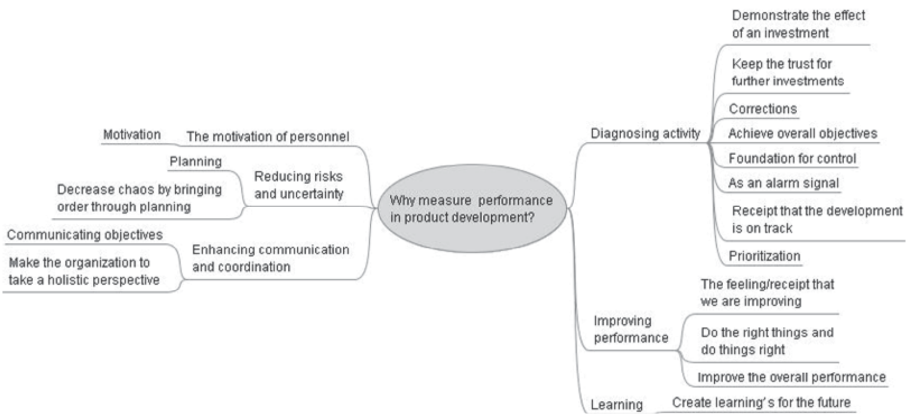

Figure 25. Why measure performance in product development?

The second question concerns how the information from the performance-measurement system is used. The same mapping was used for the result of this question. The results, shown in Figure 26, indicate that the information is not used for improving performance and that all of the categories except the diagnosis activity were sparsely covered.

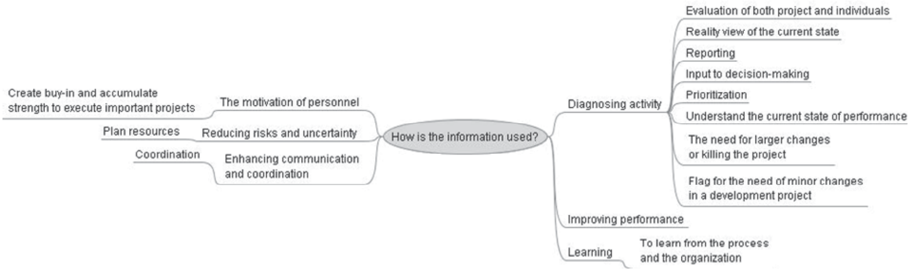

Figure 26. How is the information from the performance-measurement system used?

The overall result from the initial workshops is that there is a limited understanding of why performance is measured and how the information is intended to be used in practice. Using the information as a diagnostic activity is important, but it will not assist managers and decision makers during the development of a new product. Hence, there is a need to broaden the current perception of the performance-measurement system.

9.3.1 Semi-structured interviews

One of the objectives of the interviews was to understand how the product-development activities are organized in practice for a specific development project. All the interviewees were asked to discuss, from their point of view, input, resources, goal, and output on the basis of the development project. The product-development organizational model as shown in Figure 27 is a result of this work.

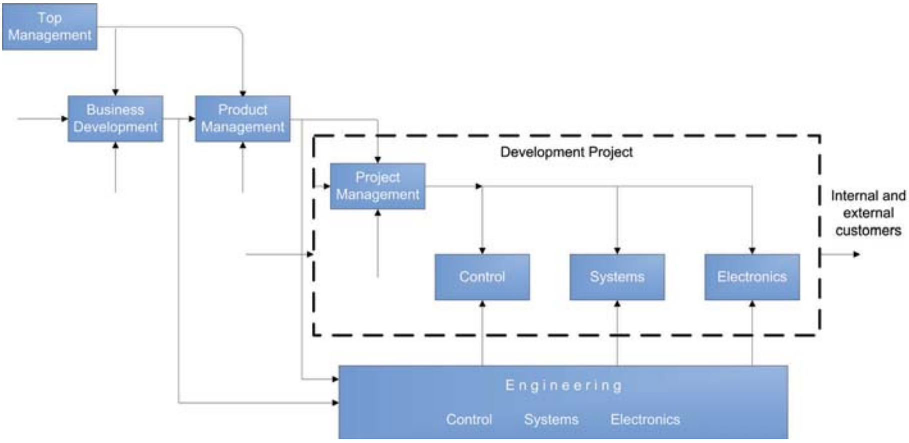

Figure 27. Organization of product development at the case company

The model was designed to show how the different activities are involved in the development of a new product at the case company. The three central activities identified, business development, product management, and development project activities, are similar to the main activity categories of the PCRM model presented in Chapter 8. The business development, product management, project management, and engineering are presented in the following sections.

Business Development Activity

The main responsibility of the business development activity is to develop a strategic point of view - what are the key future success factors. The business development activity, previously called product planning, is responsible for one of the product branches of the company with a turnover of several billion SEK. The business development involves many activities related to marketing plans and road maps for the existing product range. About one third of the work involves working with development projects. Typical interface to the business development involves both internal and external customers. This information is used as an important input in developing the strategic plan.

The business development activity role also collaborates closely with tender projects for which an order specific development project is tailored from the standard product to fit the needs of a specific customer. Business development was involved in the decision to begin the development project, by presenting an idea for a specific tender project in which the application could be beneficial. The resulting decision to invest in the development of this new product was, however, a joint decision, several stakeholders being outside the business unit. This ended up in the development project being pulled and not pushed to the market as is often the case when new technology is developed.

Development projects are often financed by a fixed development budget that sets the frames for the development work. The objective is to carry out as much development work as possible on the basis of the available budget. Business development presents a proposal on how to invest the budget in a portfolio of development activities. The most important aspects, regarding the developed products, are quality and functionality, even if it is not always communicated in the organization officially. Costs commonly exceed budgets in development projects. There is currently a strong focus on lowering the price of the product to the customer. In the end it is often the price that determines if a customer will buy the product or not, as long as it satisfies the functional and other requirements.

More recently, the case company has identified a need for more radical innovation projects in the development portfolio; there being too much focus on the incremental improvements of already established products. There are no formal performance measurements related to the business development function.

Product Management Activity

One of the primary objectives of the product management activity is to allocate resources in order to finance development projects, on the basis of the available development budget and according to the roadmap for the current product portfolio or development of new products. Hence, the road-maps of the different products are of central importance. Product management is a new function in the organization and during the interviews it was still under development. Previously the associated activities were part of the responsibility of the engineering organization. The product management function has a clear focus and is responsible for the effectiveness of the product development.

A central task for product management in this work is to ensure that the projects receive the resources needed, according to the project plan. However, it is project management that estimates and plans what activities are to be conducted in a development project. This is negotiated with the different resource owners within engineering. The development projects are managed through a company specific gate model that controls the financing of the development through one phase at the time. A global review of the development portfolio is made by top management every quarter.

The strategy has changed from being a follower to becoming a market leader but this change has not been fully deployed in the organization. This is particularly evident in the formal management processes where the focus remains on efficiency through standardization and reuse of technology. Product management is further responsible for the requirement specification for the development project on the system level. However, as the project is executed, the functional and other requirements are further detailed and the requirements for the different subsystems become more detailed. Hence, managing the requirement specification on a system level is a key task for product management.

Development projects are typically evaluated through project cost and progress, product cost, and the current state of the development. One of the problems is to know if the project will be delay while this can be corrected. This might be the consequence of having too many projects executed in parallel. Since, there are often only a small number of key expert resources that are needed in many projects, both development and order projects, the order projects are often given priority.

There are no general measurements for how the product management performs in development project. Instead, the product management function is evaluated in relation to objectives for specific projects. The focus of product management, in the development project studied will be the final product cost, the particular functional requirements of the product e.g. weight and reliability. The product management activity works in close collaboration with the project management activity.

Project Management Activity

The project management activity has both a technical and a general project manager role. The technical project manager leads the formal decision-making process regarding the design of the product in the project. One of the primary functions of the technical project management activity is to act as a system integration manager with the responsibility for the success of the technical system. The general project management role is to plan, monitor, and control project progress with respect to time and cost. The project is synchronized by meetings with one team leader from the larger functional groups i.e. systems, control, and electronics but most communications within the project is performed outside meetings rather than in meetings.

The development project in this case study was initiated in parallel with a tender project in which the new technology will be adopted. The tender project has affected the development plan in calendar time by demanding the performance of more development activities in parallel, to be able to complete the project in time. This is considered by the project manager to be a risk in the project. The technology developed is also intended for used in future order development projects. A traditional steering group for the development project has been appointed in addition to a so-called local reference group. The latter is a group of stakeholders, primarily managers which provide resources who are interested in the result of the project. It is intended that this local reference group should be more accessible to the project than the steering group.

The biggest challenges to the project management activity can be divided into short term and long term challenges. In a short-term perspective the challenge is to get resources to the project, and in a longer-term perspective to be ready in time and deliver what has been promised. At the time of the interviews the development project was staffed with only 60 per cent of the resources planned and it had been like that since the start of the project. The resources needed are preoccupied in order-development projects with a higher priority. Normally, the order specific development projects are prioritized but there have been development projects that have been given priority in order to deliver on time. When this is decided on, it sends an important signal to the organization that this development is central for the future survival of the organization. However, it is not project management but product management that is responsible for making sure that the resources needed are available according to plan.

The technical challenges in the development project will be overcome; there are no unrealistic demands on, for example, the product cost. The overall objective in the early phases of the development is to learn as much as possible before the industrialization phase of the development project. One important success factor for the development project is the availability of the team developing the electronics to deliver the requirement specification for the control team in time. This is an important factor for a successful project realization. The organizations judgment if the development project is successful or not, is purely related to the technical performance of the final product, not if the project has been completed within the budget.

The earned value methodology, with cost performance index and schedule performance index, is used for monitoring the development projects. The project manager updates the earned value every month. In parallel, the project reports the same information given by the earned value to the local reference group. Different reviews of the development project are also prepared throughout the project life cycle to identify deviations from budget.

The Engineering Organization

It is within the engineering organization that the functional engineering resources are organized, e.g. control, systems, electronics, mechanics, and lead engineers. Most of the activities related to the engineering organization are within order projects. Currently, there are about fifty order projects in the portfolio executed in parallel, with various engagement levels. Engineering is involved to approximately one third in global product-development projects, initiated by product management, and two thirds is order specific development activities controlled more locally. Hence, development projects that deploy the same resources may be given a lower priority than order projects since the date for delivery of the product to the customer is well-defined. About 500 people are engaged within engineering in very different development activities from software development, and electronics development, to mechanical design.

Product-development activities are necessary to qualify for tender projects, thus selling the company’s products to the customer. Hence most of the development is market pulled and not technology pushed. Typical measurements within the engineering organization are earned value, and re-use within the product portfolio. Earned value is regarded as a good ways to evaluate the progress of the development project according to the project plan.

9.4 Applying the Research Framework

In this section, the use of the proposed DPI method is demonstrated, as presented in Figure 24. The three steps according to the proposed methodology have been followed and are presented accordingly in the following subsections. The first step clarifies and decides on the performance objectives. This step is followed by iteratively deriving relevant performance criteria and success factors; this is the foundation and important step for developing the relevant performance measurements in the third step that will be adopted by the organization. These three steps will be further presented in the following subsections.

9.4.1 Performance Objectives

It is important that the performance objectives are compatible with the strategy of the organization. A major change in the organization's strategy, from being a fast follower to becoming a technology leader by bringing more radical products to the market has been decided on recently. However, the formal measurements currently focus on monitoring product standardization and reuse. The earned value methodology, also used within the case company, monitors resource consumption in a lagging perspective, i.e. resources already consumed.

It was decided with the case company that the required performance objective is to develop measurements that can give early warnings of development projects deviating from the plan. This may enable proactive actions in the ongoing development project and thereby avoid large overruns.

9.4.2 Iterations of Performance Criteria and Success Factors

The second step in the proposed approach to developing performance measurements is to break down the performance objective into performance criteria in order to design performance criteria derived from the performance objectives. In this study, focus was on the identification of performance criteria and success factors in the interview study. Performance criteria and success factors in this study are intended to enable proactive actions, in contrast to the reactive actions resulting from lagging measurements. Performance criteria relate more towards what needs to be done, while success factors tend to focus on how it is to be done. By analyzing the interviews the following list of performance criteria / success factors were identified:

1) A clear target of what is to be developed (Goal)
2) Planned resources available, especially key roles (Input and Resources)
3) Strong project management (Resources)
4) Requirements stability (Goal)
5) Pre-studies (Knowledge Gap)
6) Sub projects, not one big project (Knowledge Gap)
7) Team composition (Input and Resources)
8) Leverage globally available resources (Resources)

The relation to the IDEF0 model of an activity property (see Figure 23) has been added after each factor in order to analyze the affect each performance criteria / success factor has on the development output.

On the basis of the list of identified performance criteria / success factors, it was decided in consultation with the case company to focus on what was regarded as the two most important areas i.e. resource allocation and scope. Hence, for the next step in deriving performance indicators, focus was on factor 1, 2 and to some degree also on 4.

9.4.3 Deriving Performance Indicators

In order to derive relevant performance indicators for the selected performance criteria / success factors the guidelines provided by Neely (1997) were adopted. The result is presented in the following sections.

Resource Allocation

Resource allocation is of central importance for the case company and can be viewed as a leading indicator for the already established earned value methodology. As is common in many organizations, the portfolio of projects is extensive and includes parallel projects. Hence, there are many development projects competing for the same limited resources. The problem relates more to available competence than the available finance. In the development project studied, senior experts are typically needed in the development work. Moreover, it is important to take a system perspective and see the resource allocation as a whole. Cross-functional development teams are used in the development project and these teams are dependent on their different roles and competences being involved at the right time. There is otherwise a risk of other resources not being able to perform their tasks and there is a risk of a chain reaction if not all resources are available as planned.

It is proposed that one way of measuring this can be the percentage available resources as planned for within a window of the next two weeks. This could also be detailed further by specifying the type of resources needed from engineering e.g. control, system, and electronics. This can also be further developed to especially monitor the key resources needed to be able to deliver according to plan. The proposed measurement, the Resource Allocation Tracker, is expressed in the performance measurement record sheet is presented in Table 17.

Table 17. Resource Allocation Tracker

Details	
Title:	Resource allocation tracker
Purpose:	Monitor the allocated resources compared to the plan
Relates to:	The earned value methodology
Target:	100 per cent
Formula:	Percentage of allocated recourses compared to plan in the coming two weeks window.
Frequency:	Every week
Who measures?	Project manager
Source of data:	Project members and team leaders
Who acts on the data?	Project manager
What do they do?	Alert engineering and product management and ask for action.

A Clear target of What is to be Developed

It is possible to monitor the technical scope of what is to be developed by analyzing the requirement specification. It is commonly argued in the project management literature that it is important to have a well-defined set of requirements, representing the objectives, before the project is initiated. In practice, especially for development projects, there tend to be changes in the requirements. In development projects, there could be internal or external changes to the product requirement specification.

There are several possible sources of internal specification changes, but one major cause is the breaking down of the requirement specification into requirements for the various sub-systems after a baseline has been decided on. This is correlated with a risk of identifying further difficulties that may affect e.g. the planned resource consumption or even the possibility of delivering the specified product. The project can visualize the project progress by monitoring the breakdown of the requirement specification. The internal stability may also affect the stability of the requirement specification as a whole.

There could also be external changes to the requirement specification and this is also important to monitor. Possible sources are product management, tender projects, the business development or other sources internal as well as external. These could also be monitored by the number of application areas in which the product is intended to be used. There is usually a specific tender project or similar in which the product will be used, however as time passes more and more application areas tend to be identified which potentially affects the requirement specification and the development of the product.

One benefit, for managers and decision makers, of monitoring the stability of the requirement specification is that it gives an overview of the sources of changes and an understanding of the stability of the requirement specification. If there are major changes there is also a large amount of uncertainty in the project planning. Hence, there is a possibility that there will be major future changes in the project scope. It is important to acknowledge that there is no optimal value for this measurement; instead the benefit is achieved when the sources are evaluated and changes to the process decided upon are performed accordingly. This measurement can also be used to explain to and give managers a common view of the status of the development project. Further, the requirement changes can be classified according to value adding, non-value adding but necessary, and waste. The frequency of this kind of measurement depends on the current phase of the project and the frequency could be changed accordingly. No performance measurement record sheet was developed for this part as for the resource allocation tracker.

9.5 Discussion and Conclusions

This chapter proposes and outlines a method for designing performance indicators (DPI) that supports managers and decision makers in deploying proactive activities *during* the development of a new product. The proposed methodology is grounded on three consecutive steps. The first step is to decide what performance objectives are needed to be fulfilled in order to realize the pursued strategy. This step is followed by the identification of performance criteria / success factors that will contribute to the realization of the performance objectives. Performance criteria are typically related to what needs to be achieved in order to fulfill the objectives while success factors focus more on how they are to be fulfilled. Based on the most important performance criteria /success factors the supporting performance indicators can be derived from the literature or by using the performance measure record sheet by Neely et al. (1997).

The proposed method has been successfully tested in a case study. More specifically the case study described in this research has investigated how to develop indicators that integrate the product management and project management roles a development project. The result is performance indicators derived from the performance criteria / success factors of having a clear target of what is to be developed and of the project having the planned resources, especially key roles, available. A clear target can be evaluated by monitoring the changes in the requirement specification, both regarding internal and external to the project, after the first baseline. The second indicator focus on the amount of resources available compared with the committed project plan. Both indicators can be further detailed according to the needs of the organization. As has been demonstrated the indicators resulting from the method are in line with the aim of the method, since both measurements will give managers early warnings of deviations from the plan.

One conclusion from using the proposed method is that the identification of performance criteria and success factors is the key to success in developing performance indicators. This is the causal link between the objectives and how the organization should evaluate its performance in order to achieve its objectives. It is interesting to see that the proposed performance indicators are relatively simple if they are analyzed by an outsider. The real leverage in the proposed indicators is that they are grounded in the specific needs of the organization as identified in this research and confirmed through workshops at the case company.

The literature reports several attempts to find general best practices when it comes to performance measurement. It is argued in this chapter that general best practices may be suitable when evaluating the output, outcome or the amount of resources invested in product development. However, when focusing on what is important to evaluate in order to turn the invested resources into successful outputs the context plays an important role that must be reflected in the measurement system.

9.5.1 Implication for Practice

In this chapter a first verification is presented of a method for the development of performance indicators based on what the organization identifies as important in achieving success. Despite, it being the first attempt to apply the proposed method in practice; we believe there are some valuable implications for managers and decision makers, especially for project and product managers in large organizations. The proposed DPI method can be applied by managers in order to support the development of their own organization-specific indicators, which complement the traditional indicators which focus on time and cost. Additionally, the proposed method illustrates that the design of new performance indicators need not be a tedious process. The focus should instead be on establishing the performance objectives and deriving relevant performance criteria that can be used in identifying suitable performance indicators.

9.5.2 Implication for Theory and Future Research

This research aims at increasing our understanding of how to design performance indicators in a product-development context to support product and project managers, in particular, during the development of a new product. The product-development management literature contains few methods or frameworks, other than the GQM paradigm (Basili et al., 2010; Mashiko and Basili, 1997), on how to assist managers in developing relevant performance measurements based on the needs of the organization. However, there are many reports describing theoretical performance measurements. A typical example includes the need for the performance-measurement system to support the pursued strategy of the organization. But few tools for supporting the development of such performance measurements exist. This might explain why performance measurements do not reflect the changes made in strategy, as identified in a recent study by Johnston and Pongatichat (2008).

The first use of the DPI method resulted in the case company adopting the resource allocation tracker, as a leading indicator to capture the early warnings of deviation from the development plan. This is only the first verification of the DPI method for developing relevant performance indicators from the viewpoint of the managers and decision makers involved in the product-development organization. There are several future research opportunities related to the proposed methodology. More studies in which the DPI method is tested are needed, in order to ensure replicability of the method. It is also important to follow up on the case study conducted in order to evaluate the result of the proposed measurements after they have been implemented in the case company.

In this chapter focus has been on the perspective of objectives and performance measurements. Tatikonda (2008) also argues that two other perspectives are important when analyzing measurements: its metric and the incentives connected to the measurements system. More research is needed to see how the proposed performance indicators, requirement stability and available resources, are affected by other aspects of performance measurements, i.e. different metrics for calculating the actual value and how incentives should be designed in order to optimize the benefit for the organization.

Chapter 10 A Model for Products in Development

A method for using value as an integrated measure of performance *during* the development of a new product is presented in this chapter. The chapter begins by presenting a summary of the literature related to the use of value as a measure of performance. The chapter continues by outlining the research approach applied in this research and a presentation of the proposed method for integrating customer value during the development. Experiences from applying the method in practice are presented in the next section and this is followed by conclusions and future research. This chapter is based on conference paper 1, as listed in Section 1.7.

10.1 The Importance of Value in Product Development

All organizations exist in order to create value for their stakeholders. The primary objective of a for-profit organization is to maximize shareholder value and this can be done in different ways. Developing new products, in an efficient and effective manner, is one way for a product delivering company to secure future growth and profitability. Product development contributes to a corporation by generating revenues and profits that otherwise would not have been generated (Annacchino, 2007). The customer value of a new product is dynamic and different customers may interpret value in different ways.

Performance measurements are generally acknowledged to be powerful and to affect people's behaviour according to what is being measured (Hauser and Katz, 1998). It is therefore important to align the performance-measurement system with the strategic priorities of the organization (Dixon et al., 1990; Neely et al., 2005) i.e. how value will be created in the future. However, as is concluded in Chapter 6 and Chapter 7, few measurements of productivity or value are identified in the development of complex products. Cooper and Edgett (2008) argue that the concept of product-development productivity is relatively new and therefore not commonly used in practise. In most situations, value is difficult or impossible to measure; firms have to look at other alternatives (Merchant and Van der Stede, 2007). Within product development this is especially difficult e.g. because of the inherent uncertainty and long lead time between effort and pay-off.

10.1.1 Productivity and Value

Several tools and frameworks related to productivity and value appear in the literature. Value analysis developed by Lawrence Miles (1972) is a proven method to improve product design and lower costs by exploring multiple concepts, increasing communication in development teams, identifying high cost functions etc. However, it is an engineering tool and not a method to assess value creation during the development of a product.

Within the project management literature the earned value methodology is commonly used to evaluate the performance of a project as it moves from project initiation to project closure (PMI, 2004). Earned value analysis is a project monitoring method that combines the Schedule Performance Index with the Cost Performance Index, to address questions such as “how much value did we get from the effort we spent?” (Ebert and Dumke, 2007). Earned value is used to measure work accomplished and quantify the impact of known issues and uses this data to forecast estimates at completion. However, the value in earned value is not based on customer value; it is based on the development cost, since the activities are valued according to the planned cost of producing the result. Also, without a measurement of the quality and value of these outputs, as well as the quantity, the measurement system may occasion unwanted behaviour. As Brown and Svensson (1988) point out, an R&D organization can be extremely productive when measured by the quantity of outputs produced, but still not do much to further the organization’s business goals.

Real options (Schneider et al., 2008) and various methods based on discount cash flow (Ryan and Ryan, 2002) are two common ways of assessing the value of an investment. In a review of the Fortune 1000 companies Ryan and Ryan (2002) conclude that the two methods mostly used for evaluating an investment are the net present value (NPV) and the internal rate of return (IRR). The NPV of an investment opportunity is the sum of the present values of the expected future income stream. Each future income amount in the stream is discounted, meaning that it is divided by the opportunity cost of holding capital from now until the year when the income is received. The opportunity cost can either be how much you would have earned investing the capital someplace else, or how much interest you would have had to pay if you borrowed the capital. The IRR for an investment represents the discount rate that makes the NPV equal 0. One limitation of the discounted cash flow measurements is that they do not recognize the value of a wide range of competitive commitments (Baldwin, 1991). They do not value commitments to innovate in advance of the competition. When a firm invests in a new product that decreases the value of existing products, it is said to be cannibalizing its business. Capital budgeting systems are explicitly designed to prevent cannibalization (Baldwin, 1991). However, if ultimate success depends on deterring the competition, cannibalization may be the key to survival and success in the long run.

Real options valuation is analogous to financial options valuation, except that the underlying asset is a system or product to be deployed in the future, rather than a financial instrument (Bodner and Rouse, 2007). In staged funding systems, such as the Stage-Gate model (see section 2.1.2), the decision to fund a particular stage of a product development can be treated as a purchase of a call option, where exercise of that option involves funding a later stage or stages (Boer, 2000). The real options method has been viewed as the valuation method of the twenty first century, but Block (2007) argues that it is still only used by a small percentage of the Fortune 1000 companies.

Productivity has always been the focus when it comes to evaluating the performance of product-development activities. There are different definitions of the term; the most generic is to view it as output divided by input, i.e. the value of the output created by the product-development process divided by the resources consumed in creating that output. One limitation with this definition is the time lag. In the development of complex products, it can take several years until a product is developed and introduced to the market. Hence, the definition of productivity, by Cooper and Edgett (2008), implies a measure of the previous year's productivity and it will say nothing about today's performance. The new sales ratio, defined as the percentage of revenues related to products developed in the latest X years is a similar way of evaluating performance (Whitley et al., 1998). One limitation with this measurement is that it is lagging by X years and is of little use when the value of the current activities in the development of new products is to be evaluated. The challenge lies in evaluating the value of the output created during its development in order to avoid a lagging perspective.

From the point of view of productivity, performance can be improved both by increasing the expected benefit and by decreasing the cost of creating the output. However, as concluded by Kelm et al. (1995), the literature on valuation of R&D efforts has primarily focused on expenditures. Steele (1988) argues that most measurements of activities within product development finally become measurements that can be expressed in terms of human resources and money. Traditional methods are generally not appropriate because of the nature of the output which is long-term and often intangible (Stainer and Nixon, 1997).

10.2 Introducing “Products in Development”

As concluded in the summary of the literature and in Chapter 6 and Chapter 7, there is a need for methods that make it possible to evaluate how value is created *during* the development of a new product. Products in development (PiD) is a method for integrating perceived customer value as a measure of performance during the development of new products. Developing a product usually involves numerous steps and activities. From a performance evaluation point of view it is difficult to use the same criteria for measuring performance throughout this process.

In this research we extend the reasoning in Chapter 5 in which the activities of the product-development process are categorized according to planning, implementation, and sales and delivery. In this chapter focus is on the implementation activities and the interface between planning and implementation. Research question 2.2 in particular is researched in this chapter and the objective being to determine how the value being created during the development can be evaluated during the development.

If the proposed categorization of the product-development activities is considered form a value viewpoint, it is evident that the different activity categories play different roles in the creation of value. In this chapter it is argued that it is important to acknowledge and recognize these roles. Further, it is proposed to view the planning activities as capturing value, implementation activities as developing value, and the sales and delivery activities as realizing value. This holistic high level categorization makes it possible to analyze and evaluate how value is created during the development of a product. The value created is the value that has first been captured, then developed and finally realized. The natural question, for managers and decision makers, is how to determine where in the proposed categorization the organization is limiting the value created during product development.

In Scenario A Figure 28, an organization plans for the capture of a particular amount of value, but as a result of budget cuts or limited resources some of the requirements are not considered during the development of the product; hence limiting its possible value when realized. Sales and delivery may have a more difficulty in selling the product i.e. realizing its value, when some of the initial requirements have not been satisfied. As a result the value is generated through product development as illustrated as in Scenario A in Figure 28.

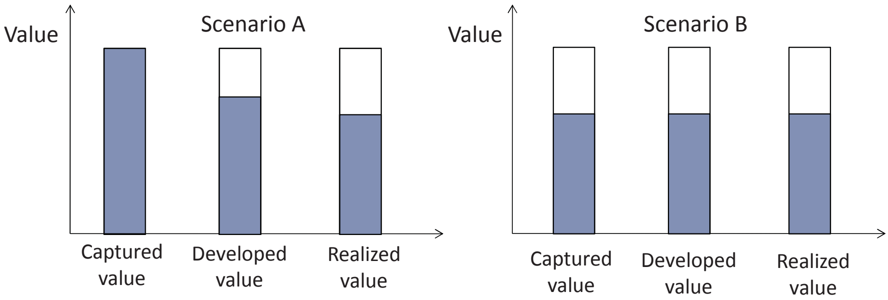

Figure 28. Two scenarios of how value can be created during the development.

In Scenario A, activities performed in the planning activities intended for inclusion in the implementation but not incorporated in the final product, may be regarded as waste. In Scenario B in Figure 28 when value is not lost during the development a more predictable execution of the development activities is possible. Moreover, there are a number of other scenarios that can be developed on the basis of this simplistic framework for reasoning about the value created during the development of a new product. The major benefit from using this framework is that it enables managers and decision makers to determine in what phase the organization has its weaknesses and strengths.

It can happen in practice that the sales and delivery activity category can be very successful in realizing more value than the value developed, due to a specific change in the market. External change in customer needs can result in a boost in the sales and delivery of the product that was not recognized as important in the planning and implementation activities. This may lead to high profits and or market growth for the organization being falsely interpreted as high performance product-development planning and implementation, even though the reality is another. Alternatively, it is possible that there is high performance in planning and implementation but for some reason the sales and delivery activities have difficulty in communicating the benefits and selling the product.

10.2.1 Requirements as Drivers of Value Creation

The framework for reasoning about value shown in Figure 28 enables the analysis and evaluation of performance on a high level in one way. In order to further detail the level of analysis, requirements are proposed as the unit of analysis of the value created during the development process. Requirements are an interface that product managers, line managers, engineers, customers and other stakeholders can discuss and agree upon. Formulating requirements is also a key step in developing a product a new product. When the requirements have been agreed upon, the development activities escalate and the more costly activities begin accumulating. Once a requirement is formulated from a customer need, it is easier to determine if it is feasible or not to incorporate the requirement in the new product.

10.2.2 Outline of Products in Development

The different steps and prerequisites included in the proposed method for evaluating value during the development are presented in this section. The inputs to the PiD method, that are assumed given, are:

- A set of n requirements
- An initial assessment of the perceived customer value for each of the n requirements
- A set of m steps or phases in the product-development implementation

The terminology for describing value in the PiD method is defined according to:

- *Captured value* is the sum of the perceived customer value of the n requirements.
- *Developed value* is the current value of the activities related to the n requirements for each of the m stages or phases in the development implementation.
- *Developed value completed* is the minimum value of the m stages or phases of the developed value.

Given these assumptions and definitions the PiD method can be described by the following steps:

Step 1: The *Captured value* is equaled to the value set in the business case. The *Developed value* and the *Developed value completed* are both set to 0. Step 1 is to be conducted as the product-development implementation is initiated.

Step N: The captured value is reassessed according to the changes in requirements from Step N-1. Requirements can be added and/or subtracted. This is followed by an updating of the perceived customer value of the updated set of requirements.

As the product-development implementation activities are continued to completion, the *Developed value* and the *Developed value completed* are updated accordingly.

The number (N) of steps of the PiD method depends on the complexity of the development project. They can be performed in conjunction with a gate review or on some other occasion. The responsibility of assessing the value of the requirements should be allocated to the product manager or other representative of the organization financing the development project. In the case in which we tested the method, the product manager and the project manager jointly valued the requirements according to their perceived customer value. It is important to stress that the customer is not explicitly involved in the valuation but could be; it is the perception of customer value of the product manager and the project manager used in the valuation of the requirements.

10.2.3 Two Value Dimensions

When evaluating and analyzing the value created in a product-development project there are two important dimensions of value to focus on:

1) The internal value - Where are we gaining/losing value during the product-development implementation?
2) The external value - Are there any market changes in value or scope changes in the requirements during the development?

These two dimensions of value are to be viewed as internal and external to the development project. From an organizational point of view, it is important that both these dimensions are taken in to consideration since the overall value will depend on the result of both the internal and external dimensions. The project manager is ultimately responsible for the internal value dimension i.e. for developing the value according to the captured value. The product manager is responsible for the external value dimension i.e. for monitoring market changes or other similar changes in the captured value that will affect the overall created value.

An example of how value is created as the development progresses between two gates is illustrated in Figure 29. On the basis of the *captured value* as assessed at G_n, the *developed value* increases progressively as the activities related to the specific requirement are completed. For example, if a requirement is valued as 7, then 7 is earned when the activities related to that requirement and gate have been completed. There can, however, be changes in the set of requirements, some of the requirements may be difficult to implement or have been omitted for other reasons. It is important to illustrate the effect this will have on the overall value created during the development of the new product.

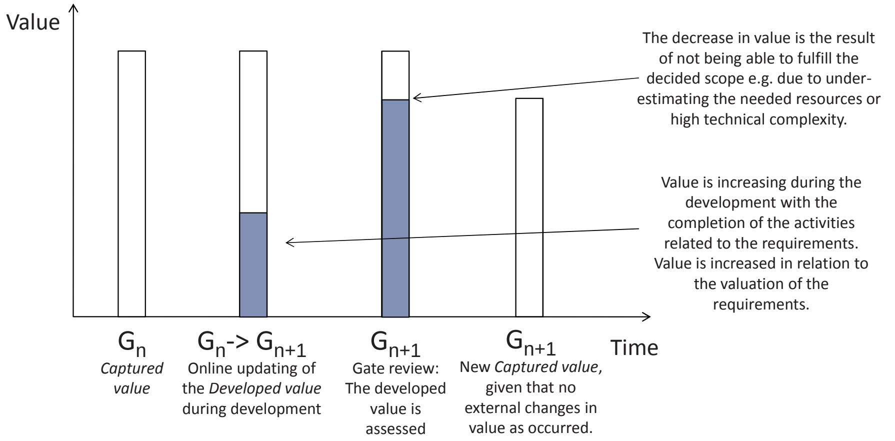

Figure 29. Example of value creation during the development

An alternative way of visualizing the evaluation of the internal dimension of the value is to first divide the development process into four different stages: Specification and design, Implementation, Integration and System test and verification. These stages were chosen with the objective of visualizing where value can be gained or lost during the product-development implementation. The first stage, Specification and design, includes all the activities involved in the writing and approval of the requirement specification and the development of a design for the incorporation of these requirements in the product. Once this is performed for a requirement, the value related to that requirement is earned for that stage. This procedure is then repeated for each of the other three stages. Figure 30 shows how value is developed during the implementation stage.

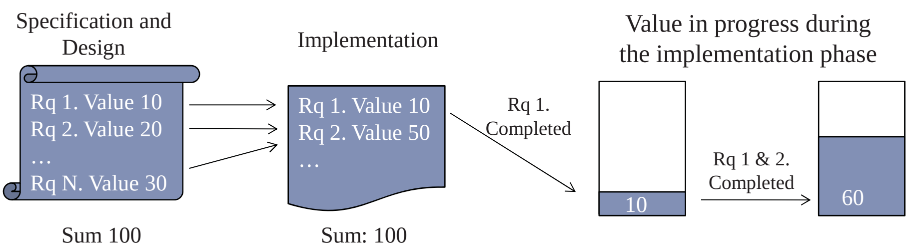

Figure 30. Progress in value during the implementation stage

The resulting activities can be valued in accordance with the perceived customer value of the requirements. The activities can be either completed or not completed, and once the activities related to a requirement are completed the inherent value is earned. Figure 31 presents a possible snap-shot of the *developed value* when using an iterative development process. In this snap-shot the value has been normalized to 100 per cent in order to visualize the developed value.

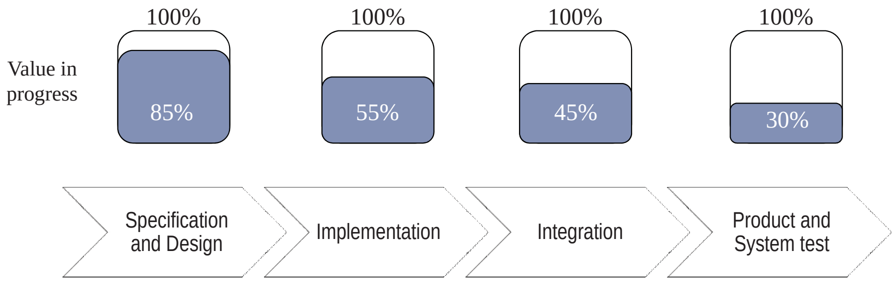

Figure 31. A possible snap-shot of the *developed value* created during the development

10.3 Research Approach

A study has been performed that began with the observation that the market value of the output of a project can be estimated *during the execution* of the project. As we have seen in the related work section, this is a novel approach. A method, based on our observations and designated *Products in Development* has been outlined that may be used to evaluate the value created during the development of a new product.

A case study has been designed to test the proposed method in a real setting, in order to gain experience that can be used to develop the method further. The case study has been performed in an organization in which the valuation of requirements has been tested separately, with good results, in an earlier project. In the case study, the data collected is from a number of workshops for the evaluation of the market value of the different requirements.

The case study company develops complex products in an organisation with facilities at three different locations in Europe and one in Asia. The product development is based on cooperation between the different parts of the organization. This means that product management and development projects define and agree on the requirements and proposed design solutions that are the basis of the planning. This handshake includes the allocation of priorities for the requirements and the preliminary resource needs.

The products are supplied as open products, the customers selecting the functionality required and configuring the parameters themselves, or as pre-configured solutions, the system being delivered with a pre-defined set of hardware, applications, and configuration data. An operator station based on a PC runs monitoring and control software tools. These tools communicate over a network with embedded devices, which run the base software, and applications. The applications themselves vary and support many different types of protection, control, and monitoring operations.

The product-development project in our study is the upgrading of an existing system, adding basic functionality such as new hardware to increase performance, as well as new applications to increase the market penetration. The planned duration of the project in was to be nine months, with approximately 30 person-years of effort. The project is executed by teams responsible for the different components, the teams working together with an architecture team to ensure that the solutions satisfy the requirements. The development is performed in increments, the components being frequently integrated, typically every second week. At each integration point, the teams focus on specific functionality defined in the integration roadmap.

10.4 Applying Products in Development in Practice

Some initial findings from the case study and reactions from the organization observed are presented in this chapter. The first preliminary indication from the organization is that the valuation of the requirements, step 1 in the proposed method, is relatively quick and easy to perform and re-estimate. This was performed jointly by the product manager and the project manager. They report that the valuation of a previous development project took approximately one hour to do, and re-do as the values were re-visited during the progress of the development project.

Previously, before the case study company began using a valuation of the requirements, they used a simple scale to prioritize between possible requirements. All the requirements were classified as high, medium, and low depending on subjective market needs and urgency but this usually resulted in a product in which only the requirements labelled high were implemented. Hence, in order to make sure that the most important requirements, from a value point of view, were being implemented first. The adoption of a valuation of the requirements according to perceived customer value was a big step in itself.

The project studied in this research was the development of a newly developed product and the main objective was to add extra functionality to the product and to correct some errors. The previous development project was more of a maintenance release, focusing solely on error corrections. When the development project began there were 20 requirements, with one main requirement representing 50 per cent of the total value. This project was executed with a low effort at the beginning for various reasons including a heavy workload in the development portfolio. When ramped up, some extra functionality that had been developed in other parts of the company was added and thus the scope of the project was widened. The list of requirements had been updated with 22 additional requirements, resulting in a total list of 42 requirements. Moreover, the first requirement valued as 50 per cent at the start of the project had been realized elsewhere and thus omitted from this project. When the project was completed a final reassessment of the value was performed. The result illustrates that additional changes to the list of requirements had been made during the execution of the project. In Figure 32 an overview of the generation of value is illustrated.

Currently the organization has no productivity perspective in its product development. However, project managers requested this during the initial workshop. Estimating or calculating productivity requires not only measurements of the value created but also of the effort with which the value was created. However, this was difficult to achieve in practice since the time registration system and policies used in the organization do not enable tracking of engineering hours/effort for specific activities.

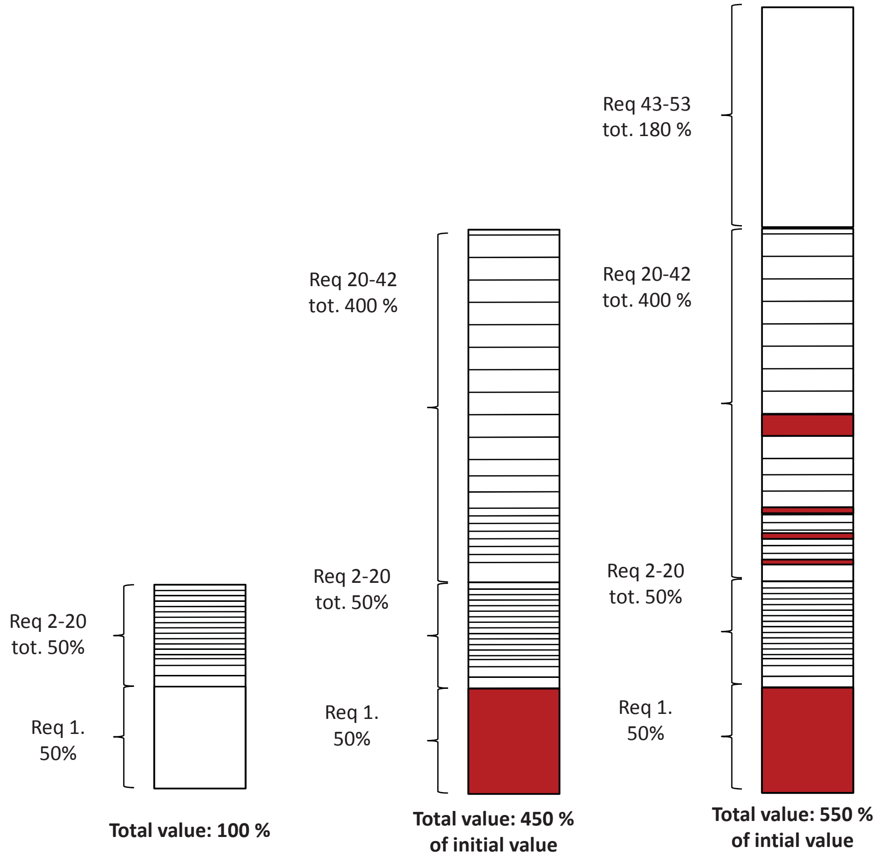

Figure 32. Value generation during the development project. The red marking indicates requirements being deleted during the execution of the project.

10.5 Discussion and Limitations

It is typically easier to estimate the value of a new product that consists of new features added to an evolving product, than that of a completely new product, developed for a new market. Given that the wish list of features and improvements often is often longer than what the organization can satisfy with its limited resources, these need to be prioritized in a way that gives the organization the optimal return. This is important in the development of complex products with large software content and it is often referred to as release planning (Lindgren et al., 2008).

When the scope of the development project is not agreed on it is difficult to track the value progress since requirements may be added or subtracted. A typical example is shown in Figure 32. This situation is difficult to manage, the proposed method helps visualize the effect these changes have in terms of value. When requirements are deleted, the effort already invested in partly realizing these requirements is wasted. The introduction of a value perspective also assists in the identification of waste i.e. work performed that will not add to customer value and future profit for the company.

Other challenges to and limitations of the proposed evaluation method include the fact the value used in the evaluation system is the customer value perceived by product management and not necessarily the realized value. It is important to acknowledge this and not rely too strongly on measured results. The strength of the method is instead that it shows how value is destroyed or wasted by changes in requirements made late in the project and by the focus of the project not being on what is perceived to create value. Late changes in development scope can be due to poor planning, e.g. overestimating the organization's capabilities, or poor market intelligence, poor performance in the implementation phase, etc.

One direct benefit of adopting a valuation of the requirements is that low quality requirements will be identified by the difficulty or impossibility experienced in their valuation due to inadequate definition. Valuation of the requirements could also be viewed as an additional quality assessment of the requirements. However, there could also be low quality requirement easy to value, this resulting in several iterations during the implementation.

10.6 Conclusions and Future Research

In this chapter a method has been outlined for integrating perceived customer value in order to illustrate how value is created in real time during the development of a product. This way of using value to assess customer value by linking it explicitly to the requirements is a unique initiative. The majority of the valuation methods identified in the literature focus on the project or firm level, and we found no performance measurement methods focusing on the requirements level in projects. Since this method is still under development there is still substantial research to be done. However, some initial conclusions, both positive and negative, from using the method have been made.

Advantages of the method from a managerial perspective include:

- A small extra effort to get an understanding of the value creation during the development. As the method is outlined, it is easy to add the evaluation of requirements and then monitor how the value progresses during the development.

- Easy to detect waste i.e. activities not creating customer value. There are many possible sources of waste during product development. However, by focusing on what creates value, by definition, the activities not contributing to the value creation are waste. If for example a requirement is disregarded in a late stage of the development, the effort invested in satisfying that requirement is waste from the development project perspective.
- Balancing the focus on time and cost with a value perspective. This is not possible if there is no way of evaluating the value. By using this method such a balanced perspective can be obtained.
- If the valuation can be agreed on, the stakeholder perception of what is important is aligned. When different solutions or opinions are discussed and evaluated the value perspective could be used as a subjective method in assisting in the decision making process.
- Changing focus from cost minimization to value optimization. This has been the result of the absence of a value perspective. Since time and cost are easy to measure, it is easy to focus on these dimensions in the search for increased productivity. If a value perspective can be integrated as part of the performance measurement system this can be balanced in a better way.
- Focus is on the complete value chain of product development. This is important and is described in Figure 28. Value needs to be captured and developed before it can be realized. By applying a system perspective to these processes, weak areas can be identified and strengthened.

Challenges in using the method from a managerial point of view:

- It may be difficult to achieve a high degree of validity of the value of requirements. Since the product is under development, the assessed value of the requirements must be treated accordingly. This can also lead to possible manipulation of the assessed value if there are for example reward systems based on the value being created. On the basis of the limited experience we have gathered, we recommend that the method be primarily used by managers within product development and not reported to external stakeholders.
- To reduce the preoccupation of the organization with cost to permit the development of an awareness of value could be a challenge because it has long been rooted in the organization.

- The method may be less beneficial for non-iterative development, since the developed value completed is 0 until the final stage of the development. The method has only been tested in an iterative development setting in which the requirements are designed, implemented, integrated and tested during two week periods and in which it is advantageous to visualize the value progress as shown in Figure 31. It can also be used in traditional linear development but then every phase will be completed one phase at a time.

Several possible future research opportunities have been observed during this study. First, this case study could be followed by further tests in different contexts and application areas. When the method has been validated, the valuation of requirements can be included as a natural part of the selection criteria for adding requirements and functions to a project. This suggests the possibility of extending the method from a project perspective to a project portfolio management perspective.

Chapter 11 Discussion and Analysis of the Research Results

In this chapter, the results presented in this thesis are discussed and analyzed. The outline of this chapter is organized according to the research questions presented in Chapter 3. Table 6 presents an overview of the treatment of the research questions in the different result chapters. In the following sections the results presented in Chapter 5 to Chapter 10 are discussed and analyzed.

11.1 RQ 1: What challenges in evaluating performance can be identified in the context of developing complex products?

The first set of questions is exploratory and aims at describing the current state of the use of measurements in evaluating performance and the challenges related to measuring performance in complex product development. Several different research study designs, as presented in Section 4.3, have been used in addressing these questions. The main sources of the data collected were the extensive multiple exploratory case studies. The results from these and related studies are presented in Chapter 5-7 and discussed in the following three sections.

11.1.1 RQ 1.1: How is performance in the development of complex products perceived by managers and decision makers?

Performance is a commonly used term but at the same time, as argued in this research, an ambiguous concept, especially for product development. From the 54 semi-structured interviews conducted as part of the exploratory multiple case studies, 54 different definitions of performance emerged. However, in Chapter 6 it was concluded that it is common to perceive performance in terms of what is measured. This implies that performance is a lagging appreciation of the achieved result. It is argued in this research that this way of perceiving performance limits the term performance to efficiency, and without consideration of e.g. effectiveness or the value created. An example of the latter is that only three of the 54 interviewees included or even reflected on the idea of creating value in their definition of performance. Further, the various perceptions of performance focus on implementation activities, neglecting planning activities. In another perspective, performance is interpreted in terms of what can be controlled by the project manager, without reference to the role of the product manager who is responsible for investing in the development of the new product. It seems as if it is taken for granted that the right product is being developed and high performance is achieved through efficient execution of the development projects.

The limitation in perception of performance might be explained by limitations in the Swedish language. There is no direct translation of the terms efficiency and effectiveness in Swedish. More recently the terms internal and external performance have been used to describe efficiency and effectiveness in the literature. However, these definitions seem not to be used in practice yet.

In none of the five case companies could a common organization-specific perception of performance be identified in terms of what is important to achieve success. This might be the result of a limited use of mental models of performance that are shared by a project or an organization. Mental models represent the deepest level of thinking that influence why things work as they do (Maani and Cavana, 2007). It could also be explained by the interviewees being selected from different parts of the product development organization e.g. product managers, project managers, line managers, who might have different concepts of performance. However, especially for large organizations, it is important to have a common objective of what is to be developed and mental models of what constitutes high performance as concluded in Section 4.1.

Section 2.2 presents a selection of the various definitions and perceptions of performance in the literature related to product development. This literature is characterized by a plethora of various definitions of performance, an abundance confirmed by this research. This might be explained, as argued in Chapter 2, that there are several different functional areas taking an interest in performance measurement and product-development research. However, there seems to be a consensus in dividing performance into effectiveness and efficiency.

The overall result of the findings and analysis indicates, however, that managers and decision makers tend to limit their perception of performance to implementation efficiency.

11.1.2 RQ 1.2: How is performance measured in the development of complex products?

The results related to research questions 1.2 are mainly covered by Chapter 6 and Chapter 7. An important tool used in this research for evaluating the measurement of performance by an organization is the Performance Measurement Evaluation Matrix (PMEX) that was developed as part of this research and presented in Chapter 7. The findings from applying the PMEX at three different case companies indicate that measurements tend to focus on the later stages of the implementation activities i.e. measurements of performance obtained are lagging measurements, while planning activities are rarely covered by the performance-measurement system. It is argued that the focus is on what is easily quantified in terms of time, cost, and quality, rather than on what might be important to measure.

This is in line with the current perception of performance, which might explain why there are few initiatives within the case companies to change the current situation, despite the consensus of opinion regarding the need for an improved performance-measurement system that was identified in all of the case companies participating in the multiple exploratory case studies. There are similar findings in the literature. For example Driva et al. (2001) found in a multiple case study that without exception, all case companies wanted to improve on their use of performance measures. Moreover, as found during this research, the interviewees had no ideas for how to improvement of the current situation. Rubinstein (2004) also concludes, on the basis of a review of the literature, that the evaluation methods used in product-development projects have not improved much over the last 50 years.

An additional finding from the use of PMEX is that technology and/or architecture, identified as important success factors in Chapter 5, are seldom evaluated by the performance-measurement system in the case companies. Godener and Soderquist (2004) concluded, from their exploratory multiple case studies within the electronics industry, that measurements were not performed within the technology management and thus questioned the usefulness of this dimension for the performance-measurement system. Despite this, technology and/or architecture are perceived as important success factors, and its measurement should be included in the performance-measurement system.

An overall finding is that it seems to be taken for granted that the right product is being developed i.e. product-development effectiveness and focus should be on monitoring the execution of the development projects in an efficient way. However, developing products that do not satisfy the targeted customer needs must be the greatest waste a company can create in product development. In contrast when success factors that enable high performance in product development are discussed, focus turns to what affects the process, i.e. the leading indicators of the performance. However, there is little support in the literature for developing performance measurements based on success factors. Despite the arguments by Kerssens-van Drongelen et al. (2000) that performance measurements is the part of the control process that not only include the acquisition and analysis of information about the actual attainment of a company objectives and plans, but also about the factors that may influence plan realization.

Hence, the overall result of the findings and analysis indicates that measurements focus on the later stages of the implementation activities i.e. what is easily quantified and not what is perceived as important for high performance in complex product development.

11.1.3 RQ 1.3: How is the performance-measurement system perceived by managers and decision makers in the development of complex products?

Traditionally, performance-measurement systems have been designed and managed by lag oriented accounting and finance functions (Bourne et al., 2000). According to the findings of this research in product development, this is clearly evident. The focus of performance-measurement systems studied in this research tend to be on reporting lagging measurements of time, cost, and quality to more senior managers. It is argued that there is a need to complement this important but limited use of a performance-measurement system, to support continuous improvements, learning, etc. in accordance with the needs of the organization. It is further argued in this research that before such a change can occur, a change in the perception of performance is needed, since an effective measurement system must be grounded in performance criteria relevant to the improvement of performance (Gharajedaghi, 2006).

The findings in this research indicate that there are two stereo-types of organizations using performance measurements. The five case companies, in the exploratory case studies, can be categorized as either measurement intensive or non-intensive. Case Company A, B, C, and E belong to the latter category and case Company D is considered to be measurement intensive. Common to all five case companies is that the actual measurements are not derived from specific performance objectives that must be achieved. In the measurement-intensive case company, in particular, new measurements of performance were considered easy to add but almost impossible to remove once included in the measurement system.

It is concluded from this research that the performance-measurement system, thus has limited the perception of performance in product development. This might explain why value creation and learning are not associated with measurements of performance. At the same time, managers and decision makers are dissatisfied with the current performance evaluation systems, but have no ideas of how to improve the situation. It is argued that improvements to the performance-measurement system should begin with improvements to the criteria for performance and how the performance evaluation system is used. For this to become a reality a change is needed in the way performance is perceived by managers and other stakeholders involved in product development.

When managers and decision makers are asked what is important for success, a different set of factors are nominated in comparison with their perception of performance. These success factors can be characterized as leading indicators of performance. A survey further validates the hypothesis that there is a weak link between success factors and what is measured in product development. It is therefore concluded that managers and decision makers should change their focus from performance measurements to what is important for success and derive their measurements on the basis of this information.

The overall result of the findings and analysis indicates that managers and decision-makers are dissatisfied with their performance-measurement system, without knowing how to change the current situation.

11.2 RQ 2: How can the performance of the activities related to the development of complex products be evaluated from a management and decision-making point of view?

The second set of questions is more prescriptive in character and aims at addressing some of the challenges described in the first set of research questions. The research studies resulting in the findings related to the second set of research questions are based on the literature supplemented with the knowledge developed in this research. This has resulted in conceptual models that have been verified in two separate single case studies. The results are presented in Chapter 8-10.

It is difficult to give direct answers to the second set of research questions and the result presented in this thesis is to be viewed as the first steps towards more general models. In the following sections the results related to two sub research questions are presented.

11.2.1 RQ 2.1: How can performance criteria be modelled in the development of complex products?

In this research one fundamental starting point is to view performance in product development, in line with the arguments by Ermolayev and Matzke (2007), as intentional action. Further, it is postulated that efficiency and effectiveness are two important dimensions of performance. In this research the definitions of effectiveness and efficiency expressed in the IDEF0 model of an activity by O'Donnell and Duffy (2002b) has been adopted. These dimensions of performance were supplemented in 0 with the knowledge gap, i.e. the difference between what is known prior to an activity compared to the goal or constraint of the activity. It is proposed to view high performance as the result of first focusing on the knowledge gap, in order to identify what new knowledge needs to be produced, and then focus on effectiveness i.e. making sure that the right product is being developed. This is to be followed by the efficiency dimension that is important in ensuring that the intended product is created consuming a minimum of resources. Performance is the result of being successful with all the three of these dimensions.

The knowledge gap may be interpreted as a leading indicator of both the effectiveness and the efficiency dimensions of performance. If a large amount of new knowledge must be created in order to achieve the objectives, there may be a higher degree of uncertainty in developing a new product effectively. This will also imply that there is uncertainty in the plans and budget for the project since it is unclear what is to be developed, which may affect the resource consumption and as a result also the time plan.

Chapter 8 presents the Performance Criteria Reference Model (PCRM) i.e. a theoretical model of performance derived using the IDEF0 model of an activity. By modelling the performance of product development as activities, as argued for and presented in Figure 22, it is possible to evaluate and analyse, in theoretical terms, the current state of performance in product development in an organization. The PCRM was designed to give a system perspective of how the product strategy, project management, and development activities are involved and affect the performance in product development.

In the PCRM, product-development effectiveness and efficiency are defined and made explicit through the IDEF0 model, see Figure 22. Product-development effectiveness is defined as the degree to which the output of the product activities meets the goal of the product strategy. It should be interpreted as the result of having well functioning product strategies, project management, and development activities that dynamically work together in order to develop successful products. Product-development efficiency is defined as the difference between the output of the development activity and the input to the product strategy, divided by the total amount of resources consumed by these activities in order to produce the intended output.

Product-development efficiency can be improved by increasing the output and/or decreasing the cost for the resources consumed in the activities.

The PCRM is intended to be used as a general model for performance criteria in product development that is to be adapted to the specific conditions present in a particular organization. This is illustrated in the case study presented in Chapter 9 in which the development organization consisted of three central generic activities: business development, product management, and development project activities, similar to main activity categories in the PCRM.

11.2.2 RQ 2.2: How can performance measurements be designed in order to support managers and decision makers in deploying proactive activities *during* the development of a new product?

Research question 2.2 has resulted in two different models for how performance measurements can be designed in order to support managers and decision makers *during* the development of a product. The first model presented in Chapter 9 aims at making the link between success factors and/or performance criteria explicit when designing new measurements. The second model, Products in Development (PiD) presented in Chapter 10, focuses on integrating perceived customer value as a measure of performance during the development.

The main principle of the method for designing performance indicators (DPI) is to divide the design of new performance indicators into three steps as shown in Figure 24. The first step of performance objectives is important, since it relates the objectives of an organization or a project with the new measurements. This is important as concluded in the literature review in Chapter 2. For example Kerssens-van Drongelen and Cook (1997) conclude that the literature stresses the importance of performance measurements that align with the objective of the measurement and contingency factors. The latter part relates to the motivation for step 2, to derive and iterate the performance criteria and the success factors that are important in order to fulfill the performance objectives. Performance criteria are to be viewed as *what* is needed to achieve the objective, while success factors relate to *how* it is to be fulfilled. In the third step, the important performance criteria and success factors are then translated into appropriate performance indicators that may be used to evaluate the current state of operation. The proposed methodology has been verified by a single case study as presented in Chapter 9. The result from this case study was the *Resource Allocation Tracker* that has been adopted as a leading indicator of performance by the case company. One key benefit from using the DPI method is that the focus is directed to what is important to measure, rather than what is possible to measure.

One of the findings from the first set of research questions is that performance measurement systems have no value perspective. Hence, there is a need to integrate value as a measure of performance in order to balance the perspectives of time, cost, and quality, especially during the development. The main assumption is that performance is the result of intentional action, thus in order for an organization to create value in product development, value must first be captured through the planning activities, developed in the implementation activities, and finally realized in the sales and delivery activities. The focus of the PiD is on the implementation activities, by relating the perceived customer value to the requirements in a development project. Hence, the activities related to a specific requirement can be valued accordingly, value being developed when these activities are completed. By adopting a value perspective during the development it is possible to balance the current focus on time, cost, and quality.

Both the PiD and the DPI method proposed in this research have been developed on the basis of the knowledge gained during this research and they relate to some of the fundamental challenges that limit the current use of performance measurements during the development of complex products. In particular, the model for PiD is a novel approach to evaluating value during the development. However, both models need further research and should be viewed as still being under development.

Chapter 12 Conclusions

This chapter presents the overall conclusions and implications based on the findings in this research. The outline of this chapter is as follows: the contributions from this research are summarized first and followed by an outline of the implications first for practice and then for theory of this research. The latter includes a discussion of future research.

12.1 Main Contributions from this Research

This research is in the field of applied sciences and aims at contributing to both theory and practice. The objectives set for this research were:

1) To evaluate the current state of practice and identify challenges of measuring performance in the development of complex products.
2) To add to knowledge by addressing one or several of these challenges i.e. by developing models and tools based on the knowledge derived from this research project.

The first objective directly maps to the first set of research questions while the second objective is reflected in the second set of research questions. On the basis of the findings related to the first objective and the first set of research questions, the following list of contributions is argued for:

1) There is no link between success factors and what is being measured by the performance-measurement system.
2) Product management is not integrated in the performance-measurement system related to product development. Focus is instead on evaluating activities related to the project management function.
3) The measurement system is not focused on the early phases of product development but rather on the later phases of the development.
4) The architecture or technology aspect was identified as an important success factor but it is rarely addressed explicitly by the performance-measurement system.
5) Value is not measured by the performance-measurement system, the focus being on time, cost, and quality. Value creation seems to be taken for granted.

On the basis of the findings related to the second objective and the second set of research questions, the following list of contributions are argued for:

1) A framework for evaluating and analyzing performance in complex product development, by categorizing the activities as planning, implementation, and sales and delivery activities.
2) The PMEX – A method to evaluate the performance-measurement systems currently used in product development.
3) The PCRM – A general model for performance criteria for product development.
4) The DPI – A method for designing performance indicators that focus on integrating relevant performance criteria and success factors when developing, in particular, leading measures of performance.
5) The concept of PiD – A method that integrates customer value as a measure of performance during the development of a new product.

Moreover, *What gets measured gets done* (Peters, 2002) and *You are what you measure* (Hauser and Katz, 1998) are two well known statements relating to the use of performance measurements. However, on the basis of the findings presented in this research it is argued that this is not the case when managing the development of complex products. Despite the limited use of performance measurements, the companies studied in this research are all profitable and often considered leaders in their market. Hence, it is suggested that the importance is in being *aware* of performance in order to manage it. Performance indicators and other performance assessments can play an important role in promoting the awareness of performance when developing complex products.

12.2 Reflections and Self-criticism

There are of course several limitations and issues that can be criticized in this thesis. My expertise as a researcher has developed since my research journey began in October 2006 but is by no means fully developed. One thing is clear; the importance of research methods cannot be overestimated. The right approach to a research project is just as important for success as early planning activities are decisive for success in product development.

As is common when performing research, even more interesting questions appear once the research is completed. I have learned and appreciated that if properly performed; research tends to generate more questions than it answers. If I were to make the same journey again I would probably choose the same overall research method. However, the first part of this research took more time than anticipated, limiting the time available for testing the proposed method for designing performance indicators (DPI) and the PiD model in practical applications. From other points of view, it was probably better, in any case, that I did not to rush the first part. This will always be a balancing act. Hopefully, there will be more time in the future for me to further develop these methods and to test them in real settings.

When entering an organization as a researcher and conducting interviews you get only a snapshot of the organization and an understanding of how it is currently functioning at the time of the study. Since the data for this research was collected in its early stages, including the exploratory multiple case studies, there has been an economic crisis that has probably affected the organizations studied in various ways. How or if there have been changes is open to speculation but they are all always under constant change due to the needs and constraints of the market. This is important to acknowledge. I believe that I have affected the organizations concerned to some extent, hopefully for the better, through interviews and by presenting my research findings in seminars.

The validity and reliability of this research is further discussed in Section 4.4. It is important to note that the use of various sources of data that has been possible in this research has increased its validity. Especially, the use of a survey turned out to be more rewarding than expected and became an important research component by complementing the qualitative data with quantitative data. When possible I have tried to validate theoretically the findings from this research with what is reported in the literature.

Despite my limitations there are some implications, both for practice and for academia as a result of this research. They are presented in the following sections.

12.3 Implications for Practice

This research project has been conducted in close cooperation with several companies that develop complex products. The focus has been on not only contributing to academia but also on providing practicing managers and decision makers in product development with new tools. The ability to evaluate performance is of value in providing managers and decision makers with the information needed to assess the current situation, and decide on actions required to improve the performance of the product-development activities.

In this research a strong desire to improve the way performance is measured was identified in all of the organizations studied but few ideas for improving the measurement of performance were expressed. This phenomenon is difficult to explain and for that reason difficult to change. An attempt to explain why this behavior is common, is made by von Stamm (2003) through the framework presented in Figure 33. The implication of this framework is that there can be insufficient understanding of a task, due to a lack of analysis that is the result of habits, assumptions and beliefs within the organization.

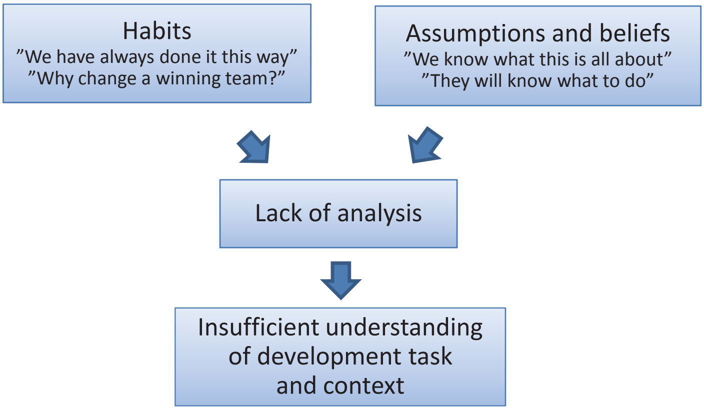

Figure 33. A framework for the consequences of habits, and assumptions and beliefs

On the basis of this research, it is concluded that this framework may be particularly useful within the development of complex products. Complex products are often built on the basis of a strong architecture or platform, intended to be reused in several products in order to decrease the technical complexity and decrease the lead time for developing new products. This strategy has proven successful, but may also contribute to this type of behavior.

Hence, in order to improve on the current situation a number of tools and models have been developed in this research, intended to increase the understanding and give new perspectives on the evaluation of performance. Sengupta et al. (2008) argue that the more managers invest in gathering and processing data, the better their forecasting will become. Moreover, increased complexity stresses the need for models that can be used by teams to develop a shared understanding (Senge, 1990). A list of the tools and frameworks developed and the managerial implications related to applying them in practice follows.

- The PMEX – is a tool for evaluating the currently used performance-measurement system in relation to important success factors and when in the development the actual measurements are performed. By using the PMEX questions of what is measured when and what is not measured can be answered. It can also be used to initiate a discussion of why a measurement is performed. Hence, the PMEX can be used to assess the current situation and give a common holistic understanding of what needs to be changed.

- The PCRM – is a generic model of performance in product development, that relates the strategy, project management, and the development activities based on the IDEF0 model of an activity. The model makes it possible to extend the usually limited perception of performance as the efficiency of the development activities, to also include the knowledge gap, effectiveness, and efficiency at three generic levels of activities in an organization. The PCRM is intended for use, not only to extend the current perception of performance, but also to develop a common perception of performance in the organization.
- The DPI – is a methodology for designing performance indicators by integrating and iterating success factors and performance criteria in relation to the performance objective set by an organization or project. If the focus is on measurements directly, a tendency may develop to measure what is possible to measure rather than what is important to measure. The latter alternative can be achieved by using the proposed method. It is important to acknowledge that every measurement need not necessarily be easily quantifiable, as long as it contains something that can be used to improve the understanding and awareness of the current situation.
- The PiD – is a concept used to integrate customer value as a measure of performance during the development of a new product. It is based on the assumption that in order to create value, value must be captured, developed, and realized. The created value is limited by the weakest of these activities, thus improvement actions should focus on this part. Value can also be evaluated during the execution of the development project by relating customer value to the requirements of the developed product.

12.4 Implications for Theory and Future research

Research tends to raise more questions than it answers and this research is no exception. This research began by reviewing the literature related to the management of product development. As part of this process, different definitions of performance and product development were reviewed. The definition of product development provided by Ulrich and Eppinger (2008) has been widely adopted in the literature and is also used in this research. However, an extension of this definition to also include the processes and tools used to identify a market opportunity is suggested, this being an important part of performance in product development. Hence, the following definition of product development is proposed:

> Product development is the set of activities beginning with the processes and tools used to perceive a market opportunity and ending in the production, sale, and delivery of a product fulfilling that market opportunity.

Within the academic research field, the management of the development of new products is mainly analyzed from the viewpoints of marketing and operations management. This is particularly the case in connection with the performance and performance-measurement literature within product development. One conclusion from the frame of reference discussed in Chapter 2 and the explorative multiple case studies conducted in this research, is the need a more consistent and less diverse terminology. As been discussed in Section 2.5, research becomes more problematic when the basic concepts and definitions that underlie a research area lack clarity, precision, and uniformity. It would be beneficial to initiate research studies with the aim of unifying the basic concepts and definitions.

Moreover, there is inadequate consideration of the early activities in the product-development process and how they can be evaluated. There is a need for further research focusing on the evaluation and measures addressing the early phases of the product-development process. The planning activities i.e. deciding on what to develop is not explicitly treated in the existing literature, focus tend to be on input, process, and output and outcome related measurements.

Similarly, the technology or architecture as a success factor is not explicitly treated in the literature related to performance measurements in product development. This is somewhat surprising since there are many companies developing complex products which are completely dependent on the technology in their products. It is suggested that this is the result of there being many quantitative studies focusing on product development as whole. Hence, specific attributes that are unique for e.g. the development of complex products, can be missed in a more general perspective. Addressing the role adopted in the overall performance of the technology of the product development is something that needs further research. How the architecture can be evaluated in order to ensure that it contributes to the overall performance in product development also deserves attention.

The review of the literature in Chapter 2 concludes that there is no common way of evaluating performance, especially in the development of complex products. It is argued in this research that possibly, there should not be a common way for evaluating performance in product development. The solution space for product development is not fixed as within for example production. Hence, the need for evaluating and managing performance in the development of complex products differs depending on the context. It is argued instead that focus should be on developing common generic methods and models for assisting managers and decision-makers in developing a set of measurements based on their current needs. This is needed especially when developing leading indicators of performance.

Appendix 1

Survey: Performance measurements in product development

Thank you for participating in this research effort to investigate the use of performance measurements in product development. This survey will take about 10 minutes to complete.

You have been contacted because you have been identified by a project champion in your organization who believes that your perspective is valuable to the organization itself, as well to our research project. This study focuses on investigating the relationship between product development success factors (identified in the literature) and performance measurements used in practice. This study is part of a doctoral research project on evaluating performance in complex product development at Mälardalen University.

Your participation in this study is voluntary, and any data you provide will be anonymous, with the information being gathered being accessible only to the researcher associated with this project: Stefan Cedergren (stefan.cedergren@mdh.se).

Please remember, that your answers will be anonymous and not be attributable to you, and any comparison data, will be aggregated.

Respondent and company information

What main role do you have within your organization? *

- ◯ Project manager
- ◯ Project member
- ◯ Line manager
- ◯ R&D manager
- ◯ Product manager
- ◯ Process manager
- ◯ Other: ________

How many years of working experience do you have? *

- ◯ 0-3 years
- ◯ 3-5 years
- ◯ 5-10 years
- ◯ 10-20 years
- ◯ >20 years

How many people are involved in an average product development project? *

- ◯ 1-5 persons
- ◯ 6-10 persons
- ◯ 11-50 persons
- ◯ 51-100 persons
- ◯ >101 persons

Is your site part of a corporate group? *

- Yes
- No

If yes, are there standard processes and/or policies inherited for product development from the corporate group?

- Yes
- No

Is the product development work distributed between different sites? *

- No
- Yes, between national sites.
- Yes, between international sites.

What types of products does your company develop? *
E.g. automotive industry, consumer electronics, industrial automation etc.

How satisfied are you with the way product development performance is measured in your organization?
*****

	1	2	3	4	5	6	7	
Not satisfied								Fully satisfied

After page 1 Continue to next page

1 out of 13

From this point on the questions will deal with 13 different product development success factors that might influence product development performance. For each factor we ask the importance of the factor both from the perspective of the company and you as an individual, in case there is a difference. This is followed up with a question if it is evaluated by the measurement system or by other means.

1. How important is top management support for successful product development in your organization?

Top management support = Senior management's favorable attitude and commitment to product development initiatives.

1a) According to your opinion *

1 2 3 4 5 6 7

Not at all	○	○	○	○	○	○	○	Most important

1b) The organization’s opinion

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

To what extent does your organization systematically evaluate top management support?

1c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

1d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

1e) Please give an example of how top management support is evaluated

Page 3 After page 2 Continue to next page

2 out of 13

2. How important is goal clarity for successful product development in your organization?

Goal clarity = The extent to which a product development project’s vision, mission, goals, and definition are clearly identified and communicated. Could also be the clarity of product requirements.

2a) According to your opinion *

	1	2	3	4	5	6	7	

Not at all ◯ ◯ ◯ ◯ ◯ ◯ ◯ Most important

2b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate goal clarity?

2c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

2d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

2e) Please give an example of how goal clarity is evaluated.

Page 4 After page 3 Continue to next page

3 out of 13

3. How important is process formalization for successful product development in your organization?

Process formalization = The use of explicit rules and standard procedures in the product development process.

3a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

3b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

To what extent does your organization systematically evaluate process formalization?

3c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

3d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

3e) Please give an example of how process formalization is evaluated.

Page 5 After page 4 Continue to next page

4 out of 13

4. How important is process concurrency for successful product development in your organization?

Process concurrency = The extent to which stages of the product development process overlap or are conducted concurrently

4a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

4b) The organization’s opinion

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

To what extent does your organization systematically evaluate process concurrency?

4c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

4d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

4e) Please give an example of how process concurrency is evaluated.

Page 6 After page 5 Continue to next page

5 out of 13

5. How important are iterations for successful product development in your organization?

Iteration = The process of building and testing a prototype in a product development initiative

5a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

5b) The organization’s opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate iterations?

5c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

5d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

5e) Please give an example of how iterations are evaluated.

Page 7 After page 6 Continue to next page

6 out of 13

6. How important is learning for successful product development in your organization?

Learning = The process through which a project team gains or creates knowledge in performing product development activities

6a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

6b) The organization’s opinion

1 2 3 4 5 6 7

Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate learnings?

6c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

6d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

6e) Please give an example of how learnings are evaluated.

Page 8

After page 7 Continue to next page

7 out of 13

7. How important is team leadership for successful product development in your organization?

Team leadership = The degree to which a project's leader possesses skills, knowledge, and experience relevant to both management and technical aspects of the project

7a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

7b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluated team leadership?

7c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

7d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

7e) Please give an example of how team leadership is evaluated.

Page 9

After page 8 Continue to next page

8 out of 13

8. How important is team experience for successful product development in your organization?

Team experience = The degree to which team members possess experiences, knowledge, and skills

8a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

8b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate team experience?

8c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

8d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

8e) Please give an example of how team experience is evaluated.

Page 10 After page 9 Continue to next page

9 out of 13

9. How important is team dedication for successful product development in your organization?

Team dedication - The degree to which team members dedicate themselves to a product development initiative. Could be the percentage of team members working full- time in the project or team member turnover.

9a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

9b) The organization’s opinion

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

To what extent does your organization systematically evaluate team dedication?

9c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

9d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

9e) Please give an example of how team dedication is evaluated.

Page 11 After page 10 Continue to next page

10. How important is internal integration for successful product development in your organization?

Internal integration = The degree of cooperation among multiple functions and interaction among team members in a product development initiative.

10a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

10b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate internal integration?

10c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

10d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

10e) Please give an example of how internal integration is evaluated.

Page 12 | After page 11 | Continue to next page

11 out of 13

11. How important is external integration for successful product development in your organization?

External integration = The involvement of external partners like suppliers and customers in a new product initiative

11a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

11b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Most important

To what extent does your organization systematically evaluate external integration?

11c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

11d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

11e) Please give an example of how external integration is evaluated.

After page 12 Continue to next page

12. How important is team empowerment for successful product development in your organization?

Team empowerment = The decision-making autonomy of the project team

12a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

12b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate team empowerment?

12c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

12d) Other means

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Fully

12e) Please give an example of how team empowerment is evaluated.

Page 14 After page 13 Continue to next page

13 out of 13

13. How important is an architecture for successful product development in your organization?

Architecture = The fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution.

13a) According to your opinion *

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

13b) The organization's opinion

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Most important

To what extent does your organization systematically evaluate the architecture?

13c) Through a measurement system *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

13d) Other means

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Fully

13e) Please give an example of how the architecture is evaluated.

Page 15

After page 14 Continue to next page

If you are interested in the result of this study please provide your e-mail address below.

References

ABDEL-KADER, M. G. & LIN, E. Y.-C. 2009. *Performance Measurement of New Product Development Teams,* London, Palgrave Macmillan.

ACKHOF, R. L. 1999. *Ackhof's best: Classic writings on management,* New York, Wiley.

ADAMS, R., BESSANT, J. & PHELPS, R. 2006. Innovation management measurement: A review. *International Journal of Management Reviews,* 8**,** 21-47.

AMARATUNGA, D. & BALDRY, D. 2002. Moving from performance measurement to performance management. *Facilities,* 20**,** 217-223.

ANDREASEN, M. M. & HEIN, L. 1987. *Integrated Product Development,* Springer-Verlag.

ANDREW, J. P., HAANAES, K., MICHAEL, D. C., SIRKIN, H. L. & TAYLOR, A. 2008. Measuring Innovation 2008. Boston, USA.

ANNACCHINO, M. A. 2007. *The Pursuit of New Product Development - The Business Development Process*, Butterworth-Heinemann.

BALDWIN, C. Y. 1991. How Capital Budgeting Deters Innovation - And What to Do About It. *Research Technology Management,* 34**,** 39-46.

BARCZAK, G., GRIFFIN, A. & KAHN KENNETH, B. 2009. PERSPECTIVE: Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA Best Practices Study. *The Journal of Product Innovation Management*, 26**,** 3-3.

BASILI, V. R., LINDVALL, M., REGARDIE, M., SEAMAN, C., HEIDRICH, J., MUNCH, J., ROMBACH, D. & TRENDOWICZ, A. 2010. Linking Software Development and Business Strategy Through Measurement. *Computer*, 43**,** 57-65.

BENBASAT, I., GOLDSTEIN DAVID, K. & MEAD, M. 1987. The Case Research Strategy in Studies of Information Systems. *MIS Quarterly,* 11**,** 369-387.

BESSANT, J. & TIDD, J. 2007. *Innovation and entrepreneurship,* Chichester, John Wiley & Sons Ltd.

BLINDENBACH-DRIESSEN, F. & VAN DEN ENDE, J. 2010. Innovation Management Practices Compared: The Example of Project-Based Firms. *The Journal of Product Innovation Management*, 27**,** 705.

BLOCK, S. 2007. Are Real Options Actually Used in the Real World? *The Engineering Economist,* 52**,** 255.

BODNER, D. A. & ROUSE, W. B. 2007. Understanding R&D value creation with organizational simulation. *Systems Engineering,* 10**,** 64-82.

BOER, F. P. 2000. Valuation of technology using "real options". *Research Technology Management,* 43**,** 26-30.
BOURNE, M., MILLS, J., WILCOX, M., NEELY, A. & PLATTS, K. 2000. Designing, implementing and updating performance measurement systems. *International Journal of Operations & Production Management,* 20**,** 754-754.
BOURNE, M., NEELY, A., MILLS, J. & PLATTS, K. 2003. Why some performance measurement initiatives fail: Lessons from the change management literature. *International Journal of Business Performance Management,* 5**,** 245-269.
BOURNE, M. & WILCOX, M. 1998. Translating strategy into action. *Manufacturing Engineer,* 77**,** 109-112.
BREMSER, W. G. & BARSKY, N. P. 2004. Utilizing the balanced scorecard for R&D performance measurement. *R & D Management,* 34**,** 229-238.
BROWN, M. G. 1996. *Keeping score: Using the right metrics to drive world-class performance* New York, Quality Resources.
BROWN, M. G. & SVENSON, R. A. 1988. Measuring R&D Productivity. *Research Technology Management,* 31**,** 11-16.
BROWNING, T. R. 2003. On customer value and improvement in product development processes. *Systems Engineering,* 6**,** 49.
BROY, M. 2005. Automotive software and systems engineering
Proceedings. Second ACM and IEEE International Conference on Formal Methods and Models for Co-Design, 2005. MEMOCODE '05.
BRYMAN, A. 1989. *Research Methods and Organization Studies* Routledge.
BURGELMAN, R. A., MAIDIQUE, M. A. & WHEELWRIGHT, S. C. 2001. *Strategic Management of technology and innovation,* New York, McGraw-Hill/Irwin.
CARLSON-SKALAK, S. 2002. *Implementing Concurrent Engineering in Small Companies,* New York, USA, Marcel Dekker Inc.
CETINDAMAR, D., PHAAL, R. & PROBERT, D. 2009. Understanding technology management as a dynamic capability: A framework for technology management activities. *Technovation,* 29**,** 237-246.
CHAPMAN, C. & WARD, S. 1997. *Project Risk management – Processes, Techniques and Insights,* Chichester, England, John Wiley & Sons.
CHEN, J., DAMANPOUR, F. & REILLY, R. R. 2010. Understanding antecedents of new product development speed: A meta-analysis. *Journal of Operations Management,* 28**,** 17-33.
CHIESA, V. & FRATTINI, F. 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. *R & D Management,* 37**,** 283-283.
CHIESA, V., FRATTINI, F., LAZZAROTTI, V. & MANZINI, R. 2009a. Performance measurement in R&D: exploring the interplay between measurement objectives, dimensions of performance and contextual factors. *R&D Management,* 39**,** 487-519.

CHIESA, V., FRATTINI, F., LAZZAROTTI, V. & MANZINI, R. 2009b. Performance measurement of research and development activities. *European Journal of Innovation Management,* 12**,** 25.

CHRISTENSEN, C. M. 2003. *The Innovator's Dilemma: The Revolutionary Book that Will Change the Way You Do Business,* New York, Collins

CHRISTENSEN, C. M. & RAYNOR, M. E. 2003. *Innovator's Solution: Creating and sustaining successful growth,* Boston, Harvard Business School Press.

CLARK, K. B. & FUJIMOTO, T. 1991. *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry,* Harvard Business School Press.

CNNMONEY.COM. 2007. *Furtune Global 500* [Online]. CNN. Available: http://money.cnn.com/magazines/fortune/global500/2007/full_list/ [Accessed 28th of August 2008].

COHEN, H. B. 1998. The performance paradox. *The Academy of Management Executive,* 12**,** 30-40.

COLQUHOUN, G. J., BAINES, R. W. & CROSSLEY, R. 1993. A State of the Art Review of IDEF0. *International Journal of Computer Integrated Manufacturing,* 6**,** 252-64.

COOPER, R. G. 1990. New Products: What Distinguishes the Winners? *Research Technology Management,* 33**,** 27-32.

COOPER, R. G. 1995. Developing new products on time, in time. *Research Technology Management,* 38**,** 49-58.

COOPER, R. G. 2001. *Winning at new products: Accelerating the process from idea to launch,* Cambridge, MA, Perseus Books.

COOPER, R. G. 2005. *Product leadership: Pathway to profitable innovation,* New York, Basic Books.

COOPER, R. G. 2006. Managing Technology Development Projects. *Research Technology Management,* 49**,** 23-31.

COOPER, R. G. 2008. Perspective: The Stage-Gate® Idea-to-Launch Process - Update, What's New, and NexGen Systems. *The Journal of Product Innovation Management,* 25**,** 213.

COOPER, R. G. & EDGETT, S. J. 2008. Maximizing productivity in product innovation. *Research Technology Management,* 51**,** 47-58.

COOPER, R. G., EDGETT, S. J. & KLEINSCHMIDT, E. J. 2002a. Optimizing the stage-gate process: What best-practice companies do-I. *Research Technology Management,* 45**,** 21-27.

COOPER, R. G., EDGETT, S. J. & KLEINSCHMIDT, E. J. 2002b. Optimizing the stage-gate process: What best-practice companies do-II. *Research Technology Management,* 45**,** 43-49.

COOPER, R. G., EDGETT, S. J. & KLEINSCHMIDT, E. J. 2004a. Benchmarking best NPD practices - I. *Research Technology Management,* 47**,** 31-43.

COOPER, R. G., EDGETT, S. J. & KLEINSCHMIDT, E. J. 2004b. Benchmarking best NPD practices - II. *Research Technology Management,* 47**,** 50-59.

COOPER, R. G., EDGETT, S. J. & KLEINSCHMIDT, E. J. 2004c. Benchmarking best practices - III. *Research Technology Management,* 47**,** 43-55.

COOPER, R. G. & KLEINSCHMIDT, E. J. 1995. Benchmarking the Firm's Critical Success Factors in New Product Development. *Journal of Product Innovation Management,* 12**,** 374-391.

COOPER, R. G. & KLEINSCHMIDT, E. J. 2007. Winning business in product development: The critical success factors. *Research Technology Management,* 50**,** 52-66.

CORBIN, J. & STRAUSS, A. 2008. *Basics of qualitative research 3e,* Thousand Oaks.

CORDERO, R. 1990. The Measurement of Innovation Performance in the Firm: An Overview. *Research Policy,* 19**,** 185-193.

CRAWFORD, M. & DI BENEDETTO, C. A. 2008. *New Products Management,* New York, McGraw-Hill Irwin.

DAVILA, T., EPSTEIN, M. J. & SHELTON, R. 2006. *Making innovation work - How to manage it, measure it and profit from it,* New Jersey, Wharton School Publishing.

DENZIN, N. K. & LINCOLN, Y. S. 2003. Introduction: The discipline and practice of qualitative research. *In:* DENZIN, N. K. & LINCOLN, Y. S. (eds.) *The landscape of qualitative research- Theory and issues.* 2 ed. Thousand Oaks, USA: Sage publications.

DIXON, R. J., NANNI, A. J. & VOLLMANN, T. E. 1990. *New Performance Challenge: Measuring Operations for World-Class Competition,* New York, McGraw-Hill Professional Publishing

DRIVA, H., PAWAR, K. S. & MENON, U. 2001. Performance evaluation of new product development from a company perspective. *Integrated Manufacturing Systems,* 12**,** 368-378.

DRUCKER, P. F. 1985. *Innovation and entrepreneurship,* New York, Harper and Row.

DRUCKER, P. F. 1991. The New Productivity Challenge. *Harvard Business Review,* 69**,** 69-80.

DWIGHT, R. 1999. Searching for real maintenance performance measures. *Journal of quality in maintenance engineering,* 5**,** 258.

EASTERBY-SMITH, M., THORPE, R. & LOWE, A. 2002. *Management research - An introduction,* London, Sage Publications.

EBERT, C. & DUMKE, R. 2007. *Software Measurement - Etablish - Extract - Evaluate - Execute,* Berlin, Springer-Verlag.

ECCLES, R. G. 1991. The performance measurement manifesto. *Harvard Business Review***,** 131-131.

EISENHARDT, K. M. 1989. Building Theories from Case Study Research. *Academy of Management Review,* 14**,** 532-550.

EISENHARDT, K. M. & GRAEBNER, M. E. 2007. Theory Building from Cases: Opportunities and Challenges. *Academy of Management Journal,* 50**,** 25-32.

EMMANUELIDES, P. A. 1993. Towards an integrative framework of performance in product development projects. *Journal of Engineering and Technology Management,* 10**,** 363-392.

ERMOLAYEV, V. & MATZKE, W.-E. 2007. Towards Industrial Strength Business Performance Management *Holonic and Multi-Agent Systems for Manufacturing.* Berlin / Heidelberg: Springer

ERNST, H. 2002. Success Factors of New Product Development: A Review of the Empirical Literature. *International Journal of Management Reviews,* 4**,** 1-40.

FITZGERALD, L., JOHNSTON, R., BRIGNALL, T. J., SILVESTRO, R. & VOSS, C. 1991. *Performance measurement in service businesses,* London, Chartered Institute of Management Accountants.

FOOS, T., SCHUM, G. & ROTHENBERG, S. 2006. Tacit knowledge transfer and the knowledge disconnect. *Journal of Knowledge Management,* 10**,** 6-18.

FOSTER, R. 1986. *Innovation: The Attacker's Advantage,* New York, Summit Books.

GERWIN, D. & BARROWMAN, N. J. 2002. An Evaluation of Research on Integrated Product Development. *Management Science,* 48**,** 938-953.

GHARAJEDAGHI, J. 2006. *Systems Thinking: Managing Chaos and Complexity - A Platform for Designing Business Architecture,* San Diego, Elsevier Inc.

GHAURI, P. & GROENHAUG, K. 2005. *Research Methods in Business Studies - A Pratical Guide,* Essex, England, Pearson Education Limited.

GODENER, A. & SODERQUIST, K. E. 2004. Use and impact of performance measurement results in R&D and NPD: an exploratory study. *R & D Management,* 34**,** 191-219.

GOFFIN, K. & MITCHELL, R. 2005. *Innovation Management: Strategy and Implementation Using the Pentathlon Framework,* London, Palgrave MacMillan.

GOLDENSE, B. L. & CRONIN, J. E. 2009. IAM and New Product Processes Are The Future. *Intellectual Asset Management [IAM] Magazine.* London, United Kingdom: The IP Media Group.

GOLDENSE, B. L. & POWER, J. R. 2005. Developmental Overload. *Mechanical Engineering,* 127**,** 13A-13A.

GREGORY, M. J. 1993. Integrated performance measurement: A review of current practice and emerging trends. *International Journal of Production Economics,* 30-31**,** 281-296.

GRIFFIN, A. 1997a. The effect of project and process characteristics on product development cycle time. *JMR, Journal of Marketing Research,* 34**,** 24-35.

GRIFFIN, A. 1997b. PDMA research on new product development practices: Updating trends and benchmarking best practices. *The Journal of Product Innovation Management,* 14**,** 429-458.

GRIFFIN, A. 2002. Product development cycle time for business-to-business products. *Industrial Marketing Management,* 31**,** 291-304.
GRIFFIN, A. & HAUSER, J. R. 1993. The Voice of the Customer. *Marketing Science,* 12**,** 1-27.
GRIFFIN, A. & HAUSER, J. R. 1996. Integrating R&D and Marketing: A Review and Analysis of the Literature. *Journal of Product Innovation Management,* 13**,** 191-215.
GRIFFIN, A. & PAGE, A. L. 1993. An interim report on measuring product development success and failure. *The Journal of Product Innovation Management,* 10**,** 291-308.
GRIFFIN, A. & PAGE, A. L. 1996. PDMA success measurement project: Recommended measures for product development success and failure. *The Journal of Product Innovation Management,* 13**,** 478-496.
HANDFIELD, R. B. & MELNYK, S. A. 1998. The Scientific Theory-Building Process: A primer using the case of TQM. *Journal of Operations Management,* 16**,** 321-339.
HANSEN, C. T. & ANDREASEN, M. M. 2004. A Mapping of Design Decision-making. *International Design Conference – Design 2004.* Dubrovnik, Croatia.
HARBOUR, J. L. 2009. *The Basics of Performacne Measurement,* New York, USA, Productivity Press.
HARTMANN, G. C., MYERS, M. B. & ROSENBLOOM, R. S. 2006. Planning your Firm´s R&D Investment. *Research Technology Management,* 49**,** 25-36.
HAUSER, J. & KATZ, G. 1998. Metrics: you are what you measure! *European Management Journal,* 16**,** 517-528.
HAUSER, J., TELLIS, G. J. & GRIFFIN, A. 2006. Research on Innovation: A Review and Agenda for Marketing Science. *Marketing Science,* 25**,** 687-717.
HAUSER, J. R. & ZETTELMEYER, F. 1997. Metrics to evaluate R,D&E. *Research Technology Management,* 40**,** 32-38.
HENARD, D. H. & SZYMANSKI, D. M. 2001. Why some new products are more successful than others. *JMR, Journal of Marketing Research,* 38**,** 362-375.
HERTENSTEIN, J. H. & PLATT, M. B. 2000. Performance measures and management control in new product development. *Accounting Horizons,* 14**,** 303-323.
HILL, T. 1993. *Manufacturing strategy: The strategic management of the manufacturing function,* London, Macmillan.
HILLSON, D. 2003. Assessing organizational project management capability. *Journal of Facilities Management,* 2**,** 298-311.
HILLSON, D. 2004. *Effective Opportunity Management for Projects – Exploiting Positive Risk,* New York, USA, Marcel Dekker
HILLSON, D. & MURRAY-WEBSTER, R. 2005. *Understanding and managing risk attitude,* Hants, England., Gower Publishing Ltd.

HIPPEL, E. V. 1988. *Sources of innovation*, New York, Oxford University Press.
HOBDAY, M. 1998. Product complexity, innovation and industrial organization. *Research Policy,* 26**,** 689-710.
HONG, P., NAHM ABRAHAM, Y. & DOLL WILLIAM, J. 2004. The role of project target clarity in an uncertain project environment. *International Journal of Operations & Production Management,* 24**,** 1269-1291.
HUDSON, M., SMART, A. & BOURNE, M. 2001. Theory and practice in SME performance measurement systems. *International Journal of Operations & Production Management,* 21**,** 1096-1115.
HULTINK, E. J., GRIFFIN, A., HART, S. & ROBBEN, H. S. J. 1997. Industrial new product launch strategies and product development performance. *The Journal of Product Innovation Management,* 14**,** 243-257.
IEEE 15939 2009. IEEE Standard adoption of ISO/IEC 15939:2007 - systems and software engineering - measurement process. *IEEE Std 15939-2008***,** C1-40.
JACKSON, M. 2000. *An analysis of flexible and reconfigureable production systems - An approach to a holistic method for the development of flexibility and reconfigurability* PhD, Linköping university.
JAGLE, A. J. 1999. Shareholder value, real options, and innovation in technology-intensive companies. *R & D Management,* 29**,** 271-287.
JIMÉNEZ-ZARCO, A. I., MARTÍNEZ-RUIZ, M. P. & GONZÁLEZ-BENITO, Ó. 2006. Performance measurement system (PMS) integration into new product innovation: A literature review and conceptual framework. *Academy of Marketing Science Review,* 10.
JOHNSTON, R. & PONGATICHAT, P. 2008. Managing the tension between performance measurement and strategy: coping strategies. *International Journal of Operations & Production Management,* 28**,** 941-967.
JOU, Y. T., CHEN, C. H., HWANG, C. H., LIN, W. T. & HUANG, S. J. 2010. A study on the improvements of new product development procedure performance-an application of design for Six Sigma in a semi-conductor equipment manufacturer. *International journal of production research,* 48**,** 5573-5591.
KAHN, K. B. 2005. *The PDMA handbook of new product development,* Hoboken, John Wiley & Sons.
KAHN, K. B., BARCZAK, G. & MOSS, R. 2006. PERSPECTIVE: Establishing an NPD Best Practices Framework. *Journal of Product Innovation Management,* 23**,** 106-116.
KAPLAN, R. S. & ATKINSON, A. A. 1998. *Advanced Management Accounting,* Upper Saddle River, New Jersey, Prentice Hall.
KAPLAN, R. S. & NORTON, D. P. 1992. The Balanced Scorecard measures that drive performance. *Harvard Business Review,* 70**,** 71-80.

KARLSSON, C. 2009. Research Operations Management. *In:* KARLSSON, C. (ed.) *Research Operations Management.* New York, USA: Routledge.

KATZ, D. & KAHN, R. L. 1978. *The Social Psychology of Organizations* New York, John-Wiley & Sons.

KEEGAN, D. P., EILER, R. G. & JONES, C. R. 1989. Are Your Performance Measures Obsolete? *Management Accounting,* 70**,** 45-51.

KELM, K. M., NARAYANAN, V. K. & PINCHES, G. E. 1995. Shareholder value creation during R&D innovation and commercialization stages. *Academy of Management Journal,* 38**,** 770-787.

KENNERLEY, M. & NEELY, A. 2002. A framework of the factors affecting the evolution of performance measurement systems. *International Journal of Operations & Production Management,* 22**,** 1222-1245.

KERLINGER, F. N. 1986. *Foundation of behavioral research* New York, CBS College Publishing

KERSSENS-VAN DRONGELEN, I. C. & COOK, A. 1997. Design principles for the development of measurement systems for research and development processes. *R & D Management,* 27**,** 345-357.

KERSSENS-VAN DRONGELEN, I. C., NIXON, B. & PEARSON, A. 2000. Performance measurement in industrial R&D. *International Journal of Management Reviews,* 2**,** 111-143.

KIM, J. & WILEMON, D. 2002. Focusing the fuzzy front-end in new product development. *R & D Management,* 32**,** 269-279.

KOCH, R. 2006. *The financial times guide to strategy - How to create and deliver a winning strategy* Edinburgh, UK, Trans-Atlantic Publications.

KOEHLER, C. & WEISSBARTH, R. 2004. The Art of Underengineering. *Strategy+Business Magazine.*

KOEN, P., AJAMIAN, G., BURKART, R., CLAMEN, A., DAVIDSON, J., D'AMORE, R., ELKINS, C., HERALD, K., INCORVIA, M., JOHNSON, A., KAROL, R., SEIBERT, R., SLAVEJKOV, A. & WAGNER, K. 2001. Providing clarity and a common language to the" fuzzy front end". *Research Technology Management,* 44**,** 46.

KOLLER, T., GOEDHART, M. & WESSELS, D. 2005. *Measuring and managing the value of companies,* New Jersey, John Wiley & Sons.

KORPELA, J., SANDSTROM, J. & KYLAHEIKO, K. 2006. Opening up the black box of performance measurement: an analytic hierarchy process-based approach. *International Journal of Manufacturing Technology and Management,* 8**,** 382-400.

KOTLER, P. 1996. *Marketing management: Analysis, planning, implementation and control* Englewood Cliffs, Prentice Hall.

KRISHNAN, V. & ULRICH, K. T. 2001. Product Development Decisions: A Review of the Literature. *Management Science,* 47**,** 1-21.

KUHN, T. S. 1970. *The structure of scientific revolutions,* Chicago, Chicago University Press.

LAWSON, H. 2010. *A Journey Through the Systems Landscape,* Milton Keynes, UK, College Publications.

LEEDY, P. D. & ORMROD, J. E. 2005. *Practical Research: Planning and design,* Upper Saddle River, Pearson Education.

LEFLEY, F. 1997. Approaches to risk and uncertainty in the appraisal of new technology capital projects. *International Journal of Production Economics,* 53**,** 21-33.

LIEBERMAN, M. B. & MONTGOMERY, D. B. 1988. First-Mover Advantages. *Strategic Management Journal***,** 41-59.

LINDGREN, M., WALL, A., LAND, R. & NORSTROM, C. 2008. A Method for Balancing Short- and Long-Term Investments: Quality vs. Features. *2008 34th Euromicro Conference Software Engineering and Advanced Applications***,** 175-182.

LOCH, C., STEIN, L. & TERWIESCH, C. 1996. Measuring development performance in the electronics industry. *The Journal of Product Innovation Management,* 13**,** 3-21.

LOCH, C. H. & KAVADIAS, S. 2008. Managing new product development: An evolutionary framework. *In:* LOCH, C. H. & KAVADIAS, S. (eds.) *Handbook of New Product Development Management.* Oxford: Butterworth-Heinemann.

LOCH, C. H. & TAPPER, U. A. S. 2002. Implementing a strategy-driven performance measurement system for an applied research group. *The Journal of Product Innovation Management,* 19**,** 185-198.

LUECKE, R. 2003. *Managing creativity and innovation,* Boston, Managing Creativity and innovation.

LYNCH, R. L. & CROSS, K. F. 1991. *Measure Up: The essential guide to measuring business performance measures,* London, Mandarin.

LYNN, G. S. 1998. New product team learning: Developing and profiting from your knowledge capital. *California Management Review,* 40**,** 74-93.

MAANI, K. E. & CAVANA, R. Y. 2007. *Systems thinking, system dynamics: Managing change and complexity,* Rosedale, New Zealand, Pearson.

MAHONEY, T. A. 1988. Productivity defined: The relativity of efficiency, effectiveness and change. *Productivity in organizations: New perspectives from industrial and organizational psychology.* San Fransisco, USA.

MALLICK, D. N. & SCHROEDER, R. G. 2005. An Integrated Framework for Measuring Product Development Performance in High Technology Industries. *Production and Operations Management,* 14**,** 142-158.

MALVIUS, D. 2007. *Information Management for Complex Product Development.* Licentiate thesis, KTH.

MARCHAND, M. & RAYMOND, L. 2008. Researching performance measurement systems: An information systems perspective.

International Journal of Operations & Production Management, 28**,** 663-686.
MARXT, C. & HACKLIN, F. 2005. Design, product development, innovation: all the same in the end? A short discussion on terminology. *Journal of Engineering Design,* 16**,** 413-422.
MASHIKO, Y. & BASILI, V. R. 1997. Using the GQM paradigm to investigate influential factors for software process improvement. *The Journal of Systems and Software,* 36**,** 17.
MCDONALD, J. 2010. *Managing the Development of Software-Intensive Systems,* Hoboken, USA, John Wiley & Sons.
MCGRATH, M. E. & ROMERI, M. N. 1994. FROM EXPERIENCE The R&D Effectiveness Index: A Metric for Product Development Performance. *Journal of Product Innovation Management,* 11**,** 213-220.
MCGREGOR, J. 2005. The performance paradox. *Fast Company***,** 29-30.
MELNYK, S. A., STEWART, D. M. & SWINK, M. 2004. Metrics and performance measurement in operations management: dealing with the metrics maze. *Journal of Operations Management,* 22**,** 209-217.
MERCHANT, K. A. & VAN DER STEDE, W. A. 2007. *Management Control Systems: Performance Measurement, Evaluation and Incentives*, Prentice Hall.
MEREDITH, J. R. 1998. Building operations management theory through case and field research. *Journal of Operations Management,* 16**,** 441-454.
MEYER, C. 1994. How the right measures help teams excel. *Harvard Business Review,* 72**,** 95-102.
MILES, L. D. 1972. *Techniques of value analysis and engineering,* McGraw-Hill.
MOLINA-CASTILLO, F.-J. & MUNUERA-ALEMÁN, J.-L. 2009. New product performance indicators: Time horizon and importance attributed by managers. *Technovation,* 29**,** 714-714.
MONTOYA-WEISS, M. M. & CALANTONE, R. 1994. Determinants of new product performance: A review and meta-analysis. *The Journal of Product Innovation Management,* 11**,** 397-417.
MORGAN, J. M. 2002. *High performance product development: a systems approach to a lean product development process.* Doctor of Philosophy, The University of Michigan.
MORGAN, J. M. & LIKER, J. K. 2006. *The Toyota Product Development System: Integrating People, Process And Technology,* New York, USA, Productivity Press.
MOXHAM, C. 2009. Performance measurement: Examining the applicability of the existing body of knowledge to nonprofit organisations. *International Journal of Operations & Production Management,* 29**,** 740-763.
NEELY, A. 2005. The evolution of performance measurement research: Developments in the last decade and a research agenda for the next.

International Journal of Operations & Production Management, 25**,** 1264-1277.
NEELY, A. 2007. *Business performance measurement,* Cambridge, Cambridge University Press.
NEELY, A., ADAMS, C. & CROWE, P. 2001. The performance prism in practice. *Measuring Business Excellence,* 5**,** 6-12.
NEELY, A. & BOURNE, M. 2000. Why measurement initiatives fail. *Measuring Business Excellence,* 4**,** 3-7.
NEELY, A., GREGORY, M. & PLATTS, K. 2005. Performance measurement system design: A literature review and research agenda. *International Journal of Operations & Production Management,* 25**,** 1228-1263.
NEELY, A., KENNERLY, M. & ADAMAS, C. 2007. Performance measurement frameworks: A review. *In:* NEELY, A. (ed.) *Business Performance Measurement - Unifying theory and integrating practice.* 2 ed. Cambridge: Cambridge university press.
NEELY, A., MILLS, J., PLATTS, K., RICHARDS, H., GREGORY, M., BOURNE, M. & KENNERLEY, M. 2000. Performance measurement system design: developing and testing a process-based approach. *International Journal of Operations & Production Management,* 20**,** 1119-1145.
NEELY, A. & NAJJAR, M. A. 2006. Management Learning Not Management Control: The true role of performance measurent? *California Management Review,* 48**,** 101-114.
NEELY, A., RICHARDS, H., MILLS, J., PLATTS, K. & BOURNE, M. 1997. Designing performance measures: a structured approach. *International Journal of Operations & Production Management,* 17**,** 1131-1131.
NEUFELD, G. A., SIMEONI, P. A. & TAYLOR, M. A. 2001. High-performance research organization. *Research Technology Management,* 44**,** 42-52.
NIXON, B. 1997. Conference report: Performance measurements for R&D. *R & D Management,* 27**,** 87-90.
NORELL, M. 1992. *Stödmetoder och samverkan i produktutveckling: Advisory tools and co-operation in product development.* PhD, KTH.
O'DONNELL, F. J. & DUFFY, A. H. B. 2002a. *Design Performance,* Springer Verlag.
O'DONNELL, F. J. & DUFFY, A. H. B. 2002b. Modelling design development performance. *International Journal of Operations & Production Management,* 22**,** 1198-1221.
O'DONNELL, F. J. & DUFFY, A. H. B. 2005. *Design Performance,* London, UK, Springer Verlag.
OJANEN, V. & TUOMINEN, M. 2002. An analytic approach to measuring the overall effectiveness of R&D - A case study in the telecom sector. *Engineering Management Conference, 2002. IEMC '02. 2002 IEEE International.*

PAGE, A. L. 1993. Assessing new product development practices and performance: Establishing crucial norms. *The Journal of Product Innovation Management,* 10**,** 273-290.
PAGE, A. L. & SCHIRR, G. R. 2008. Growth and Development of a Body of Knowledge: 16 Years of New Product Development Research, 1989-2004. *The Journal of Product Innovation Management,* 25**,** 233-233.
PAHL, G. & BEITZ, W. 2007. *Engineering design: A systematic approach,* London, Springer-Verlag London Ltd.
PARANJAPE, B., ROSSITER, M. & PANTANO, V. 2006. Performance measurement systems: successes, failures and future - a review. *Measuring Business Excellence,* 10**,** 12.
PARMENTER, D. 2010. *Key Performance Indicators - Developing, Implementing, and Using Winning KPIs,* Hoboken, New Jersey, USA, John Wiley and Sons Inc.
PATTIKAWA, L. H., VERWAAL, E. & COMMANDEUR, H. R. 2006. Understanding new product project performance. *European Journal of Marketing,* 40**,** 1178.
PATTON, M. Q. 2002. *Qualitative research and evaluation methods,* Thousand Oaks, California, Sage Publications.
PETERS, T. 2002. Tom Peters revisited: What gets measured gets done. *Office Solutions,* 19**,** 32-33.
PMBOK 2004. *A guide to the project management body of knowledge,* Newton Square, Pennsylvania, USA., Project Management Institute
PMI 2004. *PMBOK - A guide to the project management body of knowledge,* Newton Square, Pennsylvania, USA., Project Management Institute
POH, K. L. 2001. A comparative analysis of R&D project evaluation methods. *R & D Management,* 31**,** 63.
POOLTON, J. & BARCLAY, I. 1998. New Product Development From Past Research to Future Applications - A Study of Success and Failure in the U.S. Electronics Industry. *Industrial Marketing Management,* 27**,** 197-212.
PORTER, M. E. 1996. What is strategy? *Harvard Business Review,* 74**,** 61-79.
PUN, K. F. & WHITE, A. S. 2005. A performance measurement paradigm for integrating strategy formulation: A review of systems and frameworks. *International Journal of Management Reviews,* 7**,** 22.
REID, S. E. & DE BRENTANI, U. 2004. The Fuzzy Front End of New Product Development for Discontinuous Innovations: A Theoretical Model. *The Journal of Product Innovation Management,* 21**,** 170-184.
REINERTSEN, D. 1999a. Lean thinking isn't so simple. *Electronic design,* 47.
REINERTSEN, D. G. 1999b. Taking the fuzziness out of the fuzzy front end. *Research Technology Management,* 42**,** 25.

REPENNING, N. P. 2001. Understanding fire fighting in new product development. *The Journal of Product Innovation Management,* 18**,** 285-300.
RIDGWAY, V. F. 1956. Dysfunctional Consequences of Performance Measurements. *Administrative Science Quarterly,* 1**,** 240-247.
ROBERTSON, D. & ULRICH, K. 1998. Planning for product platforms. *Sloan Management Review,* 39**,** 19-31.
ROBSON, C. 2002. *Real world reserach* Oxford, UK, Blackwell Publishing.
ROLSTADAS, A. 1998. Enterprise performance measurement. *International Journal of Operations & Production Management,* 18**,** 989-989.
ROTH, G. L. & SENGE, P. M. 1996. From theory to practice: research territory, processes and structure at an organizational learning centre. *Journal of Organizational Change Management,* 9**,** 92-106.
ROTHWELL, R., FREEMAN, C., HORLSEY, A., JERVIS, V. T. P., ROBERTSON, A. B. & TOWNSEND, J. 1974. SAPPHO updated - project SAPPHO phase II. *Research Policy,* 3**,** 258-291.
RUBINSTEIN, A. H. 2004. 50 Years of Engineering and Technology Management. *IEEE Transactions on Engineering Management,* 51**,** 407-408.
RUSSELL, R. K. & TIPPETT, D. D. 2008. Critical Success Factors for the Fuzzy Front End of Innovation in the Medical Device Industry. *Engineering Management Journal,* 20**,** 36-43.
RYAN, P. & RYAN, G. 2002. Capital budgeting practices of the Fortune 1000: How have things changed. *Journal of Business and Management,* 8**,** 355.
SANDHU, M. A. 2004. Business process development in project-based industry
Business Process Management Journal, 10**,** 673-690.
SAREN, M. A. 1984. A Classification and Review of Models of the Intra-Firm Innovation Process. *R & D Management,* 14**,** 11-25.
SCHILLING, M. A. 2006. *Strategic management of technical innovation,* New York, USA, McGraw-Hill.
SCHNEIDER, M., TEJEDA, M., DONDI, G., HERZOG, F., KEEL, S. & GEERING, H. 2008. Making real options work for practitioners: a generic model for valuing R&D projects. *R&D Management,* 38**,** 85-106.
SEIDER, R. 2006. Optimizing Project Portfolios. *Research Technology Management,* 49**,** 43-48.
SEKARAN, U. 1992. *Research methods for business: A skill-building approach,* New York, John Wiley & Sons.
SENGE, P. M. 1990. *The Fifth Discipline, the Art & Practice of Learning Organizations,* New York, Currency Doubleday.
SENGUPTA, K., ABDEL-HAMID, T. K. & VAN WASSENHOVE, L. N. 2008. The Experience Trap. *Harvard Business Review,* 86**,** 94-101.
SINK, D. S. & TUTTLE, T. C. 1989. *Planning and Measurement in your Organization of the Future,* Norcross, GA, Industrial Engineering and Management Press.

SLACK, N., CHAMBERS, S. & JOHNSTON, R. 2007. *Operations Management*, Pearson Education Limited.

STAINER, A. & NIXON, B. 1997. Productivity and performance measurement in R&D. *International Journal of Technology Management,* 13**,** 486.

STAMM, B. V. 2003. *Managing innovation, design and creativity,* Chichester, England, John Wiley and Sons Ltd.

STEELE, L. W. 1988. Evaluating The Technical Operation. *Research Technology Management,* 31**,** 11-19.

SUMANTH, D. J. 1994. *Productivity Engineering and Management,* New York, McGraw-Hill.

SZAKONYI, R. 1994. Measuring R&D effectiveness - I. *Research Technology Management,* 37**,** 27-33.

SÄFSTEN, K., JOHANSSON, G., LAKEMOND, N. & MAGNUSSON, T. 2010. *Effektiv produktframtagning - Analys och hantering av osäkerhet, komplexitet och spridning,* Lund, Sweden, Studentlitteratur.

TANG, V., LIU, B., KELLAM, B. A., OTTO, K. N. & SEERING, W., P 2005. Enabling factors in successful product development. *International conference on engineering design.* Melbourne, Australia.

TANGEN, S. 2004. *Evaluation and revision of performance measurement systems.* PhD, KTH.

TATICCHI, P., TONELLI, F. & CAGNAZZO, L. 2010. Performance measurement and management: A literature review and a research agenda. *Measuring Business Excellence,* 14**,** 4-18.

TATIKONDA, M. V. 2008. Product development performance measurement. *In:* LOCH, C. H. & KAVADIAS, S. (eds.) *Handbook of New Product Development Management.* Oxford: Butterworth-Heinemann.

TATIKONDA, M. V. & MONTOYA-WEISS, M. M. 2001. Integrating Operations and Marketing Perspectives of Product Innovation: The Influence of Organizational Process Factors and Capabilities on Development Performance. *Management Science,* 47**,** 151-172.

TERESKO, J. 2008. *Metrics Matter* [Online]. Industry Week. Available: http://www.industryweek.com/ReadArticle.aspx?ArticleID=16116 [Accessed 2008-09-11 2008].

THOMAS, A. B. 2004. *Research skills for management studies,* London, Routledge

THOMAS, A. B. 2006. *Research concepts for management studies,* New York, Routledge.

TROTT, P. 2008. *Innovation management and new product development.*

TROUT, J. 2006. *Tales from the marketing wars – Peter Drucker on marketing* [Online]. Available: http://www.forbes.com/columnists/2006/06/30/jack-trout-on-marketing-cx_jt_0703drucker.html [Accessed 12/1 2007].

TURNER, J. R. 1993. *The Handbook of Project-Based Management: improving the processes for achieving strategic objectives,* Berkshire, England, McGraw-Hill.

ULRICH, K. T. & EPPINGER, S. D. 2008. *Product design and development* Singapore, McGraw-Hill Education.

VAN REE, H. J. 2002. The added value of office accommodation to organisational performance. *Work Study,* 51**,** 357-363.

WARD, A., LIKER, J. K., CRISTIANO, J. J. & SOBECK, D. K. 1995. The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster. *Sloan Management Review,* 36**,** 43-61.

WEHMEIER, S., HORNBY, A. S. & MCINTOSH, C. 2005. *Oxford Advanced Learner's Dictionary of Current English.* Oxford University Press.

WERNER, B. M. & SOUDER, W. E. 1997. Measuring R&D performance - State of the art. *Research Technology Management,* 40**,** 34-42.

VERWORN, B. 2008. The fuzzy front end of Japanese new product development projects: impact on success and differences between incremental and radical projects. *R & D Management,* 38**,** 1.

WHEELRIGHT, S. C. & CLARK, K. B. 1992. *Revolutionizing product development: Quantum leaps in speed, efficiency, and quality,* New York, Free Press.

WHITLEY, R., PARISH, T., DRESSLER, R. & NICHOLSON, G. 1998. Evaluating R&D performance using the new sales ratio. *Research Technology Management,* 41**,** 20-22.

WOMACK, J. P., JONES, D. T. & ROOS, D. 1990. *The Machine that Changed the World,* Sidney, Simon & Schuster Australia.

VOSS, C., TSIKRIKTSIS, N. & FROHLICH, M. 2002. Case research in operations management. *International Journal of Operations & Production Management,* 22**,** 195-219.

YIN, R. K. 2003. *Case Study Research: Design and Methods,* Thousands Oaks, California, Sage Publications.

YIN, R. K. 2009. *Case Study Research: Design and Methods,* Thousands Oaks, California, Sage Publications.

ZOTT, C. & AMIT, R. 2008. The fit between product market strategy and business model: implications for firm performance. *Strategic Management Journal,* 29**,** 1-27.