Abstract

In today's competitive environment, in which competition increases and the pace of technological change accelerates, the need for deploying product development investments more efficiently and effectively is stronger than ever. The ability to create streams of new successful products to the market is vital for every product delivering company's survival. Performance measurements are important in order to evaluate the current state of operation of the product development and decide on actions to improve its' performance. However, in contrast to the concept of productivity in the production process there are no commonly adopted methods for measuring performance within product development.

The methodology used in this research is explorative multiple case studies at five companies developing complex products. Complex products in this research involve mechanics, electronics, and software. Moreover, complex products are often long living and most development work is evolutionary in character. An extensive interview study among senior managers and decision makers has been conducted to get a broad and systematic understanding of what performance is and what to measure.

The main results developed from this research are two conceptual tools. The first one, the Performance Measurement Evaluation Matrix (PMEX) can be used to evaluate the performance measurement system used at a company. The PMEX makes it possible for managers to get a more holistic view and discuss what the performance measurement system is measuring, and what it is not measuring, in order to decide on what to measure. The second tool, the Product Development Organizational Performance Model (PDOPM) can be used to conceptually analyze performance in the product development process from a holistic system perspective. This is achieved by making efficiency, effectiveness, and uncertainty explicit and by showing how they relate at a strategic, project, and product implementation level. The PMEX and the PDOPM can be used by managers in order to increase the understanding of what performance is and to be able to decide on actions in order to improve the performance of the product development process.

Swedish Summary

Vad är effektivitet och hur mäts effektivitet inom komplex produktutveckling?

Ett företags förmåga att kunna utveckla nya produkter på ett effektivt sätt är en förutsättning för att vara framgångsrik på en konkurrensutsatt global marknad. Förmågan att mäta effektiviteten i en produktutvecklingsprocess är viktig för att kunna identifiera förbättringspunkter och därigenom kunna ta beslut om förbättringsåtgärder. Att mäta är att veta, och det som inte kan mätas kan inte heller styras är vanliga talesätt. Inom produktion finns det väl utvecklade metoder för att mäta effektivitet i form av produktivitet. Produktivitet kan beräknas som kvoten mellan produkterna som produceras och mängden resurser som förbrukas i företagets process för att skapa dessa produkter. Produktion, till skillnad från produktveckling, handlar om att utföra samma eller likartade aktiviteter om och om igen. Per definition innebär produktutveckling att arbeta med nya saker vilket gör det svårare att mäta effektivitet på samma sätt som man gör inom produktion.

I det här forskningsarbetet har omfattande intervjuer utförts på fem företag, som utvecklar komplexa produkter. Komplexa produkter är i det här fallet produkter som innehåller elektronik, mekanik och mjukvara, till exempel en lastbil. Eftersom det inte finns några väletablerade definitioner av vad produktutvecklingseffektivitet är och hur den kan mätas är det viktigt att få en förståelse av behoven i industrin. Med resultaten från dessa fallstudier som grund har två konceptuella verktyg utvecklats för att stödja chefer inom produktutveckling i deras förbättringsarbete.

Det första verktyget, PMEX, handlar om hur de mätetal som finns i idag kan utvärderas. Detta har gjorts genom att utveckla ett verktyg med viktiga framgångsfaktorer som en dimension och tiden för när mätningen görs som den andra dimensionen. Genom att använda PMEX kan de mätetal som används överblickas, dels i form av vad som mäts men också när mätningar görs. På så sätt kan man utifrån detta verktyg diskutera hur dagens mätsystem kan förbättras.

Ett resultat från de intervjuer som gjorts i industrin är att effektivitet ofta likställs med att hålla projektbudgeten, det vill säga tid och kostnad. Att hålla sig till budgeten är viktigt för en effektiv produktutveckling men det är också viktigt att man utvecklar en produkt som kunder vill ha. Det finns två dimensioner på effektivitet som brukar benämnas inre och yttre effektivitet. Yttre effektivitet handlar om att göra rätt saker medan inre effektivitet handlar om att göra saker på rätt sätt. Osäkerhet är också något som karakteriserar produktutveckling eftersom det är någonting nytt som ska skapas. Utvecklingseffektivitet i denna avhandling handlar om att kunna hantera och diskutera osäkerhet, inre och yttre effektivitet på tre nivåer. Den första nivån behandlar den som bestämmer vad som ska utvecklas, den andra nivån behandlar den projektledare som ska ansvara för att produkten ska utvecklas och den sista nivån är utförandenivån av de aktiviteter som är direkt sammankopplade med att skapa den nya produkten, till exempel att programmera mjukvara eller att testa att produkten uppfyller de specificerade kraven. För att underlätta diskussioner om utvecklingseffektivitet på detta sätt har ett verktyg utvecklats som kallas PDOPM.

Genom att använda dessa två konceptuella verktyg kan förhoppningsvis effektiviteten i ett företags produktutvecklingsprocess utvärderas på ett bättre sätt och beslut tas om aktiviteter för att förbättra denna process.

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Studying for a PhD is definitely a complex process in itself with many different sides to it. Some days it has been one of the loneliest tasks I have ever pursued, but mostly it has been a truly cooperative process with several people contributing in the creation of new knowledge. Looking back at my two years of research studies I have been lucky to meet and work with many competent people.

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Furthermore, Peter Wallin without your help during the interview process this work would have been more time consuming and less joyful. We have also had many discussions and ideas since we shared office. I would also like to acknowledge the importance of other colleagues reading and commenting things I have written like Dr. Rikard Land, Dr. Stig Larsson, Dr. Joakim Fröberg, and Diana Malvius. Moreover, I have also been fortunate to cooperate with Joakim Eriksson and Dr. Rolf Olsson. Our common research interest, but different background has always been good breeding ground for creative thinking, when we find the time to meet.

As a researcher you tend to bring your work with you, bothering friends and family to review your writings. Thus, I am thankful to have a language expert Claes and a lot of positive feedback from my mother and Pehr. Last but most importantly I would like to thank Jessica, for always being there to support me and encouraging me to fulfill whatever strange ideas I come up with, like pursuing doctoral studies.

Stefan Johnsson

August 2008, Clifton, Cape Town, South Africa

List of Included Papers

Paper A 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.

Paper B 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.

Paper C 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.

Paper D 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.

Additional Publications

Conference papers

- Issues Related to Development of E/E Product Line Architectures in Heavy Vehicles, Peter Wallin, Stefan Johnsson, Jakob Axelsson, Proceedings of the Hawaiian International Conference on Systems and Science, Honolulu, Hawaii, January 2009.
- Modelling 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

Table of Contents

List of Illustrations

PART ONE

THESIS

Chapter 1. Introduction

The aim of this licentiate thesis is, in broad terms, to explore how performance is perceived and measured within large Swedish companies developing complex products. Peter Drucker, [1], argues that the single greatest challenge that mangers face, is to raise the productivity of knowledge workers. The process of developing complex products is a truly knowledge intensive task. However, before actions can be identified and decided on, in order to improve the product development performance, the current performance needs to be evaluated.

1.1 Why focus on performance in complex product development?

The following section is inspired by a workshop held by Bradford L. Goldense at the Management Roundtable's 11th annual conference on Product Development Metrics in Chicago 2006.

In the beginning of the 1970s a revolution within logistics began and it became possible to deliver products worldwide in a novel, more efficient way. Today we more or less take for granted the possibility to deliver a product anywhere in the world within 24 hours. This product delivery revolution, beginning in the 1970s, made it possible to establish larger manufacturing sites; hence, it became vital to develop more efficient and effective manufacturing processes. It became the starting point of a revolution within manufacturing in the late 1970s. Nowadays, even if it is not always shown in practice, there is at least from an academic viewpoint a fairly well understood task of optimizing a manufacturing process. Next in line, in this chain of revolutions was the product development process. This began with the rapid product development revolution and has more recently also started the product definition revolution. However, we are just in the beginning of both the rapid product development and the product definition revolutions. One important activity in these revolutions is to be able to measure the performance in all activities of the product development process. This is important in order to be able to decide on actions that can lead to improved product development performance. Again, a comparison to the manufacturing process and the concept of productivity that is both well defined and measured is suitable. One conclusion to be made from this is that the easy challenges were completed first and the harder more complex challenges is still lying ahead.

1.2 Research motivation

Today's competitive environment, in which competition increases and the pace of technological change accelerates, the need for deploying product development investments more efficiently and effectively is stronger than ever [2]. In this context measurement of the performance of the product development activities is gaining importance because the effectiveness and the efficiency of these activities not only determine a firm's competitive advantage, but also its' very survival [3]. However, performance measurement in general has attracted attention from several researchers with different functional backgrounds. Hence, no body-of-knowledge has emerged despite a lot of research effort. In an attempt to initiate a body-of-knowledge Andy Neely edited a book, Business Performance Measurements [4], with contributions from researchers within different functional areas. The functional areas represented in this book are operations management, marketing, accounting, and supply chain perspective, missing though is the product development perspective. The aspect related to product development is the use of patents, as a way of measuring innovation performance [5]. Instead the process of developing new products is implicit within especially the operation management and the marketing perspectives.

However, there is a need for making the product development process more explicit. Moreover, performance measurements are important in order to make sure that the job has been done, but also to constantly be able to improve the performance [6]. The ability of developing new products is vital for every product delivering company. Cooper [7] even talks about the product innovation war and that today the corporate motto is innovate or die. Hence, it is important to continuously improve the process of developing new products. Achieving and sustaining high performance in a firm's business processes are vital for every organization competing in the global market of today. Sustaining a performance improvement is often proven to be more difficult then to temporarily improve the performance [6].

The performance measurement literature within product development devotes considerable attention to choose and implement correct process measurements [8]. Still, no generally accepted measurement approach exists even though there has been extensive research within the area performance measurement in product development [9]. There is a need for a holistic framework for evaluating the product development process, covering the range of activities required to turn ideas into useful and marketable products [10]. The existing evaluation of product development projects and programs has not improved much over the past 50 years [11]. Kuczmarski [12] identified five issues regarding performance measurements within product development; too many metrics, too focused on outcomes, too infrequent, too focused on cutting costs, and too focused on the past. With this in mind it seems like the performance measurements are not supporting the product development process.

The foundation of this research is five exploratory multiple case studies with the objective to assess how performance is currently perceived and measured within large companies developing complex products in Sweden. From these case studies a total of four research papers have been written. In this thesis, it is argued that it is important to have a well defined objective and common perception of the performance you want to measure, before it can be measured. This may be one explanation why there is not one commonly used setup of performance measurements within product development.

1.3 Research organization

This research has been conducted together with seven different companies, all developing complex products but with different products and markets. Of the participating companies, five of them participated in the exploratory case studies with the goal of understanding how performance is perceived and measured within the context of developing complex products. This research set-up has been possible since the participating companies are not competitors but share the same problems, making it possible to conduct workshops and steering-committee meetings with open discussions and experience sharing. Common for all participating case companies is that they develope products in a business to business context and they are all international companies with development in Sweden. The other two companies have been participating through workshops and steering committee meetings.

This research has been sponsored by the KK foundation, through the research school SAVE-IT, together with the participating companies. During this research the author has been employed by Level 21 Management AB that also has participated in this research mainly through industrial experience.

1.4 Thesis overview

This licentiate thesis is a collection of papers i.e., the first part of this thesis presents an overview of the research, and the second part includes a collection of the conference papers documenting the details of the research questions, methods, and results.

The first part of this thesis begins in Chapter 2 with a presentation of the frame of reference for this research. In this chapter an emphasis is put on defining the terminology and the related research is presented. With the learning's of the frame of reference, a presentation of the identified research questions is made in Chapter 3. The scientific approach, methodology and validity of the presented research are discussed in Chapter 4, focusing on the whole research project. Chapter 5 includes a presentation of the research results in relation to the research questions. The conclusions made in this research are divided into implications for management and implication for theory in Chapter 6. The first part of the thesis is concluded with a discussion on interesting possibilities for future work in Chapter 7.

Part two of the thesis includes the following papers:

Paper A "Productivity Framework for Innovative Product Development "

This paper presents a framework to reason about performance in the product development process. The framework is deducted from a definition of product development. A product development process contains three parts; Planning (what to develop), Implementation (product realization), and Marketing, Sales and Delivery. Success comes from acknowledging the fact that there are different objectives within the three parts. The performance of the product development process can be expressed as a function of the efficiencies of Planning, Implementation and Marketing, Sales, and Delivery.

Presented at the 5th International Symposium on Management of Technology, Hangzhou, P.R. China, June 2007. Authors: Stefan Johnsson, Lars Cederblad, Christer Norström, Anders Wall.

Stefan Johnsson contributed with collecting all the empirical material and performed the analysis, with Lars Cederblad, Christer Norström, and Anders Wall having advisory roles.

Paper B "PMEX – A Performance Measurement Evaluation Matrix for the Development of Complex Products and Systems"

This paper presents a conceptual tool for evaluating the performance measurement system used within product development. The Performance Measurement Evaluation Matrix (PMEX) has the different phases of the Stage-Gate process as one dimension and important success factors in the development of complex products and systems as the other dimension. The first results of using the PMEX indicate that the tool enables managers to overview what is and what is not measured. The PMEX can therefore function as a conceptual tool in the discussions for setting the scope of the performance measurement system.

Presented at the Portland International Center for Management of Engineering and Technology (PICMET) 2008 Conference, Cape Town, South Africa, July, 2008. Authors: Stefan Johnsson, Christer Norström, Anders Wall.

Stefan Johnsson contributed with collecting all the empirical material and performed the analysis, with Lars Cederblad, Christer Norström, and Anders Wall having advisory roles.

Paper C **"**Modeling Performance in Complex Product Development - A Product Development Organizational Performance Model"

This paper presents the Product Development Organizational Performance Model (PDOPM), making it possible for managers to reason about performance in product development. The model consists of three generic levels of activities: product strategy, project management, and product activities. Each level of activity uses resources to transform input to output under the direction of goals and constraints. This way of modeling the product development process with three generic levels of activities makes it possible to analyze performance from the three perspectives. Effectiveness, efficiency, and uncertainty are defined for the three generic levels of activities. The PDOPM can be used as a way of discussing what effect these three levels of activities have on product development performance as a whole (i.e., from a holistic view, aligning product strategy, project management, and product activities).

Presented at the 17th International Conference on Management of Technology, Dubai, U.A.E., April 2008. Authors: Stefan Johnsson, Joakim Eriksson, Rolf Olsson.

Stefan Johnsson contributed with the analysis and wrote most of the paper. Rolf Olsson and Joakim Eriksson helped with the analysis and wrote smaller parts of the paper.

This paper was awarded as runner-up paper at the IAMOT 2008 conference.

Paper D “What is Performance in Complex Product Development?”

This paper presents the lack of a holistic perception of performance within the development process in industry. Performance is commonly solely perceived in terms of time, cost, and quality. Thus, in order to develop better measurements of performance, the perception of performance needs to be changed first. Product development effectiveness and efficiency is defined for the complete product development process. Further, product development efficacy is introduced to describe the capability of identifying or creating a market opportunity and being able to develop and deliver a product fulfilling exactly what was identified as the market opportunity.

Presented at the R&D Management Conference 2008, Ottawa, Canada, June, 2008. Authors: Stefan Johnsson, Peter Wallin, Joakim Eriksson.

Stefan Johnsson performed the analysis and wrote the paper. Peter Wallin helped with the interviews and analysis in the case study. Joakim Eriksson contributed with feedback on the analysis.

Chapter 2. Frame of Reference

In an academic perspective performance measurement in product development is a relatively young research area, without a well defined body of knowledge. This chapter serves to describe the frame of reference in this licentiate thesis. First a definition of complex product development is presented, followed by a discussion of what performance is and how performance is perceived within literature. This chapter then continues with a brief overview of the literature within performance measurement in general, followed by how it is used to evaluate the product development process. The chapter is concluded with a discussion of issues and identified gaps in the current literature.

2.1 Defining complex product development

In the literature, both within performance and product development it is rare to find clear explicit definitions of the terminology used. When definitions are provided there seems to be several, sometimes even contradicting each other, and citation of previous definitions are seldom seen. In an attempt to define complex product development in this research, the term has been divided into complex products and product development.

Complex products in this thesis refer to products often including software, electronics, and mechanical components, usually developed in large organizations, in a business to business setting. In order to manage complex products, they are often divided into smaller subsets that can be either outsourced or developed in-house. Moreover, complex products usually have a long life time and the development of such products is therefore often more evolutionary and incremental in its nature. Usually, there is a platform or architecture as the basis of the product, in order to manage the technical complexity of the product and shortening the development time for a new product. There are several different terms related to complex products to be found in the literature e.g., software intensive products [13], complex products and systems (COPS) [14], industrial products [9], and high-tech products [15].

Similarly, to describe the process of developing new products, various terms like e.g., product innovation [16], innovation [17], engineering design [18], new product development (NPD) [19, 20], research and development (R&D) [9, 21], and product development [22] can be found in the literature. One explanation for this may be the many different perspectives on product development existing in academia. In a review of the product development literature [23], at least four common perspectives: marketing, organization, engineering design, and operations management were argued for.

In this licentiate thesis a broad interpretation of product development is made, to be able to reason about performance. It is therefore proposed to define product development as follows:

Product development is the set of activities beginning with the tools and processes 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 argued for by Ulrich and Eppinger [22]. In order to make it possible to evaluate the product development process from a performance perspective, it is important to have a well defined start and end of the process. However, there is no, as in most other business processes, clear beginning or end of the product development process in practice. In industry there are several different ways of initiating the development of a new product within a company. In literature however, the product development process is often initiated when it is already decided what product to develop, in order to satisfy a given set of customer needs. From a performance evaluation point of view, it is during the early activities of the development process, when the decision of what customer needs to fulfill, decided what the possible value of the product development can be. The activities following these decisions are all about realizing what has been decided i.e., creating the decided value.

2.2 The product development process

As is described in the definition of the product development process there are plenty of activities to be completed when a new product is to be developed. The product development process is therefore, in order to structure these activities, often divided into different phases in the literature. One generic process model for product development is shown in Figure 1.

Another popular model for developing new products is the V-model [24] it is often used when a more systems engineering oriented approach is adopted.

Figure 1. A generic product development process [22]

The generic product development process model, as shown in Figure 1, contains six phases. The first phase *planning* precedes the project approval and launch of the actual product development project. Often is a new product 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 [25] as a temporary endeavor undertaken to create a unique product, service, or result. The *concept development* identifies the customer needs and different concepts fulfilling 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*, were the production workforce is trained and remaining problems in the production process are worked out. This way of describing the product development process seems linear and straight forward; however within industry this process is often highly iterative and non-linear.

There are several methods in literature describing how to organize product development: concurrent engineering (e.g., [26]), integrated product development (e.g., [27]), 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 [28]. Complex product development include high numbers of elements, that puts demand on managing interdependent systems of products, to maintain an overall view, in order not to sub-optimise [29]. Integrated product development advocates the integration of work procedures, information management and support tools so the complexity can be managed in an effective and efficient way [28].

2.3 The Stage-Gate model

The Stage-Gate model, developed by Cooper et al. [30], is a management tool for the product development process. The Stage-Gate model, shown in Figure 2, is a conceptual and operational map for moving product development projects from idea to launch. It can be seen as the blueprint for managing the product development process to improve both effectiveness and efficiency [31].

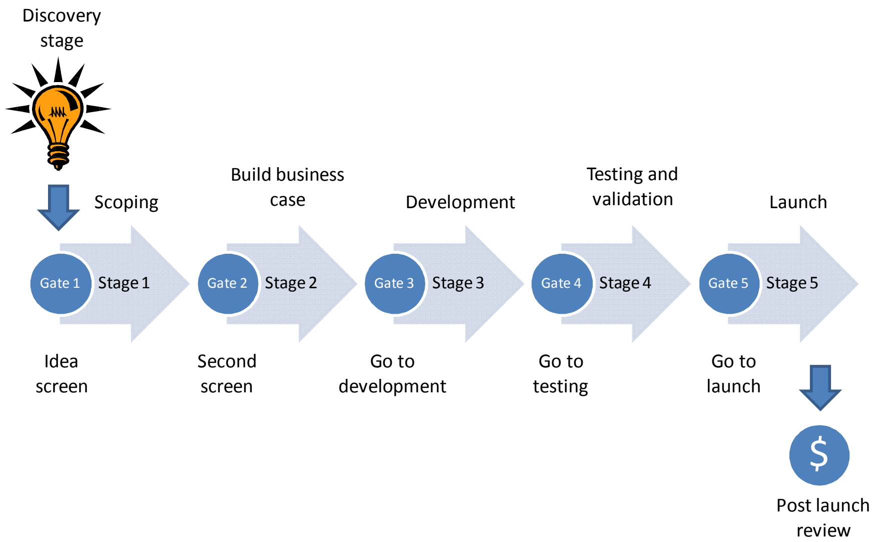

Figure 2. The generic Stage-Gate Model [32, 33]

The Stage-Gate model, consists of a series of stages, where the project team undertakes the work, obtains the needed information, and does the subsequent data integration and analysis, followed by gates, where go/kill decisions are made i.e., to continue to invest in the project or not [31]. Usually the Stage-Gate model involves four to eight stages and gates in a by the company modified process [34]. Cooper [31] compares the Stage-Gate model with buying a series of options on an investment. Initially, one purchases an option for a small amount of money, then does some due diligence, and finally decides whether or not to continue to invest. This is a task repeated for every stage within the model. The Stage-Gate model is often modified according to the specific needs of the company and it is also proven to improve the efficiency of the product development process [35].

Even if product development, from an academic perspective, still is a young research area there are signs of a maturing field. Page and Schir [20] identified a shift in focus, from a few success factors or a staged development process to variables and more sophisticated models. Their review included 815 articles between 1989 and 2004 within product development.

2.4 The ambiguity of performance

The term performance is often used but seldom defined within the academic literature [36]. Quotes like “increased performance” or “positive influence on performance” are common but used in a highly ambiguous manner. This is an obstacle all measurement practitioners must deal with since the terminology within the field of performance measurement is not clear. Frequently used concepts like effectiveness, efficiency, and performance are often misused and confused with each other [37]. However, when a definition is provided there seems to be a consensus to equal performance with effectiveness and efficiency [36, 38]. In the following subsection efficiency and effectiveness are further described.

2.4.1 Efficiency and effectiveness

In the Oxford dictionary [39] efficiency is used to describe the ratio of the amount of energy going in to a system and the amount it produces. It can be used as the skillfulness in avoiding wasted time and effort. Effectiveness is more an interpretation of the produced result, if it was intended or wanted. Neely et al., [40] argue that effectiveness refers to the extent to which customer requirements are being met, while efficiency is a measure of how economically a firm’s resources are being used, providing a given level of customer satisfaction. In [6] effectiveness is described as doing the right things at the right time, with the right quality. Efficiency is similarly described as doing things right, often expressed as a ratio between resources expected to be consumed and resources actually consumed. However, this definition of efficiency seems to be more of an efficiency aspect of the planning activities and the predictability of the organization, then of the product development process. Moreover, Cordero [41] define efficiency as measuring resources to determine whether minimum amounts are used in the making of these outputs. Similarly, the same author defines effectiveness as measuring output to determine if they help accomplish objectives.

An interesting attempt to define efficiency and effectiveness is the one proposed by O'Donnell and Duffy [36] where they further develop the activity model of the IDEF0 framework [42] previously developed in a research project by the US Air Force. This activity model, shown in Figure 3, is often used within system engineering.

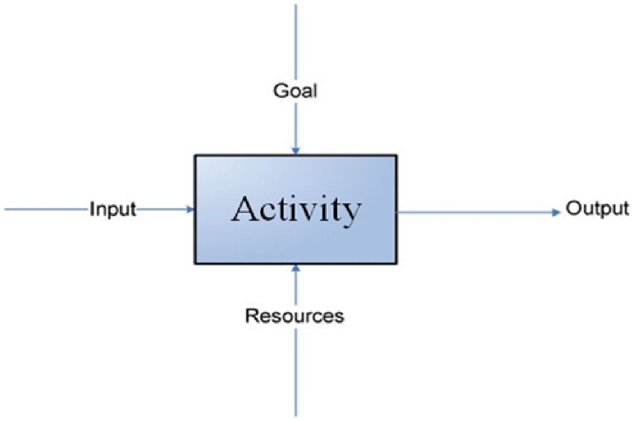

Figure 3. An activity model based on the IDEF0 [43]

This way of modeling an activity is to be interpreted as follows: an activity uses resources to transform input to output under the direction of a goal [36]. Input refers to the initial state of knowledge while output is the final state of the performed activity. Resources are not just the people involved in the activity but also other resources 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. Moreover, O'Donnell and Duffy use this activity model to define efficiency and effectiveness. Efficiency is defined as the difference between output and input i.e., the value created by the activity, divided by the resources consumed in creating the output. Effectiveness is defined as how the output of the activity meets the goal of the activity; is the intended output created? Table 1 provides a summary of some of the definitions of efficiency and effectiveness identified in literature.

Table 1. Definitions of efficiency and effectiveness, based on [37]

Author(s)	Definition of efficiency	Definition of effectiveness
Sink and Tuttle [6]	Efficiency is an input and transformation process question, defined as the ratio between resources expected to be consumed and actually consumed.	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.
Kurosawa [44]	Efficiency is used for passive or operational activity, which is usually defined technically so that the system and its behavior are foreseeable in advance	Effectiveness is basically used in active or innovative activity performed by a risk taker and based on a rather broad perspective.
Sumanth [45]	Efficiency is the ratio of actual output attained to standard output expected, and reflects how well the resources are utilized to accomplish the result	Effectiveness is the degree of accomplished of objectives, and show how well a set of results is accomplished
Neely et al. [40]	Efficiency is a measure of how economically the firm's resources are utilized when providing the given level of customer satisfaction	Effectiveness refers to the extent to which the customer requirement are met
Jackson [46]	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	Effectiveness in manufacturing can be viewed as to what extent the cost is used to create revenues
van Ree [47]	Efficiency refers to the ratio between aimed resources use and the actual resources use in order to transform an input to an output	Effectiveness refers to what extent the actual result (output in quality and quantity) corresponds to the aimed result
Ojanen and Tuominen [48]	Efficiency is the degree to which inputs are used in relation to a given level of outputs.	Effectiveness is the degree to which a predetermined objective is met.
Oxford Advanced Learner's Dictionary [39]	Efficiency is the quality of doing something well with no waste of time or money.	Effectiveness is about producing the result that is wanted or intended.
Cordero [41]	Efficiency is measuring the resources to determine whether minimum amounts are used in the production of these outputs	Effectiveness is measuring the output to determine if they help accomplish objectives

These examples, provided in Table 1, of efficiency and effectiveness illustrate the diversity in the currently used terminology associated with performance. In general, effectiveness is related to the attainment of objectives or goals and efficiency is seen to relate to the use of resources [36]. The 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. In addition, efficiency is similar to the concept often used within manufacturing, referred to as utilization rate (i.e., degree of utilization), which means how much the equipment or a process is used in practice compared to its theoretical maximum [37]. Effectiveness, on the other hand, is a more diffuse term and in most cases very difficult to quantify. It is often related to the creation of value for the customer or the organization. Furthermore, a good description of effectiveness is the ability to reach a specified objective or the degree to which a desired result is achieved [37].

2.4.2 Other dimensions of performance

In literature further dimensions of performance exists other then efficiency and effectiveness. Process performance in a development project is a behavioral measure of how effectively the development team is working on the project [8]. It indicates how well the team is currently working, rather than overall end-result, the development performance of the project or its commercial success. Effective process performance consist of three component dimensions: teamwork, team productivity, and engineering change time, that characterize how effectively product development processes at the project level are functioning [8]. Another important dimension of performance, seldom used within product development, is productivity. Within manufacturing, productivity is one of the most frequently used measure of performance. In the field of product development, productivity can be defined as the output, measured as new product sales or profits, divided by the input, measured as product development costs and time [16]. For example:

$$\text{Product development productivity} = \frac{\text{Profit or sales from new products}}{\text{Product development spendings}}$$

Because 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 almost no companies measure or report their product development productivity as a business metric [49-51].

2.5 Performance measurements in general

Similar to product development and performance there are several definitions of performance measurements in the literature. In a recent literature review by Slack et al. [52], no less than 17 definitions of a business performance measurement system were identified. The same authors underline that a no-consensus situation on a performance measurement systems definition, can inhibit the development of the field. Van Drongeln and Cook [9] argue that performance measurements is that part of the control process that has to do with the acquisition and analysis of information about the attainment of a company's objectives, plans, and factors that may influence the realization of that plan. Sink and Tuttle [6] argue that the main focus of the performance measurement system is to provide managers with the needed information to be able to make decisions about what actions to take in order to improve the performance of the organization. Moreover, Lynch and Cross argue that the purpose of performance measurements is to motivate behavior leading to continuous improvement in customer satisfaction, flexibility, and productivity. Performance measurement can also be defined as the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from the actions by its management [53]. The basic function of any performance measurement system lies in its integration into operative processes and in its actual use for taking action upon improvements leading to improved performance in the area targeted [54].

Performance measurements is, similar to the product development process, a diverse subject, including researchers with functional backgrounds as varied as accounting, operations management, marketing, finance, economics, psychology, and sociology, all actively working in the field [4]. It could be argued that performance measurement is not and can never be a field of academic study because of its diversity [55].

2.5.1 Performance measurement in a system perspective

There is no direct value, from a business perspective, to have performance measurements, rather the opposite. Since there is a cost associated with the actual measurement. Value can only be achieved through the integration of the performance measurements into the firms' improvement processes. In Figure 4 a typical performance measurement lifecycle is shown.

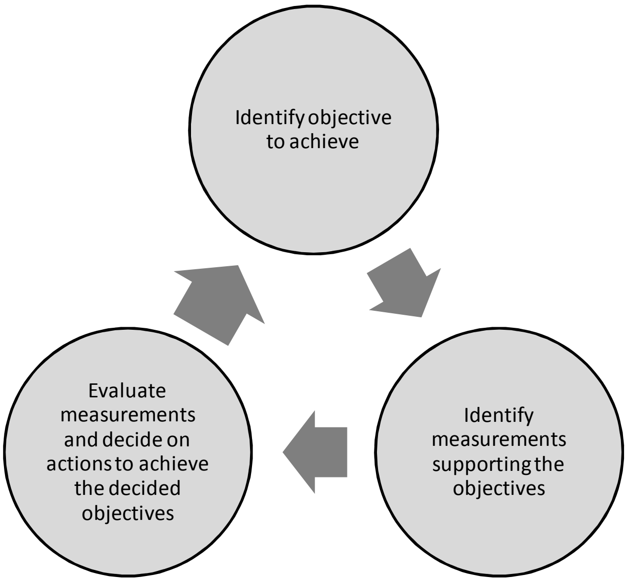

Figure 4. Performance measurements in a life-cycle perspective

A performance measurement system is not only consisting of its measurements but also the way they are used [56]. There are no set of measures that will remain definitive over time. Just like an organization, performance measurements needs to be flexible over time to reflect the changes in objectives and needs [57]. Performance measurements are often an important part of any quality system like TQM [58]. Performance measurements are also an important part of most improvement processes e.g., Six sigma [59] and CMMI [60].

2.5.2 Categorizing performance measurements

In literature several attempts to categorize performance measurements exists. One classical classification is to divide them into quantitative and qualitative measurements. Historically, performance measurements have been financially oriented, hence quantitative in nature. Dividing the performance measurements into financial and non-financial is common within the management accounting literature [61]. The problem with this taxonomy, especially for product development, is that the cluster of non-financial measures is still very large [9].

Research within performance measurements in product development can similarly be categorized, according to their research approach, into *quantitative* and mostly *qualitative* research. Chiesa and Frattini [62], propose to further divide the quantitative measurements into *objective* and *subjective* indicators, as illustrated in Figure 5. Quantitative objective indicators are numeric metrics obtained from the application of a definite algorithm. Hence, 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 however translated into a numeric score through alternative techniques. Finally, qualitative subjective metrics are not expressed numerically, but through the personal judgment of the evaluator.

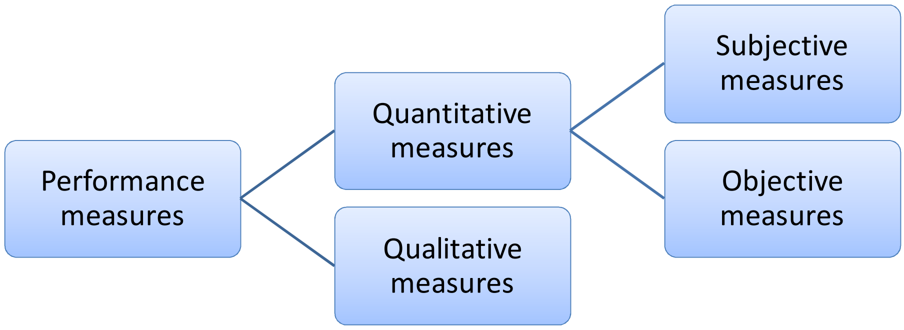

Figure 5. One categorization of performance measures [62]

Moreover, quantitative measurements tend to focus on what can be quantified not necessarily what is important [63]. Early attempts at the use of quantitative approaches for project selection and portfolio management were based on analyzing the link between inputs and outputs [9].

Another classification is lagging or result oriented measurements and leading or process oriented performance measurements. Result oriented measurements tells 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 [56]. Most result oriented measurements track what goes on within a function, not what happens across functions. Process measurements monitor the tasks and activities throughout an organization that produce a given result [56]. Such measures are essential for cross-functional teams that are responsible for processes that deliver an entire service or product to a customer, like the product development process [56]. Moreover, Mankin [64] argue for four types of performance measurements: result-based measurements, process measurements, project measurements, and portfolio measurements of product development performance.

Eccles [65] argue there to have been a revolution within performance measurements. At the heart of this performance measurement revolution lie 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.

2.5.3 The performance paradox

A well known concept regarding performance measurement and improvements is the performance paradox. The basis for the performance paradox is that if you deliver, you only qualify to deliver more [66]. Cohen [67] argue 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.

It is important to acknowledge the existence of the performance paradox, in order to be successful with improvements in performance and performance measurements.

2.6 Performance measurement frameworks

Several performance measurement frameworks exist in the literature. One early framework is the *Performance Measurement Matrix* proposed by Keegan et al., [68], 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 [69]. Another framework is of the *Strategic Measurement And Reporting Technique (SMART) pyramid*, that supports the need to include internally and externally focused performance measurements of performance [70]. In the SMART pyramid the objectives and measurements can be viewed from three directions [48]. 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, which entity do the objectives belong to? The SMART pyramid is presented in Figure 6.

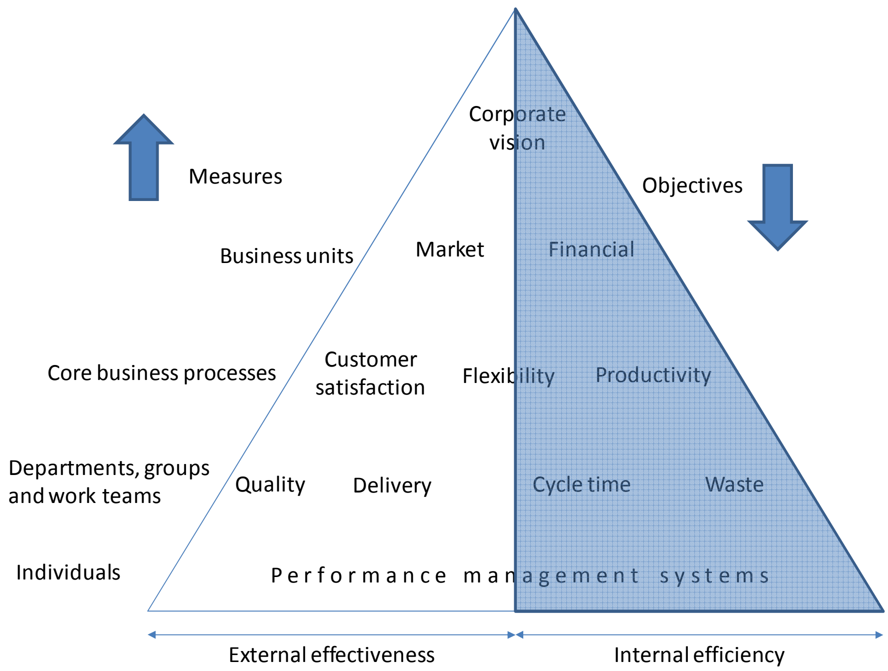

Figure 6. The SMART pyramid [70]

One of the first performance measurement frameworks to reflect on the cause and effect relationship is the result-determinants framework proposed by Fritzgerald et al., [69]. 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 in the *Input-Process-Output-Outcome* *framework* [71]. The Input-Process-Output-Outcome framework is presented in Figure 7.

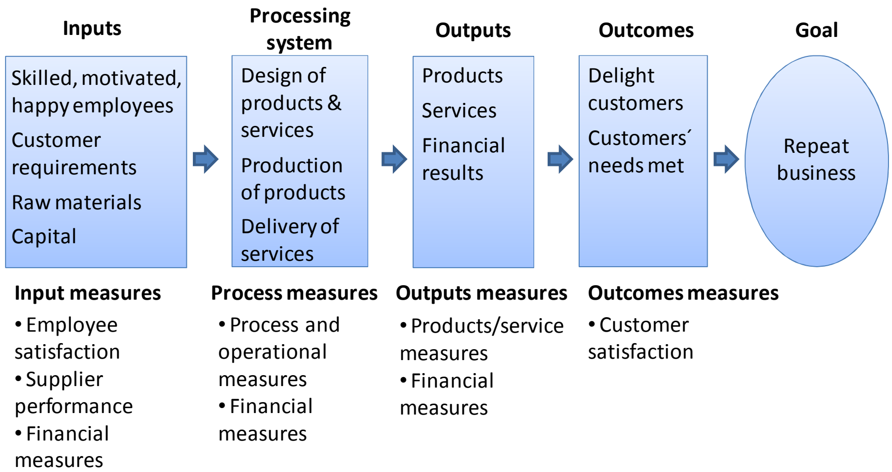

Figure 7. The Input-Process-Output-Outcome framework [71]

Brown's model 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 [69].

The most popular and wide spread of the performance measurement frameworks is of the *Balanced Scorecard* that identifies and integrates four perspectives of performance: financial, customer, internal business, and innovation and learning [72]. The Balance Scorecard was developed by Kaplan and Norton [73] in the year 1992 and is presented in Figure 8.

Financial measurements alone cannot adequately reflect factors such as quality, customer satisfaction, and employee motivation [57]. 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 [74]. It is argued that financial performance, the drivers of it, 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 is the financial perspective given more weight on the expense of the other perspectives.

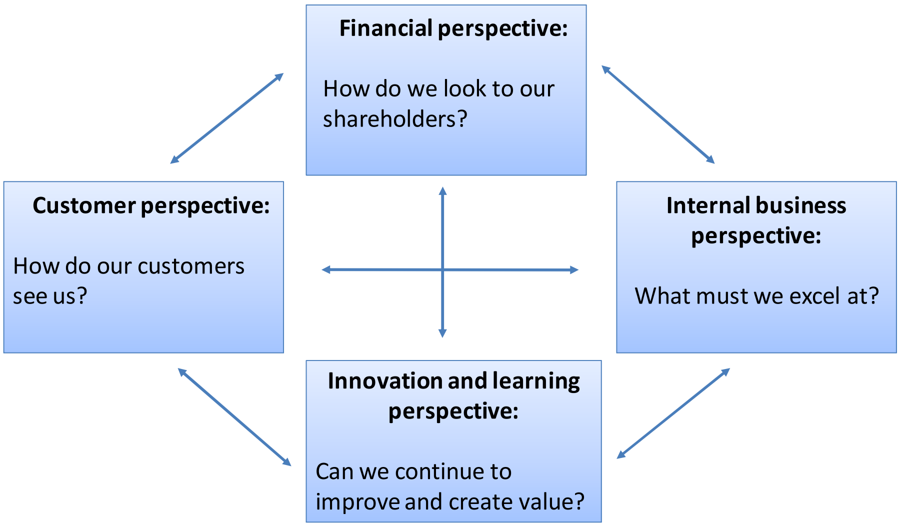

Figure 8. The Balanced Scorecard [73]

The Balanced Scorecard still prevails as the dominant performance measurement system [75]. By the year 2001 the Balanced Scorecard had been adopted by 44 per cent of organizations worldwide [4]. However, successful implementations of the Balance Scorecard are much less prevalent and translating the Balanced Scorecard into concrete action is still a problematic area. In [76] a framework to integrate the Balanced Scorecard in R&D management is presented. However, the Balanced Scorecard has not reached the same success within the product development process as it has within other business processes.

One of the more recent developed conceptual performance frameworks is of the Performance Prism [77], proposing a performance measurement system to be 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 ensure 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 like the Balanced Scorecard. Neely et al [77] argue that the common belief that performance measurements should be strictly derived from strategy is incorrect. It is the wants and needs from different stakeholders that first 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 to rely on.

2.7 Performance measurements in product development

Despite more than 30 years of research into the process of developing products, the issues surrounding success and failure still remain much the same [78]. The evolution of management of the product development process has evolved from a strategy of hope, to become strategically and organizationally embedded for management [79]. Measurements of product development performance have always been associated with several difficulties, due to the nature of the activities within product development. Product development is more difficult to measure than most other business processes e.g., due to non-programmed decision situations and inherent uncertainty. The decision making process can be categorized as programmed when there is a possibility of defining a procedure for handling them so that they do not have to be treated anew each time they occur. On the contrary non-programmed decisions are novel, unstructured, and consequential. There is no cut and dried method for handling these decisions since they have not arisen before, or because its' precise nature and structure are elusive or complex.

Since the objective with the product development process is to create something new, it is inherently a non-repeatable task, consequently several non-programmed decisions needs to be made when a new product is to be developed. This could be one reason why there are no broadly accepted performance measurements, as there are for example in the manufacturing process [80]. Chiesa et al. [2], have identified three reasons for this; first, the degree of uncertainty of an activity within product development is very high; second, once completed, the product development output itself is often highly fuzzy and not definable and, thus, not measurable; third, the ultimate result of a product development activity can usually only be viewed after several years, once an innovation has been brought to the market. At this time, the outcome is the result of efforts of both the R&D unit and other company functions. The product development organization has, for reason like these, always been treated as an expense centre, hence the difficulty of negotiating resources for development projects [2].

Recently however, product development has been thought of as an accountable process, even if it was once considered unique, uncertain, creative and unstructured, one difficult, if not impossible to monitor and control [81]. However, it is generally agreed that financial measurements are most useful at higher levels of management where they can reflect the success of pursued strategies [57].

Performance measurements in product development is a fundamental aspect to quality in product development and to overall business performance [81]. It is easier to measure performance in the manufacturing process compared to the product development process, due to the repetitive tasks in production compared to the more non-programmed decision making in product development.

Hauser and Zettlemeyer [82] argue for at least three reasons why to use performance measurements within product development. First, such measurements document the value of product development and are used to justify investments in this fundamental, long-running, and risky venture. Second, good performance measurements enable top managers to evaluate people, objectives, programs, and projects in order to allocate resources effectively. Third, measurements affect behavior. When scientists, engineers, managers, and other employees are evaluated on specific measurements they make decisions, take actions, and otherwise change their behavior in order to improve the measured performance. The right performance measurement can align employees' goals with those of the corporation, consequently, the wrong measurements can be highly counterproductive and lead to narrow, short-term, and risk avoiding decisions and actions.

2.7.1 Performance measurement frameworks

In general, few performance measurement systems, except the Balanced Scorecard, have had any wide spread acceptance within companies. Within product development this is even more evident, since not even the Balance Scorecard has reached any wide acceptance. However, there are some performance measurement frameworks that have been developed within the literature. One of the most cited in the literature is the performance measurement categorization by Griffin and Page [38] shown in Figure 9. This categorization consists of customer acceptance, financial success, product and project success, and firm level success. This categorization illustrates that the proposed measurements are heavily lagging or result oriented and the perspectives of process or leading indicators are missing.

Figure 9. Performance measurements categorization [38]

Godener and Söderquist [54] have further developed this categorization proposed by Griffin and Page into seven different areas of performance measurement: financial performance, customer satisfaction, process management, innovation, strategic, technology management, and knowledge management.

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 [83].

Customer satisfaction measurements, where high performance is seen as exceeding or at least satisfying customer expectations [84]. This perspective originated in the need to evaluate market expectations of a new product, but also 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 [82].

Process management measurements, where high performance rhymes with optimizing quality, lead time and cost, and ensuring project progress according to process related goals [83]. 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 [21].

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 [81].

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 fit between product development and business strategy [82], 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 differentiates from the others by its focus on the coupling between product and process technology, through the important concept of product platforms [85]. The purpose is to focus management attention to the technical and commercial effectiveness of R&D and product development on a product family basis. This is achieved by looking into 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 [86].

2.7.2 Performance measurement in complex product development

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., [3], aiming to assess the overall contribution of the product development to a company's business performance. The authors aim to 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. argue that process performance influences output performance through the operational management of the development projects. A number of variables are defined: development process management, development output performance, and business success. Two separate regression analysis are performed and the analysis provide some kind of indication of relationships within the developed framework. The framework is shown in Figure 10. However, this framework has received some critics, e.g., O'Donnell and Duffy [43] argue that there were no process variables with significant relationship with the output measurements of "new product productivity" and "design quality". However, this framework is still important since it is one of few studies with an explicit focus on more complex product development.

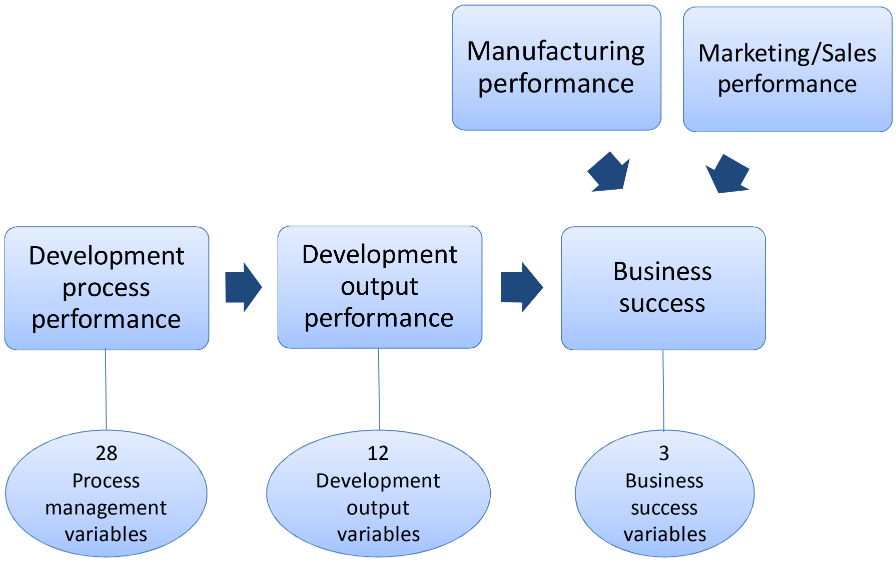

Figure 10. A framework of product development performance [3]

Brown and Svensson [21] propose another perspective of performance in product development by emphasizing a systems perspective. This system perspective on performance, shown in Figure 11, 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 hypothesis, 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; usually this includes marketing, manufacturing, buyers and aftermarket or other departments. *Outcomes* are the accomplishments 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 feedback this information to its people. Outputs are usually measured in terms of quality, quantity, and cost, however, simply measuring outputs is not enough; *outcome* must also be measured and fed back to the system. It is only through measuring the outcome that the real value of the product development function can be assessed.

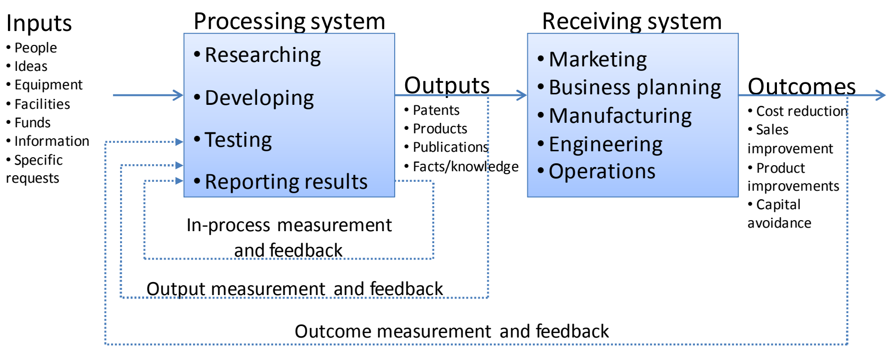

Figure 11. The product development process as a system [21]

This way of modeling the complex product development process is interesting in order to increase the understanding of why performance measurement fail i.e., focus is too much on internal measurement [21]. Instead, it is important to analyze the product development process from a system perspective and design the performance measurement accordingly.

2.7.3 The product development measurement problem

The difficulty of measuring performance in product development is well documented in literature. In a review of the literature within industrial product development van Drongelen et al. [9] identified the following difficulties that characterizes the performance measurement problem in product development.

- Isolating the value of different contributions
- Intertwined efforts result in outcome
- Difficult to quantify benefits
- Asses spill over effects
- Matching inputs with outputs
- Lead time between effort and payoffs
- Difficult to benchmark two development projects

There is a difficulty of accurately isolating the contribution of the R&D department to overall company performance from the other business activities within the organization. It is always the intertwined efforts that eventually result in outcomes to the marketplace. Also, part of the benefits it generates is hardly quantifiable: e.g., giving the company a high-tech image may attract new highly competent employees. A related dimension is what economists call product development spill over effects; that is the difficulty firms have in capturing the benefits of new knowledge for themselves alone and the tendency for knowledge to flow across the firm and industry boundaries.

The problem of matching specific product development inputs in terms of money or man-hours and intermediate outputs e.g., research findings, new technologies, new materials, etc with final outcomes including new or improved products and processes. Moreover, there is also a time lag between a product development effort and its payoffs in the marketplace. This time lag is especially apparent in basic research, but also applies to applied research and product development projects. It is also difficult to compare and contrast two development projects, as they will always be different. The difference is stronger in more basic research projects compared to product development projects. This is also a problem when a firm wants to benchmark against competitors as many measurements are of subjective character.

2.8 Concluding discussion

The research area of performance measurement in product development are still young in an academic perspective, with scientists from different functional backgrounds doing research, making it difficult to attain a body of knowledge. Marchand and Raymond [87] argue that research is more problematic when the basic concepts and definitions that underlie a research area lack clarity, precision, and uniformity. Accumulating and integrating research results into a coherent body of knowledge is more difficult, as the lack of a common language end up making different studies less comparable [87]. Moreover, conceptual and definitional imprecision also makes it more difficult to import knowledge from other disciplines or fields, hence aggravating the possibility of a deeper understanding of the phenomena under study.

Since performance measurements research is characterized by researchers with different functional areas, it is important to attempt to bring the different functional research areas closer together. A rare attempt in this direction is the one provided by Andy Neely in his editing of the book Business Performance Measurement [4]. However, in his attempt of bringing different research disciplines tighter together the explicit focus of performance measurements in the product development process is forgotten or left out. Instead this perspective is partly overlapped by the marketing and operations management perspectives.

It has long been recognized that performance measurement has an important role to play in the efficient and effective management of organizations [88]. The need for companies to align their performance measurement systems with their strategic goals is well documented in the literature (e.g., [89, 90]). Kennerley and Neely [88] has 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. Moreover, there are certainly many success stories in aligning corporate strategy with performance measures [91], but there is also a growing literature addressing the difficulties of implementing performance measurement initiatives, e.g. [92, 93]. This could maybe be explained by the performance paradox, if you deliver, you only qualify to delivering more [66].

When reviewing the literature, few studies are found focusing on performance measurements in complex product development. The research studies performed with a product development context often focus on the development project, not on evaluating the performance from a holistic manager perspective. However, it is not surprising to find most research studies on the actual development project, since it is the most common way of organization product development activities. A project is set up for a limited period of time, necessary to achieve the set of objectives for the project. Second, the scope of a project is stated to be unique. Moreover, the scope of a project differs depending on the objectives to be met, hence, organizing the implementation activities of the product development process in a project setting, seem to be suitable. However, looking back at the proposed definition of product development, the value creation is mainly decided before the project scope is fixed and the project is set to be initiated. From a value perspective, focusing on the product development project only, the important aspects of maximizing the possible value may be missed out.

Chapter 3. Research Questions

During the two years of research presented in this thesis, several questions have intrigued and guided this research. This is illustrated in the appended research papers were the particular research questions for each particular paper is presented. The overall research question for this licentiate thesis will be presented in this chapter.

Robson [94] suggest the following characteristics to be important when designing research questions. The first is to be *clear* i.e., the questions posed are unambiguous and easily understood, but also *specific* meaning sufficiently specific to be clear what constitute an answer to the posed question. Research questions should also be *answerable*, in the sense of what data is needed to answer them and how the data can be collected. Moreover, it is important that the set of questions asked are *interconnected* in some meaningful way, but also *substantively relevant*, they should be worthwhile, non-trivial, and worthy of a research effort.

Ultimately this research aims to contribute to the following overall research question: *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 contribute to this question, four related research questions have guided this research. The first two questions involve the actual performance measurement system, while research questions three and four focus on exploring the different perceptions of performance in complex product development.

Research question 1. *How can a performance measurements system be evaluated from the perspective of a product development manager?*

From the literature review in Chapter 2 it is concluded that much research attention has been put on the design of new performance measurements systems. This research question instead focuses on the importance of designing a method for evaluating the evaluation system, since the performance measurement system is used to assess the current state of the performance, in order to decide on actions and to continuously improve the performance. With this perspective in mind the question of how the evaluation system is being evaluated becomes central. If the measurement system is not supporting the improvement of the development process, there is a strong chance that it is contra productive and hinders performance, instead of enabling it. In this research question a manger perspective have been chosen in order to emphasize a holistic company view to the evaluation process.

Research question 2. *How is performance measured within the development of complex products in Swedish industry today?*

This research question is important from both an empirical and theoretical perspective. In the literature there is a vast amount of different performance measurements available e.g., O'Donnell and Duffy [43] have compiled a list of different measures to be used in a product development context. However, as the frame of reference in Chapter 2 indicates there has not been any well established framework in industry besides the Balance Scorecard. This research question aims to explore and identify what is measured within complex product development industry in Sweden.

Research question 3. *How is performance in the development of complex products perceived by product development managers?*

Performance in complex product development is, in relation to other business process e.g., production, not a well defined concept. As concluded from the frame of reference in Chapter 2, no generally accepted definition of performance exists. With this in mind it is important to explore how performance is perceived within industry developing complex products. Performance in product development process is an ambiguous concept and high performance could mean different things within different settings. The perception of performance also influence what performance measurements can be used in order to measure the particular perception of performance.

Research question 4. *How can a conceptual model for reasoning about performance in complex product development be designed?*

There are many different aspects to performance in product development depending on the perspective and context, no commonly adopted definition of performance in complex product development exists. The definition of product development adopted in this thesis (see Section 2.1) aims towards a more holistic approach to the development process, were the product development process is viewed as a system. This is achieved by emphasizing the early activities when the decisions are made of what to develop and how it is going to be achieved. In literature few similar attempts are reported, especially in this perspective and context. With this in mind, it is interesting to explore how performance can be defined and modeled in a holistic systems perspective.

By answering these four research questions, the aim is to increase the understanding of performance and how it is measured within the process of developing complex products.

Chapter 4. Research Method

This chapter includes an overview of the research method, together with a brief presentation of the scientific approach adopted in this research. In the scope of this thesis, four conference papers have been written and they are appended in part two. In each paper there is a description of the research method applied in that particular paper. The chapter is concluded with a discussion of the general research strategy, as well as the overall validity.

4.1 Introduction

Research can be described as a systematic and organized effort to investigate a specific problem that needs a solution [95]. Leedy and Ormrod [96], 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. A research method is important when conducting research, since the aim of research is to contribute to our knowledge, it has to be carried out in a properly fashion. This is in contrast of studying, where the aim is to contribute one self's knowledge. Epistemological considerations are also important and often regarded more important than choosing research method. Moreover, what distinguishes scientists from non-scientist is not *what* they study but *how* they study [97].

4.2 Research approach

The term paradigm, originally from Kuhn [98], is used to describe the world view and mind set of researchers. The thought pattern in any scientific discipline is often referred to belong 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 changes 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.

In contrast to 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. Contrasting the hermeneutic paradigm where the world is viewed as a social construct.

Arbnor and Bjerke [99] propose three research approaches related to the two main paradigms in social science, i.e., positivism and hermeneutics, relevant for creating knowledge: the analytical approach, the systems approach, and the actors approach. The relation of these three approaches to the two paradigms is shown in Figure 12.

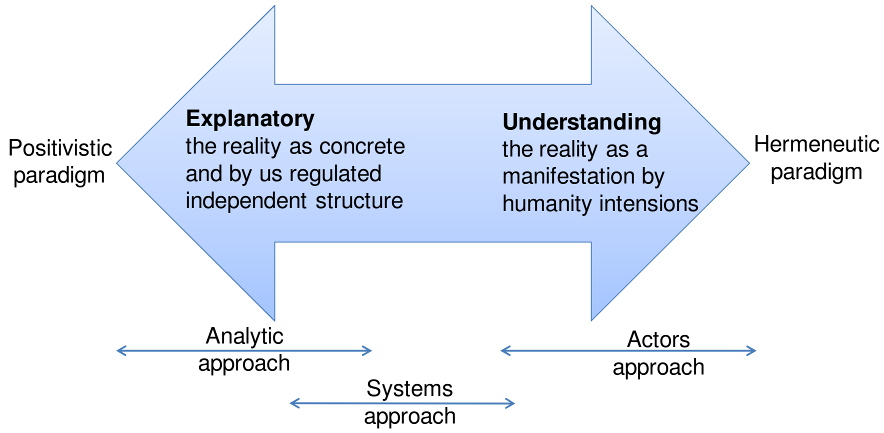

Figure 12. Different research approaches and their relation to different types of knowledge creation, adapted from [99]

The analytic approach has the perspective on reality as being concrete and conforming to laws. This approach is closely connected to explanatory knowledge creation. The actors approach has, in contrast to the analytic approach, a clear view on reality as a social construction and a manifestation of human intentionality. According to this approach knowledge is not objective; instead it is focused on understanding different social constructs.

The actors approach aims at exploring and understanding with focus on explaining, hence the actors approach is not suitable for this research. Moreover, according to the analytical approach, the world can be described by laws and the analytical 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. The analytical approach is therefore not a suitable approach for this research.

This research is instead closer related to the systems approach, developed during the 1950s as a response to the resistance to the analytical approach and its ineffectiveness in managing social problems within e.g., technical problems [100]. The systems approach aims at both explaining and understanding what forces the cause of a particular effect. Furthermore, the systems approach argues, in contrast to the analytical approach, 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 influence each other. This research agrees with the systems approach, since the product development environment is complex and constantly changing. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [101]. Hence, there is a need of adopting a holistic view as emphasized in the systems approach. Knowledge is obtained by acknowledging, not only cause and effect relations as in the analytical approach, but also through the interaction of human beings and their values and beliefs within a system.

4.2.1 Systems thinking

As an engineer it is easy to view the world in accordance with Newton physics [102], meaning that:

- Complete understanding of the universe is possible.
- The world can be understood through analysis i.e., breaking the whole into pieces and examine the parts separately.
- All relationships can be described through linear cause-and-effect.

The current worldview and the way we work is deeply influenced by the thinking that originated in the seventeenth century [103]. In systems thinking 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 [103]. However, mental models are difficult to discuss and some researchers argue that they are impossible to discuss. By thinking in terms of mental models of an individual or an organization and trying to understand and acknowledge them, it is possible to introduce and contribute to sustainable changes.

4.2.2 The importance of language

To understand any complex human activity we must first grasp the language and approach of the individuals who pursue it [104]. Language is indeed fundamental to any form of investigative enterprise [97]. In this research this has been approached in two parts; the first part involves the previous literature where a special focus has been on identifying definitions of the terminology used and this is presented in the frame of reference in Chapter 2; the second part is to investigate the use of the terminology in practice and therefore one of the reasons why pursuing an exploratory multiple case studies.

4.3 Qualitative and quantitative research methods

Within social science there has mainly been two basic categorize of research methods, *qualitative* and *quantitative* research. An important decision in regards to research method is whether to pursue a qualitative or quantitative oriented research method. When the purpose of the research is to explain and predict, confirm and validate, or to test theory, a quantitative method is suitable. In the past, quantitative research methods have dominated management research, much attention have been given to describing, coding, and counting events, often at the expense of why things are happening [105]. If the purpose on the other hand is to describe and explain, or explore and interpret, or to build theory, a qualitative research method may be more suitable.

Qualitative methods might concentrate on exploring in greater depth the nature and origins of people's viewpoints, or the reasons for, and consequences of, the choice of performance criteria [105]. Another advantage of the qualitative research approach is the possibility of considering the entirety in a way that is not possible with a quantitative approach. In the category of qualitative research, many methods and approaches such as case studies, politics and ethics, participatory inquiry, interviewing, participant observation, visual methods, and interpretive analysis exists [106].

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 [96]. Since this research is about exploring how performance is perceived and how performance measurements is being used within complex product development it is natural to pursue a more qualitative approach.

Few studies seem to emphasize qualitative research methods in order to increase the understanding of performance in product development by more in depth studies. 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. To this research stream is the research carried out by PDMA (Product Development Management Association), see e.g., [19, 38, 107-111], and the studies by APQC (America Productivity and Quality Center), see e.g., [32, 33, 49-51], typically good examples of. In a review of 16 years of product development research, Page and Schirr [20] found that the dominant form of quantitative empirical research, the single-informant, cross-sectional survey where the data came primarily from recall, remains subject to memory and survivor bias.

4.4 Explorative case study design

The foundation of this research project is multiple explorative case studies conducted at five of the participating companies. An exploratory case study approach may be especially suitable for learning more about a little known or poorly understood situation [96]. The decision to use multiples case studies was also influenced by this research being founded by seven companies developing complex products. Moreover, the research questions asked in Chapter 3 are more explorative in their nature, making case studies appropriate. The objective with the multiple explorative case studies, other than answering the presented research questions, was to get a broad understanding of the needs and difficulties of measuring 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 [112]. A case study research strategy focuses on understanding the dynamics present within a single setting [113] and may therefore be suitable for exploring the perception and measurements of performance in complex product development. The aim of the multiple exploratory case studies is to get a deeper understanding of especially the planning and implementation processes within products development. This broad understanding will then serve as the foundation for further research.

In Figure 13 an overview of the explorative case study design applied to each of the five case companies is presented.

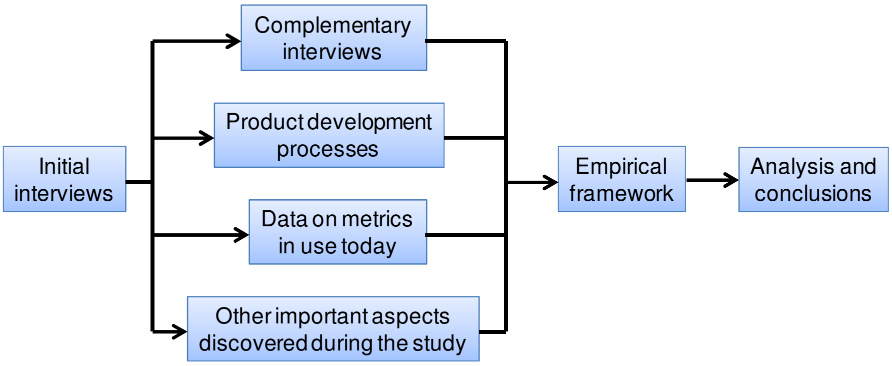

Figure 13. Explorative case study design

4.4.1 Data collection

The major source of data collection was through interviews as illustrated in Figure 13. The data collection was also performed by reading e.g., internal documents, organizations charts, and data on performance measurement currently used. An important aspect of this case study design is the *other important aspects discovered during the studies* (see Figure 13) depending on the case company. Explorative case studies, compared to most quantitative research methods, makes it possible to have an initial general research design, but also customize some parts of the study according to what is discovered along the discoveries of the research.

A total of 54 semi-structured interviews with open questions have been held at the five case companies. As shown in Figure 13, some of the interviews were performed in the initial interview phase and others, when necessary, in the complementary interview phase. At first an initial set of respondents were chosen together with the senior manager representing the company in the steering committee. During these interviews additional respondents were identified and interviewed when necessary. This selection of respondents represented the case company at most occasions. Only in some of the cases companies further respondents were identified. An important observation from the interviews was to include respondents with different roles within the product development process. A project manager and a product manager could have very different views of what is important, since they view the product development process from different perspectives.

During the first two case companies, the interviews were recorded and the transcription was sent back to the respondents in order to verify that nothing had been misunderstood or missed-out during the interview. The use of a recorder was accepted by all respondents, except one interview at the first case company. Moreover, only two respondents had any complaints with the transcription and some small changes were adopted accordingly. Case company 3-5 the interviews were conducted by two researchers, one taking notes and one asking questions. This interview method proved positive in most aspects. It became possible to discuss the overall impressions from the interview afterwards. Hence, increasing the quality of the analysis of each interview, but also of the overall analysis of the case company as well as comparisons cross cases. Also the time consuming process of transcribing from tape was decreased.

The analysis of the interviews began with data reduction into common categorize related to the questions posed during the interviews. In this way one complete document with the different answerers to the different questions related to the category was collected. Hence, it was possible to overview and make direct comparisons of the answers from the different respondents. In this way it also became possible to overview the results from each case company and compare the analysis between cases.

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 perspective. The respondents were all managers and decision makers at different levels of responsibility within the organization. Every interview lasted between 50 minutes and 2 hours. The main difficulty for the interviews was finding time for the interviews; all of the respondents have important roles within the organization and with tight schedules.

The study was initially performed in a sequential manner, with one case at the time. A process that was beneficial in the beginning but it turned out to be very time consuming because of the difficulty of finding time for the interviews. It was therefore decided to conduct the other cases more in parallel as shown in Figure 14.

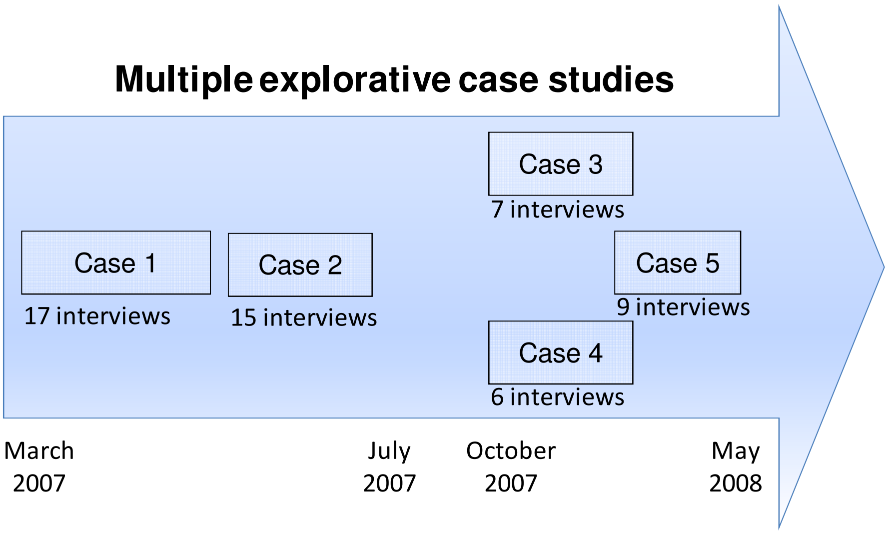

Figure 14. Multiple explorative case studies

4.5 Presentation of the case companies

Access to the real world is often cited as one problematic issue regarding management studies. In this research access has not been an issue, since relevant case companies already were involved in this research, and it was natural to select the cases from the participating companies.

This research has been conducted in close cooperation with international companies developing complex products in Sweden. The participating companies are not competing on each other's markets and have different products in their portfolio. However, they all have in common that they share similar difficulties and challenges in their endeavor for a high performing product development process and be able to measure its' performance. All of the five case companies are divisions within a larger corporate group, and all of these corporate groups belonged to the Fortune 500 list in July 2007 [114], hence they are all well established firms with success in their particular market.

The five case companies 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.

Two of the case companies are developing products that are sold to an external customer while the other three develop products that are more of a platform or a standard product. This platform is often delivered to another division within the firms, adding an application specific solution in order to deliver a specific solution to the end customer. The products often have long life time and the development work is characterized by a more evolutionary context rather than radical. However, there are also completely new products developed but often is a new part or a function developed and then integrated to one or several products.

4.6 Steering committee meetings

During this research there have been a total of seven steering committee meetings in order to report the progress made in the project. Also, the aim of these meetings has been to validate early research results in order to keep the research relevant for the participating companies. At some occasions these meetings have been more of a workshop in character. By using these meetings as a way of discussing findings and proposals they have been a good way of triangulating the research findings. Moreover, these steering committee meetings have had a positive and constructive atmosphere and proven to be a good forum for these senior managers to ventilate and discuss issues within their organization. The tone has been positive and constructive at these meetings.

Having seven companies actively participating in this research have been important, since this research is of inductive nature and the steering committee meetings have been a vital part of the empirical nature of this research.

4.7 Literature review

An important part of all scientific work is to search for previous research in the literature. The importance of a literature review is often to improve and more clearly understand the research problem, and to see what other attempts have been like. However, it is important to acknowledge the role of the literature review in research to be considered a mean to an end, not an end itself [37]. Yin [112] argue that more experienced researchers usually review previous research in order to develop sharper and more insightful questions about a topic.

In this research a grounded theory [115] inspired approach has been adopted especially in the literature review. In this research the literature search has been a natural part along the research journey depending on the direction of the findings from the multiple explorative case studies. This is due to the vast literature available, since this is a broad, not well defined, research area with no common body of knowledge. However, some authors argue that there are some indications of one starting to be established [20]. The main sources of previous literature were found in 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 found by using keywords like product development, performance, and performance measurement. However, since the literature search was conducting in a longitudinal way throughout the research project, there were many different key words used depending on the motive of the search. Since the previously mentioned journals were identified as important a more longitudinal study of these journals was performed by reading the title and abstract in all the issues for the last decade. The literature review also included books, often identified from the reference list of the journal articles.

4.8 Some notes on the research journey

As argued by Eisenhardt [113] it is important when entering an under-researched area in an exploratory manner, that the research needs to be guided by emergent empirical findings. This has truly been the case in this research and the final result as displayed in this thesis is in accordance with Figure 15. However, the research results presented in this thesis is the output of a research process that has hardly been as linear and structured as displayed here.

Figure 15 present the relation of the conference papers to the initial workshop and the multiple explorative case studies. What is missing in Figure 15 is the continuous literature review undertaken along the complete research process. This has been important since this topic is vast but also diverse, with no common body of knowledge, making it difficult to make one final literature review. Instead the literature has been scanned continuously throughout the research activity.

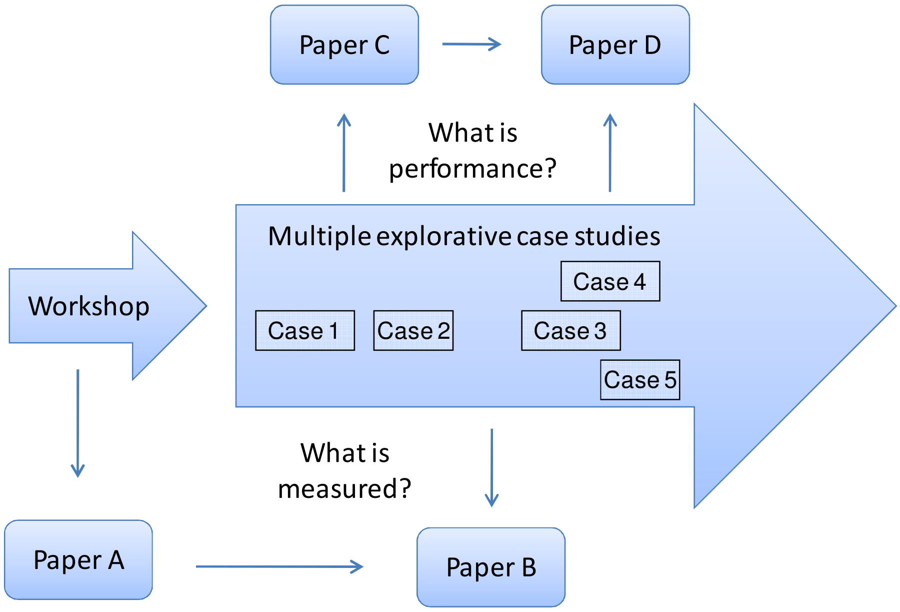

Figure 15. An overview of the research journey in this thesis

As the research journey illustrates, this research began with an initial workshop in order to identify what senior management identified as important success factors for complex product development. This workshop together with an initial literature review was the foundation for the first conference paper, Paper A. The results from this workshop became the initial foundation for designing the multiple exploratory case studies that was initiated shortly after the workshop. During the exploratory case studies a deeper understanding was developed and the need for defining performance was identified and thus the foundation for Paper C and D was made. Moreover, the framework for performance in complex product development presented in Paper A was then further developed into a matrix, with the purpose of evaluating the currently used performance measurement systems. This was then further developed, in Paper B, into a conceptual tool that can be used to evaluate what is and what is not measured by the performance measurement system.

This research process has consequently been inductive since the results have been developed from an empirical base. Since there is a lack of research focusing on how to measure performance in complex product development, it has been beneficial to base the understanding on induction. In this way pre-understanding has been limited and focus has been to establish a substantial understanding of what is important, from an industry point of view, when it comes to performance and performance measurements in complex product development. In this research the ambition has been to contribute to earlier deduction-based research grounded in qualitative descriptive evidence from multiple explorative case studies. Hence, my data collection and analysis was based on induction [113]. However, this research could also have taken a more deductive approach by basing the study of a reconfiguration of previous theories and assumptions that could be verified in case studies or by using a more quantitative approach. Since this research will continue towards a doctoral degree it has been natural to begin with an inductive research approach.

4.9 Evaluation criteria and validity

Most authors within the academic literature agrees that evaluation of qualitative research is necessary, but there is little consensus about what the evaluation should consist of [115]. One issue related to this is of the concept of validity, generalization, and reliability, initially developed within the context of traditionally fixed designs used to collect quantitative data; its applicability for more flexible designs with qualitative data has therefore been questioned [94]. Moreover, knowledge developed according to a systems approach does not become general in the same absolute way as knowledge developed in accordance with the analytical approach [116].

Thomas [117] argue for the following criteria for evaluating case studies; *Justification*, why was the strategy adopted? Is it appropriate to the problem? Was the intention to describe, explain or both? *Selection*, how many cases were used? How were they selected? Why these cases? If access to a site was required, how was this obtained? *Ethics, w*as it necessary to disguise the identity of the cases? Where there any other ethical difficulties? *Data*, what data were obtained, from what resources and by what methods? *Analysis*, how were the data organized and summarized? Was cross-case analysis possible? *Presentation*, has a coherent and convincing account of the study been written? How has the presentation been organized?

When validity of a research study is considered, two basic types are traditionally proposed i.e., internal and external validity [96]. However, there is some critique against this way of validating qualitative research. Instead it has been suggested that words like credibility, dependability, confirmability, verification, and transferability should be used instead of validation [96].

In this research an evaluation approach is used by adopting four dimensions of validity based on Robson [94] and Yin [112]; construct validity, internal validity, external validity, and reliability.

4.9.1 Construct validity

The construct validity is about ensuring that the construction of the use cases or interviews, actually relate to the problem you wish to discuss, and that the chosen sources of information are relevant. In this research multiple sources of information have been used in accordance with the case study design shown in Figure 13. The respondents have also been selected in discussion with the senior manager representing the company in the steering group. By selecting the respondents in this way and searching for further respondents from the initial interviews, have ensured that the interviews have related to the right problem. Moreover, respondents have reviewed the interview material to further ensure the construct validity.

4.9.2 Internal validity

The internal validity is to ensure that the actual conclusions made are true. For example if the conclusion is that X causes Y to happen when it in fact is the unknown factor Z that actually causes Y. This is one difficult task to validate and no guaranties can ever be made. However, to strengthen the internal validity the questions asked during every interview were stated in an open way, to minimize the possibility of affecting the answer of the respondent. By approaching the interviews in this way the respondents could discuss what they think is important. This approach also minimizes the possibility of affecting the data while collecting it. Moreover, the number of respondents were not decided beforehand but were dynamic according to what was identified for every case company. Other ways of strengthening the internal validity of this research could e.g., be to increase the sample size and this could be done in a larger quantitative study. Something that is further discussed in Chapter 7 and this will also be considered in the next phase of this research.

4.9.3 External validity

The external validity or generalizability regards the generalization of the research results. Are the conclusions made valid for other areas then the one studied i.e., are results from one case company also valid at other case companies and maybe in a general context. This can either be assured by theory or replicate case studies at other companies in different areas. Yin [112] propose to use analytical generalization for case studies, meaning that the result should be compared with existing theory. By comparing with established theory there can be support or not for the proposed findings. In this research, that has been explorative in nature, this has been performed in order to identify research gaps. Moreover, in this research seven companies from different domains have been involved and the resulting tools are conceptual, hence general in their nature in order to be able to adapt them according to different contexts. These tools can therefore only be validated by having the conceptual tools proven in practice.

4.9.4 Reliability

The reliability or conclusion validity concerns the ability for others to draw the same conclusion when analyzing the case study and the interview material. One way in handling this can be to use proper documentation of the study. The aim of the study has not been to end up in a general result that could be attained by any other researcher. Every interview has been documented in a way that makes it impossible to identify the respondent, which may make it a bit more difficult to reach exactly the same conclusions. Also all information available during an interview, can be difficult to document e.g., the openness of the respondent, the tone of the interview etc. Factors like this may be influential of how the findings are interpreted. The use of triangulation [105] in terms of e.g., related literature and other documentations from the case companies may be easy to replicate, but steering group meetings etc. has not been documented and may therefore be difficult to use in a replication purpose. During the case companies 3-5 two researchers were present during every interview, one asking questions and one taking notes. The discussions after an interview, when analyzing the interview material have been beneficial since at some occasions we have not totally agreed about the findings. This way of analyzing the interviews have increased the reliability of presented research.

Chapter 5. Research Results

This chapter presents the results from this research. The presentation summarizes results from the appended papers and is structured according to the research questions posed in Chapter 3. A more extensive and detailed presentation of the research results can be found in the four conference papers appended in part two of this thesis. The chapter is concluded with a brief overview of the relation between the conference papers and how they relate to the research questions.

5.1 How can a performance measurement system for product development be evaluated?

The first research question presented in Chapter 3 is:

How can a performance measurements system be evaluated from the perspective of a product development manager?

This is an important question that is rarely studied in literature. The aim of the performance measurement systems is to be able to evaluate the performance of the product development process within an organization in order to decide on actions to improve it. The findings show that if a process is to be evaluated it is important to have a clear understanding of where the process starts and ends. With this in mind the definition of the product development process presented in Chapter 2.1 is adopted.

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

It is concluded from this holistic definition of the product development process to categorize it, from a performance evaluation perspective, into activities involving: *Planning*, *Implementation,* and *Marketing, Sales, and Delivery* of a product. This categorization is illustrated in Figure 16 and a more extensive presentation is made in paper A and B.

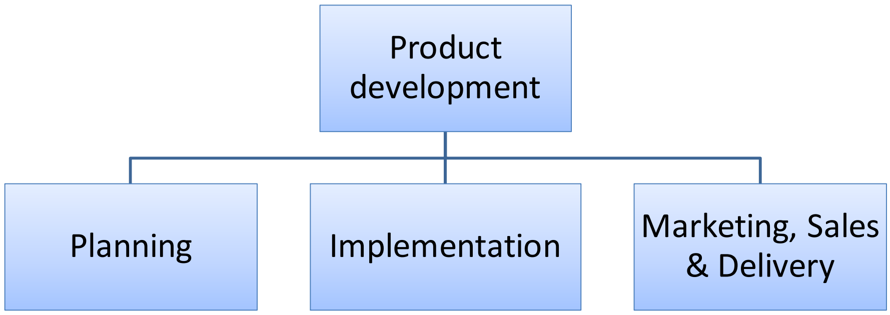

Figure 16. Categorization of product development from a performance evaluation perspective

Planning involves all the activities related to what to develop, and the development project has been approved and the activities related to Implementation begins. In this research it is concluded that when performance in the product development process is discussed, focus turns to the Implementation activities often missing out on the activities within Planning. In paper A it is concluded that when product development is to be measured it is important to acknowledge the fact that there are different objectives within these three categorizes of the product development process. Performance of the product development process can be expressed as a function of the effectiveness and efficiency of the *Planning, Implementation, and Marketing, Sales and Delivery* activities. Moreover, in paper A it is argued that the product development process cannot be considered successful, in a company perspective, until all three categorize have been completed successfully and a product has been delivered to the customer. However, the Marketing, Sales, and Delivery activities were not further investigated for limitation reasons.

First, in order to evaluate a performance measurement system it is important to understand which the important success factors for complex product development are. This categorization of the product development process was used as input to a workshop as presented in Chapter 4, with the objective of identify important success factors for the Planning and Implementation activities. According to the initial workshop with the steering committee, the important success factors for the Planning activities can be categorized according to: *Why*, *What*, *How*, and *When*. The categorization of the important factors for the Implementation activities on the other hand were categorized according to: *Technology*, *Management*, *Process*, *People*, and *Process*. In Paper A and B a more detailed description of the success factors within these categorize are presented.

Second, in order to evaluate a performance measurement system it is not just the important factors for success that are important, but also when the actual measurements is made. This is important because a measurement can mean different things depending on when the actual sampling is performed. In general, the earlier a performance measurement is conducted, the possibility of taking appropriate actions in order to manage the product development project in the wanted direction increases. It is suggested that early performance measurements enable the possibility of finding the root cause of why something occurred. The need for early performance measurements can e.g., be illustrated by the measurements of change orders of a delivered product to customers. If the number of severe change orders increases it is difficult to identify the root causes, since it can be explained by several factors e.g., the code review process was not performed as intended or the customer has started using the product in a novel way etc.

As described in Chapter 2.1 it is common to use some kind of Stage-Gate model in the product development process. The Stage-Gate model can be used to represent the time perspective of a development project. Hence, it was decided to let the stages of the general Stage-Gate model represent the timing of when the measurement is performed. Combining this time representation with the important success factors for complex product development resulted in the Performance Measurement Evaluation Matrix (PMEX). The PMEX, presented in Paper B and in Figure 17, has the different phases of the Stage-Gate process as one dimension representing when a measurement is performed. The other dimension of the PMEX, the identified success factors in the development of complex products, represents what is important to measure in order of having a successful product development process.

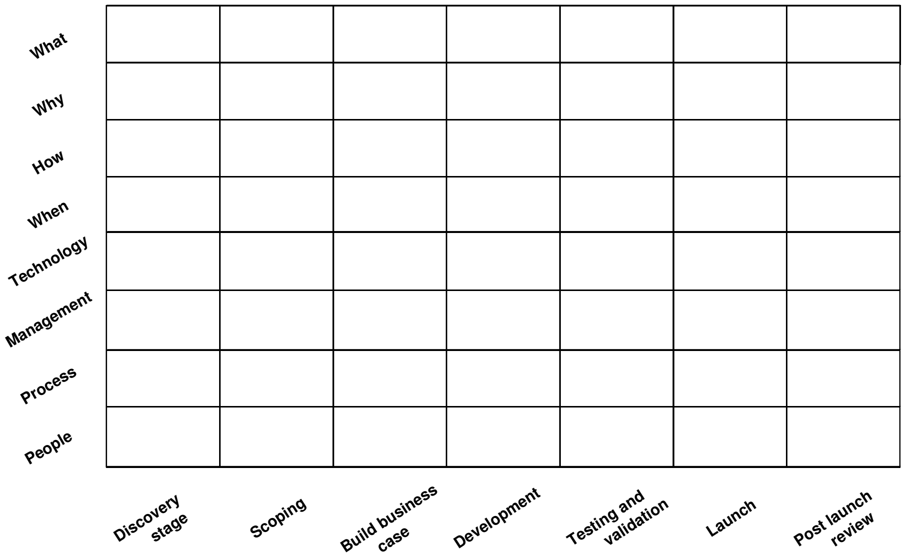

Figure 17. The Performance Measurement Evaluation Matrix (PMEX)

In paper B the success factors identified for complex product development in this research were compared to the success factors found in literature. An important finding was that the role of technology as a success factor for product development is often overlooked. It is concluded in this research that it is common for research studies not to have an explicit focus on the development of complex products [9, 10, 34, 38, 108, 111, 118-120].

The PMEX can be used as a holistic conceptual tool for managers to evaluate what is measured and what is not measured by the current performance measurement system.

5.2 What is measured within complex product development?

In order to ameliorate the use of existing performance measurements systems it is important to understand what is currently measured. The second research question presented in Chapter 3 is

What is measured by the performance measurement system within the development of complex products in industry today?

This is an interesting question since the literature often is focused on designing new performance measurements. In order to evaluate what is measured the PMEX has been applied on two case companies. The result is shown in Figure 18. The different performance measurements are represented by stars and circles instead of the actual performance measure in order to focus on *what* is measured instead of the actual measurement.

The first result from applying the PMEX to the performance measurements used by the two case companies were that the majority of the measurements focused on the dimensions of cost, time, and quality. The PMEX was therefore extended accordingly. In Paper B the performance measurements used by the two case companies are further presented.

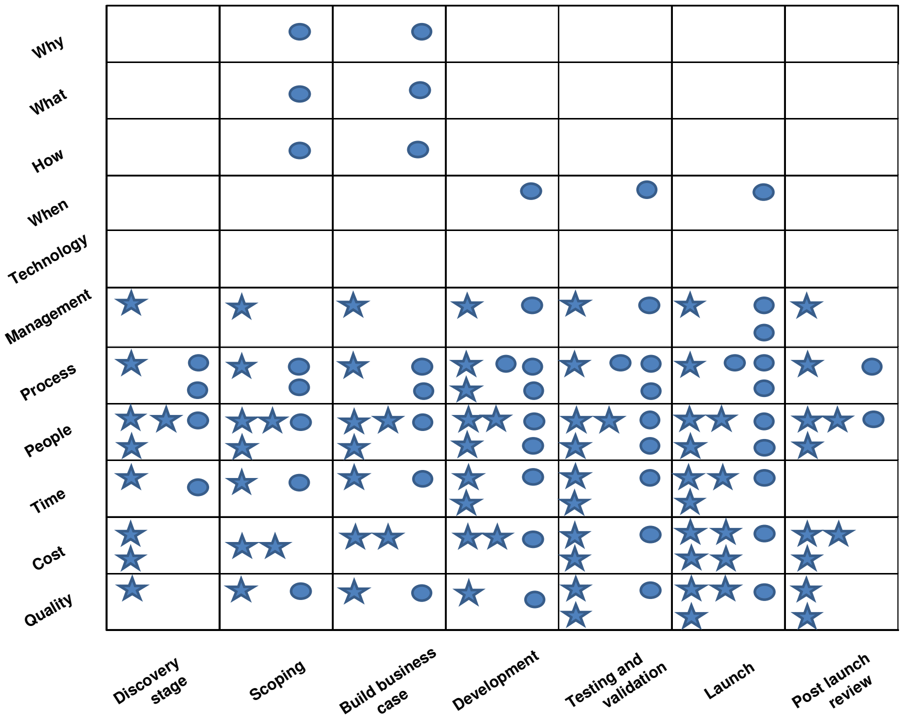

Figure 18. The PMEX illustrates what and when there are measurements present in the product development process for the two companies. The stars represent case company 1 and the circles represent case company 2.

As is shown in Figure 18, the performance measurement systems focus on the Implementation activities and the time, cost, and quality aspects, especially in the later stages of the development process. Findings show that measurements related to Implementation activities at the early phases of the product development process are missing. The Planning activities, on the other hand, are not measured at all by case company 1 and only sparsely by case company 2. There seems to be a strong potential for adding measurements for the planning activities. What is worrying though is that when the performance measurement system is focused on the Implementation activities, especially at the later stages of the product development, it cannot support the process, only report the end result. From the performed analysis it is concluded that the technology aspect is not measured by any of the two case companies. This is a bit surprising since technology was emphasized, by the participants, as important during the steering committee workshop.

The evaluation of the project post-launch is not performed in the two case companies. This is similar to the findings in [54] where there was an absence of a formal and regular post mortem evaluation with the objective of evaluating the product development process and providing information for potential transformation of the latter. This could be considered as a serious weakness in the operation of the performance measurement system because a post launch review is a crucial last step in the Stage-Gate model [30].

5.3 How is performance perceived within complex product development?

Performance is, as presented in section 2.4, an ambiguous concept. In product development, performance can easily be interpreted differently depending on the context. The third research question presented in Chapter 3 is

How is performance of the development of complex products perceived by product development managers?

As illustrated in Chapter 2 there are several different interpretations of performance in the literature and no commonly accepted definition is to be found. One reason for this is that the area of performance has challenged scholars from different functional backgrounds resulting in rich and deep streams of functionally specialized research, with little cross-fertilization. As a result, it is difficult for researchers to build on previous work.

In order to continuously improve the capability of developing new products it is important to be able to measure the performance in the product development process. The literature study and findings based on industry experience indicate the dilemma though, is that there are no commonly accepted performance measurements within product development. One reason, as concluded in this research, may be the lack of a common holistic perception of performance within the development process.

With this in mind a total of 54 semi-structured open interviews at five case companies regarding performance in complex product development, as presented in Chapter 4, were performed. The results indicate that performance is commonly perceived in terms of time, cost, and quality i.e., what is measured by the performance measurement system. Below, five typical citations of the perceptions of performance from the semi-structured open interviews are shown:

1) *Performance within product development is to do the right things, as quickly as possible, and with as low cost as possible.*

2) *Performance within product development is to work with process improvements to shorten the lead time and make sure that the whole chain is involved at the right time.*

3) *Performance within product development is to shorten cycle times, deliver on time, and reduce time to market. If you look at the calculations, the normal cash flow, cash in cash out, for a normal net present value calculation, it is clearly shown that it is important to reach a positive cash flow as quickly as possible. It is equivalent of having a short time to market. Quality is also important, we have high costs for everything that is delivered to a customer and not working properly.*

4) *If it took three years to develop a new product a couple of years ago, I would want it to take 6 months today. The processes and steps that are required to develop a new product shall be more efficient to decrease the lead time. The pace should be higher and higher. You get more development per spent SEK.*

5) *Performance within product development is about managing the four dimensions time, product cost, project cost, and quality within a project. Efficiency is about not having to redo things and focus on what creates value and doing things right. Effectiveness is about doing the right things and it is the product manager that decides what to develop. What to develop is seldom purely a R&D decision but more of a market strategy decision. This has a high effect on the performance of product development.*

These five citations of performance mainly reflect the efficiency aspect of the Implementation activities. The perspectives of effectiveness and the Planning activities are often forgotten. Citation 5 represents one of few respondents reflecting on performance with a more holistic perspective. One interesting observation is that only one of the five citations of product development performance relates it to value creation. Performance seems commonly to be perceived in terms of time, cost, and quality i.e., what is measured by the performance measurement system. It may be argued that the perception of performance has been influenced by what is measured, instead of the other way around, i.e., measure of what we perceive as important for performance. Thus, there is a clear need for changing this view of performance into a more holistic system perspective of performance.

5.4 How can a conceptual model of performance within complex product development be designed?

In order to improve and align the perception of performance within an organization, it may be beneficial to have a conceptual model to reason about the current performance of the product development process. The fourth and final research question presented in Chapter 3 is

How can a conceptual model for reasoning about performance in complex product development be designed?

In order to be able to answer this question the definition of what performance in product development is, has to be revisited. With the definition of product development, presented in Chapter 2 in mind, it is suggested to view the product development process as three generic levels of activities; *Product strategy*, *Project management*, and *Product activities*. The reason why these generic levels of activities are proposed is that they require different organizational capabilities in order to be successful. A high performing product development process in a company needs to be successful in all these activities. It is proposed in this research to model the product strategy, the project management, and the product activities as activities according to the IDEF0 model, as shown in Figure 3. By relating these generic levels of activities with the IDEF0 model the Product Development Organizational Performance Model (PDOPM) was constructed. This way of conceptually modeling the product development process as activities makes it possible to define efficiency, effectiveness, and uncertainty for each generic activity level. The PDOPM is presented in Figure 19 and in Paper C and D a more detailed description of the model can be found.

Each generic level of activity in the PDOPM uses resources to transform input to output, under the direction of goals and constraints. The goal of the product strategy activity is related to the business strategy and the output of the activity becomes the goal for the project management activity. Project management translates the goal into outputs that become goals for the product activities were the product is realized. This way of conceptually modeling the product development process makes it possible to define effectiveness, efficiency, and uncertainty for each activity level. Effectiveness can be expressed as how the output of the activity relates to the goal of the activities, whereas efficiency can be defined as the difference between output and input i.e., what has been created divided by the consumed resources. The uncertainty can similarly be viewed as the difference between the goal and the input. Hence, a measure of what is needed to be created by the activity in relation to what is already available in order to realize the goal.

Modeling the product development process with three generic levels of activities makes it possible for managers to conceptually discuss and analyze performance from these three perspectives. As illustrated in Figure 19, it is possible to define effectiveness, efficiency, and uncertainty for the three generic levels of activities in the PDOPM; thereby extending the traditional scope of efficiency and effectiveness, by explicitly defining them for the three generic levels of activities. Hence, it is possible to reason about e.g., the efficiency of the product strategy activities and the effectiveness in the product activities. In Paper C, the definitions of uncertainty, efficiency, and effectiveness at each generic activity level is further described.

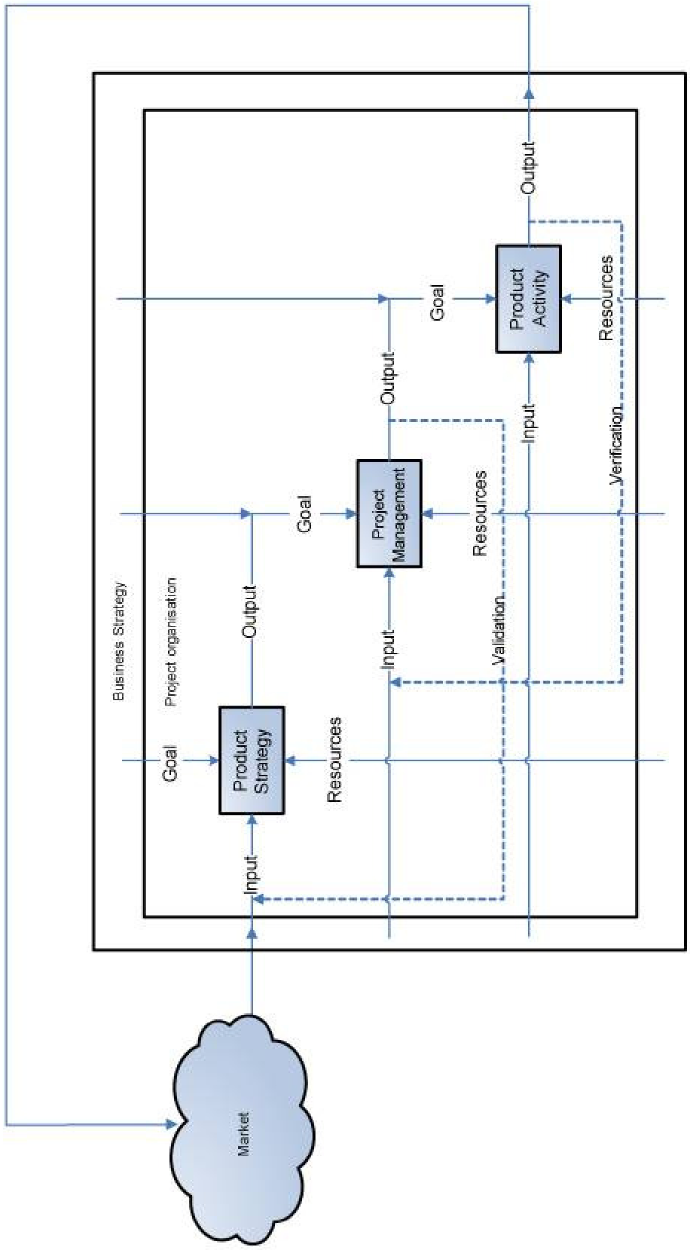

Figure 19. The proposed PDOPM model with the three generic levels of activities: product strategy, project management, and product activity

In Figure 20, the concept of effectiveness and efficiency is further extended by defining efficiency and effectiveness for the complete product development process. Product development effectiveness is defined as how the output of the product activities meets the goal of the product strategy. The goal of the product strategy is to fulfill the business strategy, thus, it is important that the output of the product strategy is in line with the business strategy. Product development effectiveness is an important foundation for a successful development process. Product development efficiency 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. Hence, product development efficiency is a measure of how the invested resources are used. Moreover, the product development efficiency is defined as ratio and can consequently be improved by increasing the denominator i.e., the output or decreasing the numerator i.e., the cost of the resources consumed by the activities. From the perceptions of performance in research question 3 it is concluded that much emphasis is on decreasing the cost while keeping the output level fixed. The highest leverage for increased efficiency can be achieved by considering both the output and resources consumed by the activity.

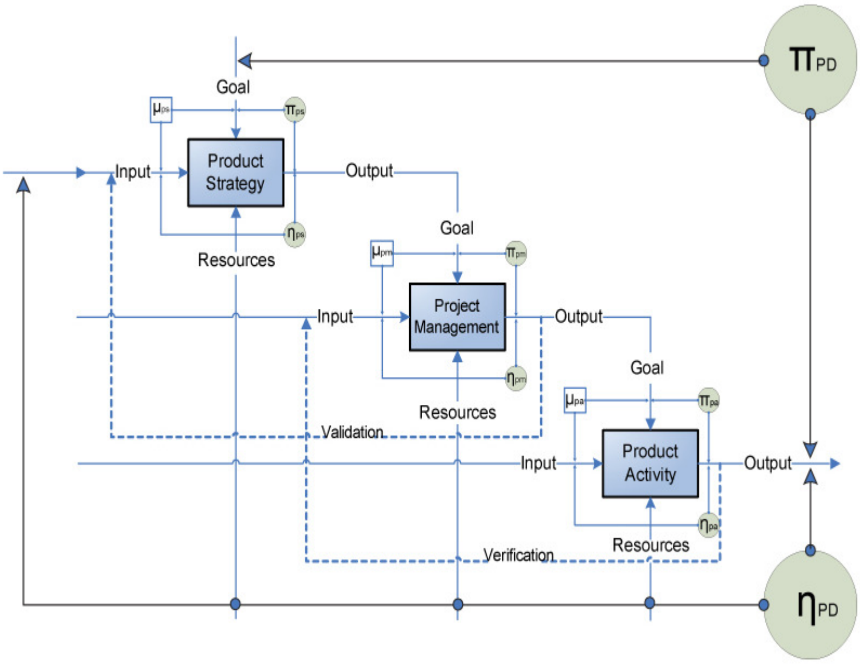

Figure 20. The PDOPM with effectiveness and efficiency for the product development process

The performance of the product development process depends on both the effectiveness and the efficiency of the performed activities in order to be successful. The triple constraint of time, cost, and quality is often used to evaluate projects [25], thus focus easily turns to the recourses and the output aspects of the product activities. Hence, the effectiveness and the value perspectives of what is being developed are missing or taken for granted.

One important finding from the perception of performance is the neglecting of the product strategy's role in product development performance. It seems that it is taken for granted that the right product is being developed. One reason may be in the limitations and ambiguity in the words describing performance. Thus, the term *product development efficacy* is introduced to describe the capability of identifying or creating a market opportunity and being able to develop and deliver a product fulfilling exactly what was identified as the market opportunity. Efficacy can be described as the ability of something, especially a drug or a medical treatment, to produce the results that are wanted [39]. Efficacy is often used in the sense of capacity or power to produce a desired effect.

The product strategy is important for high product development efficacy, since it is the balancing act between what is needed by the market and the internal capabilities within the organization when deciding what to develop. It is argued that if this is not performed successfully, it is difficult to be corrected within the project management and product activities. Moreover, it is concluded that product development efficacy can be viewed as the result attained through continuously managing the uncertainty, effectiveness, and efficiency in each of the three generic levels of activities in the PDOPM. If the customer needs changes during the development of a new product, it needs to be reflected in the product development project in order to secure that the right product is developed. High performance in the product development process is achieved when there is efficacy in the complete product development portfolio.

Every product development project target specific customers within a specific market and must manage certain market specific constraints, in order to be successful. Within the defense industry, for example, there may by a lead time of many years for a new product to be developed. In contrast to the mobile phone industry, where time to market is a very deciding factor on the success of a new product. In order to conceptually discuss these dimensions affect on performance, the verification and validation feedback-loops were included in the PDOPM. The validation loop represents the feedback from the output of the project management and it is modeled as an input to the product strategy. The validation loop can be viewed as a representation of the time to market constraint of the chosen customer needs. The task of developing the right product is often taken for granted and not questioned once a project is initiated. Within complex product development it is highly possible that the customer needs change during a product development project, especially when the cycle-time of a development project could be several years. Moreover, the validation loop influence the verification loop since, if there are changes in the customer needs, they must reflect the product development activities. The verification loop in the PDOPM is modeled as the feedback from the product activity output to the input of the project management activity. The verification feedback loop can 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 timeframe of the validation loop. If the targeted market is expecting 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 secure that the output from the product development project is aligned with the output from product strategy. If the selected customer needs have changed, it is important to understand these changes and act accordingly. The timeframe of the verification loop differs depending on the validation loop, as the verification timeframe is linked to the validation loop. Hence, changes in the market put constraints on the verification loop in order to fulfill the validation time frame. The validation and verification loops are further described in Paper C.

The holistic system view of performance in the product development process modeled in the PDOPM is to be seen as a way of conceptually discuss the current performance within an organization. By reasoning about the effect the product strategy, project management, and product activities have on the performance of product development process as a whole, decisions on actions can be made in order to improve performance.

5.5 How the research papers relate to the research questions

In the second part of this licentiate thesis four research papers have been appended. As Figure 21 illustrates, there are two main themes in the papers. In paper A and B the focus is on performance measurements and how the performance measurement system can be evaluated. The ambiguity of performance in product development and how it can be defined within the product development process is presented in Paper C and D.

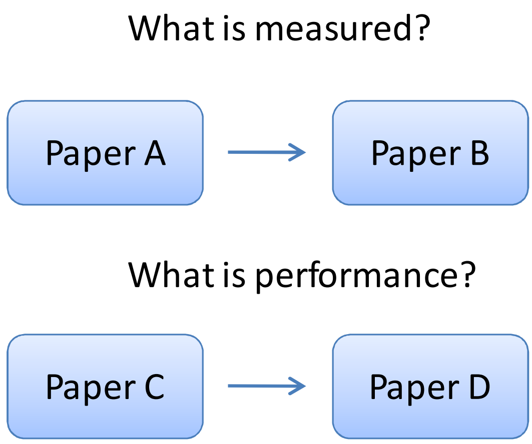

Figure 21. Relation between included research papers in this thesis

In Paper A the initial main ideas when the research project was initiated, is presented by proposing the concept of categorizing performance of the product development process into Planning, Implementation, and Marketing, Sales, and Delivery. In this paper, the first version of the developed framework was presented and it was also used in the explorative multiple case studies for verification and further development. Moreover, Paper B contributes to research questions 1 and 2 by further developing the framework presented in paper A by introducing the PMEX. A summary of how paper A-D contributes to the research questions is shown in Figure 22 below. Paper A does not explicitly relate to any of the research questions but it represents the first steps in the research journey and it was later developed into the PMEX in Paper B.

During the interviews in the explorative case studies it was concluded that there is confusion in terminology used and a strong need for developing and defining product development performance exist. This became the input that resulted in Paper C and D. In Paper C the PDOPM as a conceptual model for performance is presented, in an attempt to answer research question 4. Research questions 3 and 4 are treated in paper D where the perception of performance in the product development process is presented and product development efficacy is introduced as an attempt of defining performance in the product development process.

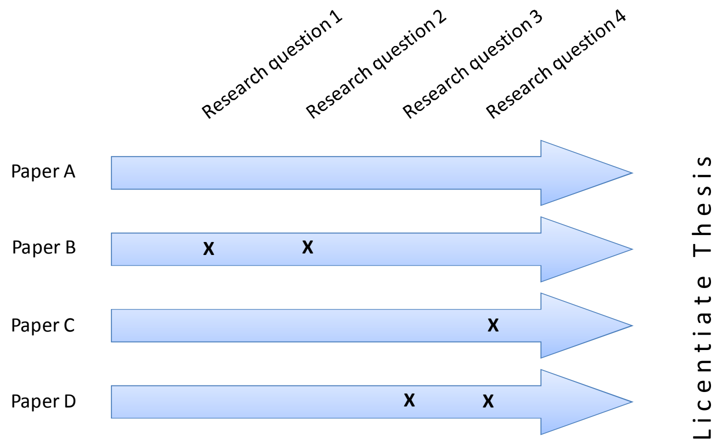

Figure 22. Illustration of how paper A-D contributes to the four research questions

Chapter 6. Reflections and Conclusions

This chapter will present reflections and conclusions made from the results in Chapter 5, since this research is ongoing and the results have only recently been developed there are limitations in the conclusions. Research is about creating knowledge and in this thesis the knowledge contribution is divided into implication for management and implications for theory. The chapter begins with some reflections of the Performance Measurement Evaluation Matrix (PMEX) and the Product Development Organizational Performance Model (PDOPM).

6.1 The Performance Measurement Evaluation Matrix (PMEX)

The PMEX is to be viewed as a conceptual tool to be used by managers within product development organizations, in order to evaluate and initiate discussions of what is measured and what the performance measurement system should and should not measure. This way of evaluating the performance measurement system makes it possible to holistically view what is currently being measured, something that could be problematic otherwise. The first result of using the PMEX was that time, quality, and cost had to be integrated to the PMEX, if the performance measurement system used by the case companies were to be include. During the steering committee workshop these dimensions where never explicitly discussed as important, in order to be successful in the Planning and Implementation activities. This is an indication of the performance measurement system not being designed for supporting the product development process.

Moreover, the first results from using the PMEX show a focus on measurements in the later phases of the product development process. This is when it is difficult or even too late to make any changes to what is currently being developed. In this sense it seems that performance measurements are not utilized in order to support managers in deciding on actions for improvements. Also, the Planning parts of the PMEX are not covered by any measurements at all by case company 1. In case company 2 there is only one measurement that is related to Planning. Thus, a potential for adopting new measurements from literature or designing new measurements exists.

Further, technology as a performance measure is not found in the case companies. This is a bit surprising since the case companies develop complex products and are highly dependent on the technology in their products. From what have been identified so far, using the PMEX is that there are no measures of technology or architecture at any of the five case companies. Despite the high influence the technology and the architecture can have on performance in specially the development of complex products with long life cycles. This development is evolutionary in its character, since it adds new features and changes to existing products. How the technology adopted in these products support this type of development is directly influencing the efficiency, but what and how a new function is to be implemented, is also affected.

One difficulty with the PMEX is how to treat performance measurements that are not directly related to one particular phase of the product development process. This can be, measurements of e.g., if the objective with job rotations within the department has been met or how many hours of the total hours that are spent in development projects. These two measurements could be measured at any time during the development, and has therefore been illustrated in the PMEX at all squares along the timeline. However, this could instead be treated by introducing one extra dimension to the PMEX, to illustrate the supporting functions that are not project specific.

Moreover, the PMEX is to be viewed as a conceptual tool in order to evaluate the performance measurement system. It is possible to add or withdraw any of the success factors depending on the context the PMEX is to be used in. This can also be done for the time dimension; e.g., it is suggested to add the application specific version of the Stage-Gate model used by the company, instead of the general one as is presented here.

6.2 The Product Development Organizational Performance Model (PDOPM)

The PDOPM provide managers within product development with a conceptual tool, to be used in order to facilitate a holistic way of analyzing the current state of performance in their development process. In order to identify strong and more problematic areas that needs to be improved. It is concluded in this research that there is a tendency to further improve what is already well functioning, while the more difficult issues are not dealt with. In this respect the PDOPM can be used in order to pinpoint the root cause of a current issue by analyzing the activities in terms of input, output, resources, and goal in the activity model. One important aspect of the PDOPM is within the arrows connecting the activities, since it describes the relation between different activity levels that themselves have different objective. Moreover, different resources are usually involved in different activities, making knowledge transfer of great importance in order for the product development process to have high performance. Having the PDOPM as a conceptual tool to facilitate discussions is important in order to pinpoint areas were improvements needs to be made.

In industry it is common for management to look for easy solutions to boost performance in the product development. Hence, focus is often turned to the efficiency of the product activities in order to improve the overall product development performance. In this research it is suggested that performance in the product development process is achieved through three steps. The first step is to manage the uncertainty, since it represents the knowledge of what needs to be created to fulfill the goal. The second step is to secure effectiveness, in order to create the right product. The third step is to focus on efficiency, once the first two steps are established. In this research it is argued that performance is attained when uncertainty, effectiveness, and efficiency is managed at all the three generic levels of activities in the PDOPM.

6.3 Implication for management

This research project has been conducted in close cooperation with seven companies developing complex products. Focus has been on, not only contributing to academia but also contribute to managers within product development. Every manager within product development wants to improve the performance of the company's product development process. Performance measurements are important in order to support management with the information needed, i.e., to assess the current state, and decide on actions in order to improve the performance of the product development process. Within both case companies it is common for development projects to be late and over budget. However, from the interviews a strong desire to improve performance and an openness to introduce new performance measurements within the product development process were identified. This may be the result of having development activities moved to low cost countries or overall awareness of the increasing competitiveness in the market. However, few ideas exist of how to improve the measurement of performance. This is in line with other studies in the literature, e.g., in a multiple case study with ten participants, all of them wanted to improve their use of performance measurements, but they did not know how [57]. This phenomenon is difficult to explain and for that reason difficult to change, but it may be the reason why nothing changes. One attempt of explaining why this type of behavior exist, is made by the framework developed by von Stamm [78], shown in Figure 23. According to this framework it is easy to end up with an insufficient understanding of a task, due to a lack of analysis that is the result of the assumption and beliefs together with habits.

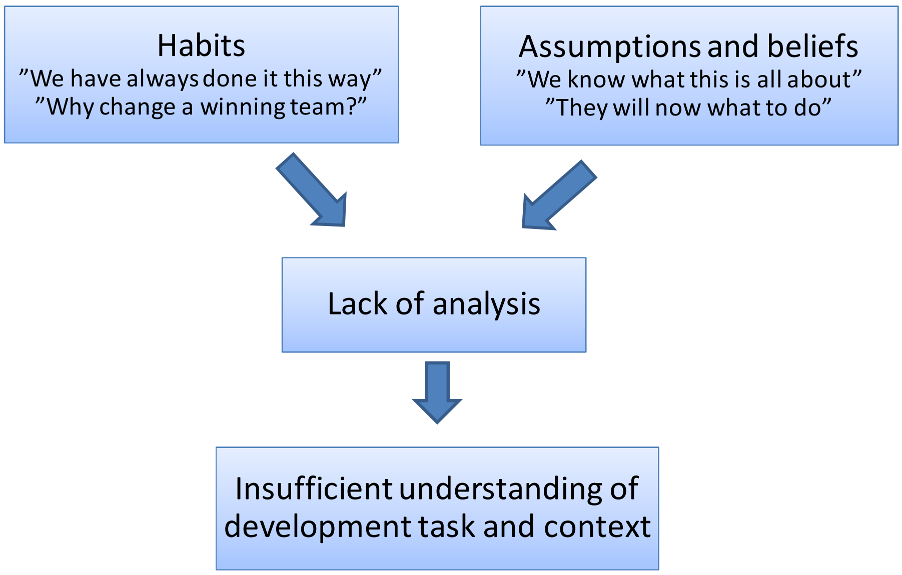

Figure 23. Consequences of habits and assumptions [78]

This may particularly be the case within complex product development were there often is a strong architecture or platform as the basis of the product. A platform or architecture is intended to be reused within 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, as proposed by von Stamm [78]. A performance measurement system could be used in order to detect if such a situation is present within the organization. If this type of behavior can be detected it may be possible to improve the situation.

The framework proposed by von Stamm, illustrates the difficulties that needs to be handled before any changes to the product development process can be made. According to this it is the *habits*, and *assumptions and beliefs* that cause many issues within product development. This is also supported in a study performed by Sengupta et al., [121], where they 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 [101]. With this in mind the PMEX and the PDOPM developed in this research can be used in overcoming this step.

6.4 Implication for theory

Within the academic research field, the process of developing products is treated mainly through the perspectives of marketing and operations management. This is especially true when it comes to 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 for having the terminology more unified and less diverse. As been discussed in Chapter 2.8, 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 more research with the aim of unifying the basic concepts and definitions. Moreover, as emphasized in this thesis, further research with a more holistic system approach to performance measurements in especially complex product development is needed. Few research studies have adopted a holistic view to the product development process, as defined in this research, within the area of complex product development.

Balance Scorecard is the only performance measurement framework today that has reached a wide audience and been adopted by industry. One reason why no other frameworks or models have been adopted by industry may also be explained by the framework in Figure 23. Von Stamm [78] argues that habits together with assumptions and beliefs contribute to the lack of analysis. Hence, the need for adapting academic tools for performance measurements is never identified by industry and the tools that are developed in academia never reach a wide audience.

Moreover, there is a lack of attention in the early activities of the product development process and how they can be measured. There seems to be a clear need for further research focusing on evaluation and measurements addressing the early phases of the product development process. The planning i.e., deciding on what to develop is not specifically mentioned in existing literature, focus tend to be on input, process, and output and outcome relate measurements.

In this research it is concluded that the product development process cannot be considered successful in a company perspective until the product has been delivered to the customer. This partly contradicts the product development process proposed by Ulrich and Eppinger [22], were the product development process ends with production ramp up.

Technology as a success factor is not explicitly found in literature of performance measurements in product development. This is a bit surprising since there are a lot of companies developing complex products and they are highly dependent on the technology in their products. This is something that needs further research, to address the role of the technology adopted, on the overall performance of the product development.

Chapter 7. Future Work

In this chapter a discussion about possible future work is made, since this is a licentiate thesis, this research will continue. The aim of most research is to provide an answer to one or several research questions. However, research has a tendency to also reveal new research questions. It is not unusual to end up with more unanswered questions then answered, since this research is explorative and inductive in its nature this becomes even more evident.

7.1 The multiple explorative case studies

The foundation for this research is multiple exploratory case studies. From these studies both the PDOPM and the PMEX have emerged. However, there has not been a complete analysis of all the 54 interviews at the five case companies. There have been continues analysis of the interviews from the case studies, but it is important to finalize an overall analysis of the complete case study, with cross case analysis, in order to identify further issues that are associated with performance and performance measurements in complex product development. If further issues related to performance and performance measurements are identified these could be studied in a broader quantitative study, through e.g., a questioner. It would also be interesting to see how other companies within other countries work with performance measurements in complex product development, to see if the same findings are also present outside Sweden.

7.2 Evaluating performance measurement systems

The PMEX matrix developed in this research has only been verified as presented in paper B and further work to more formally test the PMEX is needed. This verification and validation will be extended to also include the other case companies. Moreover, looking into the concept of using technology as a performance measurement in complex product development is interesting. There is no dispute over the important role technology have on the performance of the product development process in this context. Looking back in history there are many examples of companies struggling or even going bankrupt when there are changes in the technology.

7.3 Modeling performance in product development

The PDOPM has shown great potential so far as a conceptual tool for especially managers within product development to asses and discuss performance in product development, in a more balanced and holistic way. However, like the PMEX, the PDOPM has not been formally validated and would benefit from a more formal validation process. However, validating the PDOPM can only be done by using the conceptual model in practice. Another suggestion has been to adopt the terminology of the PDOPM according to the terminology used in the Project Management Book of Knowledge [25].

In Paper C and D, the PDOPM is presented in a general manner in order to be used by managers as a starting point in conceptual discussions about performance. There is a potential in making the PDOPM more case specific depending on the organization it is to be used in. This could be important in order to adopt the specific terminology used within the organization, hence be able to integrate the model together with the other tools and processes used within the product development process.

7.4 Designing new performance measurements

The first results of using the PMEX show that there are few performance measurements within the early phases of the product development process. It is within these activities it is decided what to develop, hence the value of what is to be developed is decided. Consequently all the measurements after this activity are all about realizing the value that has been decided in the Planning part of the product development process. With this perspective in mind there is a need to shift focus in order to have early process measures of the development process.

The PMEX is a conceptual tool that can be used to evaluate the performance measurement system; the PDOPM is a conceptual tool to be used to reason about performance in product development. Moreover, the PDOPM could also be used as a way of defining new performance measurements in areas identified by the PMEX. Designing performance measurements from the PDOPM could be performed by formulating more explicitly what the output, input, resources, and goal are, at the different activity levels. This could also be interesting to combine with an organization specific version of the PDOPM, as proposed in 7.3. This engage the interest since then the performance measurements would be related to the perception of performance and not the other way around that may be the case today.

7.5 Illustrating the value in the product development portfolio

An important concept for evaluating performance within manufacturing is *work in progress* i.e., products that are within the manufacturing process and will be delivered to a customer. The concept of work in progress makes it possible to calculate the value progress of the products along the production process. However, a high performing manufacturing process is managed towards minimizing the capital tied up in work in progress, since production is a capital intensive process. Instead the objective is to produce as much output as possible using as little capital as possible. The aim of the production process is to optimize the process i.e., minimize the value of the current work in progress.

The concept of work in progress in manufacturing has no similarity within product development. In this research it is argued that by introducing the concept of *products in development* it would be possible to assess a value to the products that are in the development. This would be welcomed, because as concluded in this research it is easy to translate high performance in the product development process into time and cost minimization. In this simplification the important aspect of optimizing the value creation over the portfolio i.e., the ability of creating as much value as possible given a specified investment is easily forgotten.

One possible way of illustrating the value creation might be to use the business case, as is normally collocated in order to decide on project approval. However, it is common to forget the business case once the project has been initiated. In a first attempt, the activities that are adding value to the developed product can be assigned a value in accordance with the business case. In doing this it becomes possible to illustrate the value creation in the process of developing products. Hence, products in development could be used in a way of securing that the business case is being fulfilled, that the right product is being developed, and that the intended value really is created. It is important to remember that the product development process is characterized by uncertainty and there cannot be any definite statements as within manufacturing. However, since the uncertainty of the development process decrease as the development progresses, the uncertainty of the value creation also decreases. Hence, this could be a promising attempt of managing the product development process and it can be summarized in order to cover the complete development portfolio. In Figure 24 a value creation perspective of the product development process is proposed. Product development is inherently an uncertain process and the value creation must be managed accordingly i.e., in an estimating manner. However, as the product approaches market launch the uncertainty decreases and the estimation becomes stronger. This concept of products in development can be a promising novel attempt on managing the value in the product development process. A successful product development portfolio is all about balancing the value creation with the available resources and capabilities.

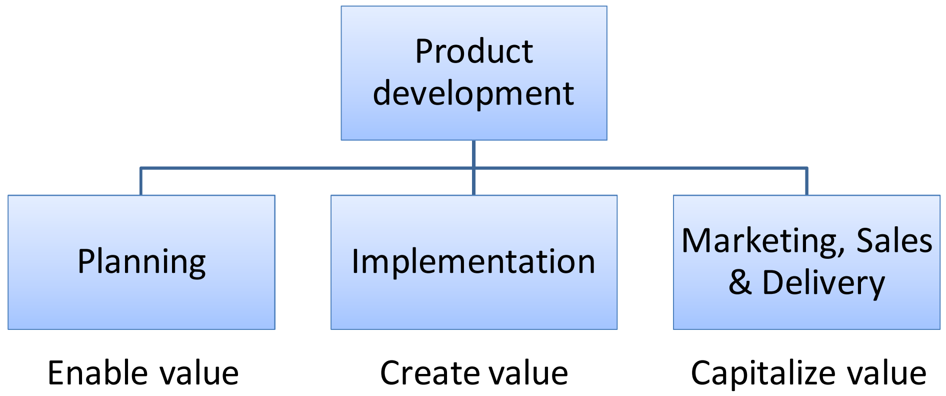

Figure 24. A value creation perspective on the product development process

References

[1] P. F. Drucker, "The New Productivity Challenge," *Harvard Business Review,* vol. 69, pp. 69-80, 1991.

[2] V. Chiesa and C. Masella, "Searching for an effective measure of R&D performance," *Management Decision,* vol. 34, pp. 49-57, 1996.

[3] C. Loch, L. Stein, and C. Terwiesch, "Measuring development performance in the electronics industry," *The Journal of Product Innovation Management,* vol. 13, pp. 3-21, 1996.

[4] A. Neely, *Business performance measurement*, 2 ed. Cambridge: Cambridge University Press, 2007.

[5] R. Katila, "Measuring Innovation Performance," in *Business Performance Measurement - Unifying theory and integrating practice* 2ed, A. Neely, Ed. Cambridge: Cambridge University Press, 2007.

[6] D. S. Sink and T. C. Tuttle, *Planning and Measurement in your Organisation of the Future*. Norcross, GA: Industrial Engineering and Management Press, 1989.

[7] R. G. Cooper, *Product leadership: Pathway to profitable innovation*, 2 ed. New York: Basic Books, 2005.

[8] A. Syamil, J. Doll William, and H. Apigian Charles, "Process performance in product development: measure and impacts," *European Journal of Innovation Management,* vol. 7, pp. 205-217, 2004.

[9] I. C. Kerssens-van Drongelen, B. Nixon, and A. Pearson, "Performance measurement in industrial R&D," *International Journal of Management Reviews,* vol. 2, pp. 111-143, 2000.

[10] R. Adams, J. Bessant, and R. Phelps, "Innovation management measurement: A review," *International Journal of Management Reviews,* vol. 8, pp. 21-47, 2006.

[11] A. H. Rubinstein, "50 Years of Engineering and Technology Management," *IEEE Transactions on Engineering Management,* vol. 51, pp. 407-408, 2004.

[12] T. D. Kuczmarski, "Five fatal flaws of innovation metrics," *Marketing Management,* vol. 10, pp. 34-39, 2001.

[13] B. Regnell, R. B. Svensson, and T. Olsson, "Supporting Roadmapping of Quality Requirements," *IEEE Software,* vol. 25, pp. 42-47, 2008.

[14] M. Hobday, "Product complexity, innovation and industrial organization," *Research Policy,* vol. 26, pp. 689-710, 1998.

[15] C. Easingwood, S. Moxey, and H. Capleton, "Bringing High Technology to Market: Successful Strategies Employed in the Worldwide Software Industry," *The Journal of Product Innovation Management,* vol. 23, pp. 498-511, 2006.

[16] R. G. Cooper and S. J. Edgett, "Maximizing productivity in product innovation," *Research Technology Management,* vol. 51, pp. 47-58, 2008.

[17] T. Davila, M. J. Epstein, and R. Shelton, *Making innovation work - How to manage it, measure it and profit from it*. New Jersey: Wharton School Publishing, 2006.

[18] J. P. Gonzalez-Zugasti, K. N. Otto, and J. D. Baker, "Assessing value in platformed product family design," *Research in Engineering Design,* vol. 13, pp. 30-41, 2001.

[19] A. Griffin, "PDMA research on new product development practices: Updating trends and benchmarking best practices," *The Journal of Product Innovation Management,* vol. 14, pp. 429-458, 1997.

[20] A. L. Page and G. R. Schirr, "Growth and Development of a Body of Knowledge: 16 Years of New Product Development Research, 1989-2004," *The Journal of Product Innovation Management,* vol. 25, pp. 233-233, 2008.

[21] M. G. Brown and R. A. Svenson, "Measuring R&D Productivity," *Research Technology Management,* vol. 31, pp. 11-16, 1988.

[22] K. T. Ulrich and S. D. Eppinger, *Product design and development* 3ed. Singapore: McGraw-Hill Education, 2003.

[23] V. Krishnan and K. T. Ulrich, "Product Development Decisions: A Review of the Literature," *Management Science,* vol. 47, pp. 1-21, 2001.

[24] R. Stevens, P. Brook, K. Jackson, and S. Arnold, *Systems Engineering - Coping with Complexity*. Hertfordshire, UK: Prentice Hall, 1998.

[25] PMBOK, *A guide to the project management body of knowledge*. Newton Square, Pennsylvania, USA.: Project Management Institute 2004.

[26] S. Carlson-Skalak, *Implementing Concurrent Engineering in Small Companies*. New York, USA: Marcel Dekker Inc, 2002.

[27] M. M. Andreasen and L. Hein, *Integrated Product Development*: Springer-Verlag, 1987.

[28] M. Norell, "Stödmetoder och samverkan i produktutveckling: Advisory tools and co-operationin product development." vol. PhD Stockholm, Sweden: KTH, 1992.

[29] D. Malvius, "Information Management for Complex Product Development," in *Machine design*. vol. Licentiate thesis Stockholm: KTH, 2007.

[30] R. G. Cooper, "Stage-Gate Systems: A New Tool for Managing New Products," *Business Horizons,* vol. 33, pp. 44-55, 1990.

[31] R. G. Cooper, "Perspective: The Stage-Gate® Idea-to-Launch Process - Update, What's New, and NexGen Systems," *The Journal of Product Innovation Management,* vol. 25, pp. 213-213, 2008.

[32] R. G. Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Optimizing the stage-gate process: What best-practice companies do-I," *Research Technology Management,* vol. 45, pp. 21-27, 2002.

[33] R. G. Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Optimizing the stage-gate process: What best-practice companies do-II," *Research Technology Management,* vol. 45, pp. 43-49, 2002.

[34] A. I. Jiménez-Zarco, M. P. Martínez-Ruiz, and Ó. González-Benito, "Performance measurement system (PMS) integration into new product innovation: A literature review and conceptual framework," *Academy of Marketing Science Review,* vol. 10, 2006.

[35] J. E. Ettlie and J. M. Elsenbach, "Modified Stage-Gate® Regimes in New Product Development," *The Journal of Product Innovation Management,* vol. 24, pp. 20-20, 2007.

[36] F. J. O'Donnell and A. H. B. Duffy, "Modelling design development performance," *International Journal of Operations & Production Management,* vol. 22, pp. 1198-1221, 2002.

[37] S. Tangen, "Evaluation and revision of performance measurement systems," in *Department of Production Engineering*. vol. PhD Stockholm: KTH, 2004.

[38] A. Griffin and A. L. Page, "An interim report on measuring product development success and failure," *The Journal of Product Innovation Management,* vol. 10, pp. 291-308, 1993.

[39] S. Wehmeier, A. S. Hornby, and C. McIntosh, in *Oxford Advanced Learner's Dictionary of Current English*. vol. 7: Oxford University Press, 2005, p. 1907.

[40] A. Neely, M. Gregory, and K. Platts, "Performance measurement system design: A literature review and research agenda," *International Journal of Operations & Production Management,* vol. 25, pp. 1228-1263, 2005.

[41] R. Cordero, "The Measurement of Innovation Performance in the Firm: An Overview," *Research Policy,* vol. 19, pp. 185-193, 1990.

[42] G. J. Colquhoun, R. W. Baines, and R. Crossley, "A State of the Art Review of IDEF0," *International Journal of Computer Integrated Manufacturing,* vol. 6, pp. 252-64, 1993.

[43] F. J. O'Donnell and A. H. B. Duffy, *Design Performance*. London: Springer Verlag, 2005.

[44] K. Kurosawa, *Productivity Measurement and Management at the Company Level: The Japanese Experience*. Amsterdam: Elsiver, 1991.

[45] D. J. Sumanth, *Productivity Engineering and Management*. New York: McGraw-Hill, 1994.

[46] M. Jackson, "An analysis of flexible and reconfigureable production systems - An approach to a holistic method for the development of flexibility and reconfigurability " in *Department of mechanical engineering*. vol. PhD Linköping: Linköping university, 2000.

[47] H. J. van Ree, "The added value of office accommodation to organisational performance," *Work Study,* vol. 51, pp. 357-363, 2002.

[48] V. Ojanen and M. Tuominen, "An analytic approach to measuring the overall effectiveness of R&D-a case study in the telecom sector," in *Engineering Management Conference, 2002. IEMC '02. 2002 IEEE International*. vol. 2, 2002, pp. 667-672 vol.2.

[49] R. G. Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Benchmarking best NPD practices - I," *Research Technology Management,* vol. 47, pp. 31-43, 2004.

[50] R. G. Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Benchmarking best NPD practices - II," *Research Technology Management,* vol. 47, pp. 50-59, 2004.

[51] R. G. Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Benchmarking best practices - III," *Research Technology Management,* vol. 47, pp. 43-55, 2004.

[52] M. Franco-Santos, M. Kennerley, P. Micheli, V. Martinez, S. Mason, B. Marr, D. Gray, and A. Neely, "Towards a definition of a business performance measurement system," *International Journal of Operations & Production Management,* vol. 27, pp. 784-784, 2007.

[53] N. Slack, S. Chambers, and R. Johnston, *Operations Management*, 5 ed.: Pearson Education Limited, 2007.

[54] A. Godener and K. E. Soderquist, "Use and impact of performance measurement results in R&D and NPD: an exploratory study," *R & D Management,* vol. 34, pp. 191-219, 2004.

[55] A. Neely, "The evolution of performance measurement research: Developments in the last decade and a research agenda for the next," *International Journal of Operations & Production Management,* vol. 25, pp. 1264-1277, 2005.
[56] C. Meyer, "How the right measures help teams excel," *Harvard Business Review,* vol. 72, pp. 95-102, 1994.
[57] H. Driva, S. Pawar Kulwant, and U. Menon, "Performance evaluation of new product development from a company perspective," *Integrated Manufacturing Systems,* vol. 12, pp. 368-378, 2001.
[58] B. Creech, *The Five Pillars of TQM: How to Make Total Quality Management Work for You*. USA: Penguin Group 1995.
[59] B. Bergman, K. Magnusson, and D. Kroslid, *Six SIGMA the Pragmatic Approach*, 2 ed. Lund, Sweden: Studentlitteratur AB, 2004.
[60] M. B. Chrissis, M. Konrad, and S. Shrum, *CMMI: Guidlines for process integration and product improvement*. Westford, Massachusetts Addison Wesley, 2007.
[61] R. S. Kaplan and A. A. Atkinson, *Advanced Management Accounting*, 3 ed. Upper Saddle River, New Jersey: Prentice Hall, 1998.
[62] V. Chiesa and F. Frattini, "Exploring the differences in performance measurement between research and development: evidence from a multiple case study," *R & D Management,* vol. 37, pp. 283-283, 2007.
[63] L. W. Steele, "Evaluating The Technical Operation," *Research Technology Management,* vol. 31, pp. 11-19, 1988.
[64] E. Mankin, "Measuring Innovation Performance," *Research Technology Management,* vol. 50, pp. 5-7, 2007.
[65] R. G. Eccles, "The performance measurement manifesto," *Harvard Business Review,* pp. 131-131, 1991.
[66] J. McGregor, "The performance paradox," *Fast Company,* pp. 29-30, 2005.
[67] H. B. Cohen, "The performance paradox," *The Academy of Management Executive,* vol. 12, pp. 30-40, 1998.
[68] D. P. Keegan, R. G. Eiler, and C. R. Jones, "Are Your Performance Measures Obsolete?," *Management Accounting,* vol. 70, pp. 45-51, 1989.
[69] A. Neely, M. Kennerly, and C. Adamas, "Performance measurment frameworks: a review," in *Business Performance Measurement - Unifying theory and integrating practice*, 2 ed, A. Neely, Ed. Cambridge: Cambridge university press, 2007.
[70] R. L. Lynch and K. F. Cross, *Measure Up: The essential guide to measuring business performance measures*. London: Mandarin, 1991.

[71] M. G. Brown, *Keeping score: Using the right metrics to drive world-class performance* New York: Quality Resources, 1996.
[72] K. F. Pun and A. S. White, "A performance measurement paradigm for integrating strategy formulation: A review of systems and frameworks," *International Journal of Management Reviews,* vol. 7, p. 22, 2005.
[73] R. S. Kaplan and D. P. Norton, "The Balanced Scorecard measures that drive performance," *Harvard Business Review,* vol. No. January-February, 1992.
[74] M. Bourne, J. Mills, M. Wilcox, A. Neely, and K. Platts, "Designing, implementing and updating performance measurement systems," *International Journal of Operations & Production Management,* vol. 20, pp. 754-754, 2000.
[75] B. Paranjape, M. Rossiter, and V. Pantano, "Performance measurement systems: successes, failures and future - a review," *Measuring Business Excellence,* vol. 10, p. 12, 2006.
[76] W. G. Bremser and N. P. Barsky, "Utilizing the balanced scorecard for R&D performance measurement," *R & D Management,* vol. 34, pp. 229-238, 2004.
[77] A. Neely, C. Adams, and P. Crowe, "The performance prism in practice," *Measuring Business Excellence,* vol. 5, pp. 6-12, 2001.
[78] B. v. Stamm, *Managing innovation, design and creativity*. Chichester, England: John Wiley and Sons Ltd, 2003.
[79] T. Kumpe and P. T. Bolwijn, "Toward the innovative firm - Challenge for R&D management," *Research Technology Management,* vol. 37, pp. 38-45, 1994.
[80] M. E. McGrath and M. N. Romeri, "FROM EXPERIENCE The R&D Effectiveness Index: A Metric for Product Development Performance," *Journal of Product Innovation Management,* vol. 11, pp. 213-220, 1994.
[81] I. C. Kerssens-van Drongelen and A. Cook, "Design principles for the development of measurement systems for research and development processes," *R & D Management,* vol. 27, pp. 345-357, 1997.
[82] J. R. Hauser and F. Zettelmeyer, "Metrics to evaluate R,D&E," *Research Technology Management,* vol. 40, pp. 32-38, 1997.
[83] B. M. Werner and W. E. Souder, "Measuring R&D performance - State of the art," *Research Technology Management,* vol. 40, pp. 34-42, 1997.
[84] E. J. Hultink, A. Griffin, S. Hart, and H. S. J. Robben, "Industrial new product launch strategies and product development performance," *The Journal of Product Innovation Management,* vol. 14, pp. 243-257, 1997.
[85] D. Robertson and K. Ulrich, "Planning for product platforms," *Sloan Management Review,* vol. 39, pp. 19-31, 1998.

[86] G. S. Lynn, "New product team learning: Developing and profiting from your knowledge capital," *California Management Review,* vol. 40, pp. 74-93, 1998.

[87] M. Marchand and L. Raymond, "Researching performance measurement systems: An information systems perspective," *International Journal of Operations & Production Management,* vol. 28, pp. 663-686, 2008.

[88] M. Kennerley and A. Neely, "A framework of the factors affecting the evolution of performance measurement systems," *International Journal of Operations & Production Management,* vol. 22, pp. 1222-1245, 2002.

[89] D. Amaratunga and D. Baldry, "Moving from performance measurement to performance management," *Facilities,* vol. 20, pp. 217-223, 2002.

[90] M. J. Gregory, "Integrated performance measurement: A review of current practice and emerging trends," *International Journal of Production Economics,* vol. 30-31, pp. 281-296, 1993.

[91] M. Bourne and M. Wilcox, "Translating strategy into action," *Manufacturing Engineer,* vol. 77, pp. 109-112, 1998.

[92] A. Neely and M. Bourne, "Why measurement initiatives fail," *Measuring Business Excellence,* vol. 4, pp. 3-7, 2000.

[93] M. Bourne, A. Neely, J. Mills, and K. Platts, "Why some performance measurement initiatives fail: Lessons from the change management literature," *International Journal of Business Performance Management,* vol. 5, pp. 245-269, 2003.

[94] C. Robson, *Real world reserach* 2ed. Oxford, UK: Blackwell Publishing, 2002.

[95] U. Sekaran, *Research methods for business: A skill-building approach*, 2 ed. New York: John Wiley & Sons, 1992.

[96] P. D. Leedy and J. E. Ormrod, *Practical Research: Planning and design*, 8th ed. Upper Saddle River: Pearson Education, 2005.

[97] A. B. Thomas, *Research concepts for management studies*. New York: Routledge, 2006.

[98] T. S. Kuhn, *The structure of scientific revolutions*. Chicago: Chicago University Press, 1970.

[99] I. Arbnor and B. Bjerke, *Methodology for Creating Business Knowledge*. USA: Sage Publications, 1997.

[100] S. Elfving, "Managing collaborative product development - A model for identifying key factors in product development projects," in *Innovation, design and product development*. vol. PhD Västerås: Mälardalen university, 2007.

[101] P. M. Senge, *The Fifth Discipline, the Art & Practice of Learning Organizations*. New York: Currency Doubleday, 1990.

[102] R. L. Ackhof, *Ackhof's best: Classic writings on mangement*. New York: Wiley, 1999.
[103] K. E. Maani and R. Y. Cavana, *Systems thinking, system dynamics: Managing change and complexity*, 2 ed. Rosedale, New Zealand: Pearson, 2007.
[104] F. N. Kerlinger, *Foundation of behavioral research* New York: CBS College Publishing 1986.
[105] M. Easterby-Smith, R. Thorpe, and A. Lowe, *Management research - An introduction*, 2 ed. London: Sage Publications, 2002.
[106] N. K. Denzin and Y. S. Lincoln, "Introduction: The discipline and practice of qualitative research," in *The landscape of qualitative research- Theory and issues*, 2 ed, N. K. Denzin and Y. S. Lincoln, Eds. Thousand Oaks: Sage publications, 2003.
[107] A. Griffin, "Product development cycle time for business-to-business products," *Industrial Marketing Management,* vol. 31, pp. 291-304, 2002.
[108] A. Griffin and L. Page Albert, "PDMA success measurement project: Recommended measures for product development success and failure," *The Journal of Product Innovation Management,* vol. 13, pp. 478-496, 1996.
[109] K. B. Kahn, *The PDMA handbook of new product development*, 2 ed. Hoboken: John Wiley & Sons, 2005.
[110] K. B. Kahn, G. Barczak, and R. Moss, "PERSPECTIVE: Establishing an NPD Best Practices Framework," *Journal of Product Innovation Management,* vol. 23, pp. 106-116, 2006.
[111] A. L. Page, "Assessing new product development practices and performance: Establishing crucial norms," *The Journal of Product Innovation Management,* vol. 10, pp. 273-290, 1993.
[112] R. K. Yin, *Case Study Research: Design and Methods*, 3 ed. Thousands Oaks, California: Sage Publications, 2003.
[113] K. M. Eisenhardt, "Building Theories from Case Study Research," *Academy of Management Review,* vol. 14, pp. 532-550, 1989.
[114] CNNMoney.com, "Furtune Global 500." vol. 2008: CNN, 2007.
[115] J. Corbin and A. Strauss, *Basics of qualitative research 3e*, 3 ed. Thousand Oaks, 2008.
[116] R. Olsson, "Managing Project Uncertainty by Using An Enhanced Risk Management Process." vol. Doctoral Västerås: Mälardalen University, 2006.
[117] A. B. Thomas, *Research skills for management studies*. London: Routledge 2004.

[118] H. Ernst, "Success Factors of New Product Development: A Review of the Empirical Literature," *International Journal of Management Reviews,* vol. 4, pp. 1-40, 2002.

[119] S. L. Brown and K. M. Eisenhardt, "Product development: Past research, present findings, and future directions," *Academy of Management. The Academy of Management Review,* vol. 20, pp. 343-379, 1995.

[120] R. G. Cooper, "From Experience: The invisible success factors in product innovation," *Journal of Product Innovation Management,* vol. 16, pp. 115-133, 1999.

[121] K. Sengupta, T. K. Abdel-Hamid, and L. N. Van Wassenhove, "The Experience Trap," *Harvard Business Review,* vol. 86, pp. 94-101, 2008.

PART TWO

APPENDED PAPERS

PAPER A

A Productivity Framework for Innovative Product Development

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Abstract

Innovative product development (IPD) give companies the competitive advantage required to be successful in the highly competitive market of today. The natural question is: how do you make your organization as effective as possible in the IPD process? This paper presents a framework to reason about the subject of productivity in the IPD process. The framework is deducted from the definitions of innovation and product development, an effective IPD process contains three parts; Planning (what to develop), Implementation (product realization) and Marketing, Sales and Delivery. Success comes from acknowledging the fact that there are different objectives within the three parts. The productivity of the IPD process can be expressed as a function of the efficiencies of Planning, Implementation and Marketing, Sales and Delivery. This paper is the first qualitative result of research together with seven high-tech industrial companies, with the goal to find what is required to be efficient in the Planning and the Implementation process. The key factors for success as well as some general conclusions are presented in this paper.

Keywords

Innovation, Product Development, Core Competence, Productivity Measures, R&D

1. Introduction

Every company strives for sustainable growth and improved productivity in order to maximize their output per unit of input. Sustainable growth is the most elusive goal a company faces [1]. The traditional way of increasing productivity is to focus on and improve the processes that are easy to measure in monetary terms like manufacturing. As a result there are plenty of metrics related to productivity in the operation process [2], [3]. However, in innovation and new product development there are not as many productivity measurements available, even though the total R&D spending in the 1000 largest companies in the world in the year 2002, exceeded one quarter of a trillion dollars [4]. Today the stock market has become interested in new product development metrics such as the new product sales of total sales [5].

The difficult task of translating promising ideas of new products into monetary terms has forced companies to view their R&D spending as a cost rather than an investment. Accounting rules require that R&D spending is treated as a cost; even though in the economic reality it is more of an investment [6]. Due to the same reason, R&D productivity measures are almost nonexistent. Research in the US reveals that only 52 percent of the total spending on new product development is made on projects that are financially successful [7]. If a factory showed similar result it would not last, at least not with the present management. Important to remember is the fact that it is those 52 percent that will have to account for 100 percent of the R&D spending. An increase in the success rate of new product development will therefore increase the future revenues and decrease the cost load, which will be positive for a company's profit.

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."[8]. Today, when top management is surveyed, their priorities in order are: finance, sales, production, management, legal and people, missing from the list, marketing and innovation [9].

To be able to reason about innovation and product development productivity in large complex high-tech industrial companies, this paper introduces a holistic framework for innovative product development (IPD) that enables higher productivity and efficiency. Moreover this paper outlines different aspects of what is needed to succeed with IPD. A holistic view of the IPD enables the recognition that there are several different competences and understandings needed for the IPD process to be successful. The IPD framework, proposed in this paper, is developed together with managers within seven international high-tech industrial companies active in Sweden all having genuine experience in developing complex industrial systems within telecommunications, automotive and automation. This research is qualitative and includes workshops and interviews.

The outline of the paper: In chapter 2 is innovation and product development defined and a productivity framework for IPD is deducted. This framework is further developed in chapter 3. In chapter 4, IPD productivity is discussed and the paper ends with conclusions and future work in chapter 5.

2. Innovation and Product Development

Innovation and product development are often discussed without proper definitions. The word innovation has its origin in the Latin word nova meaning new. In an abstract way innovation can be defined as:
"Innovation is the embodiment, combination, or synthesis of knowledge in original, relevant, valued new products, processes or services." [10]

We define innovation as the implementation of a creative idea and benefit from doing it. To be creative means to look at issues in a novel way and an idea can be described as a recipe for dealing with an issue. This implies innovation, to solve an issue in a new way, but the key for it to be an innovation is to benefit from it in some way. Invention and innovation are closely related but with some distinction. An invention is the result of a creative idea or concept, while innovation is the process of turning the invention into a commercial success [11].

The term product development, just like innovation, is often used without proper definition. In this paper we take a holistic view on product development agreeing with the following definition:

"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." [12]

Product development is therefore a process that must involve all departments at a company and not just the engineering as it is traditionally. What is also noticeable is that innovation and product development are similar. In this paper we introduce innovative product development to describe the process of producing new, better and more profitable products that meet the customer's need and requirement.

3. A Framework for Innovative Product Development

Innovative product development involves all of the different functions in a company. This insight that all departments must be active in the IPD process for it to be successful is new to many companies. From our definition of IPD there are three different parts that need to be addressed if the process shall be successful, see Figure 1.

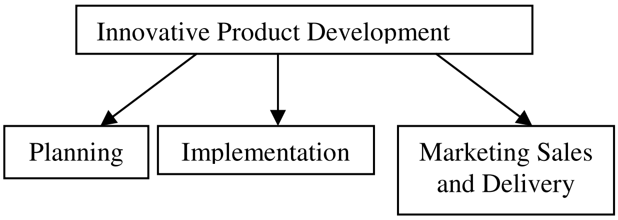

Figure 1. A framework for innovative product development involves planning, implementation and marketing, sales and delivery.

The IPD process involves: *Planning* (what to develop), *Implementation* (product realization) and *Marketing, Sales and Delivery* of the product to the customer. All the three parts require unique specific competence and objectives for it to be victorious.

3.1 Innovative product development planning

The first part in the IPD process is to plan what to develop this is also unrelentingly the most important phase. It is during the planning the boundary for the total success and productivity of the R&D spending is set. The overall objective in the planning stage is to transform customer needs and requirements into something that utilizes a company's resources in the best way possible that also generates the best possible future profit. There are two main questions to answer during the planning stage; the first question is *what and why* to develop and the second *how and when* to develop it, see Figure 2.

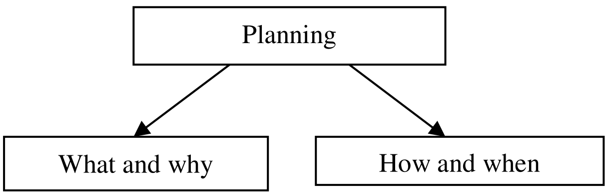

Figure 2. The IPD Planning involves answering the main questions: *what and why* and *how and when* to develop it.

What and why are the most crucial, since it sets the boundaries for both the technical and economical value. When a firm has decided what to develop and why, the value and productivity of the R&D money spent, is limited.

From our research the following is what managers in international high-tech industrial companies active in Sweden consider most important in the quest of answering *what and why* to develop (without mutual ranking):

Table 1. Factor for *what and why* to develop

Market Environment Analysis	Involves different aspects: technology, competitors, the customers' future business and processes, market knowledge etc.
Customer Needs and Wants	The ability to fully understand the customer needs and wants.
Business Case	Clearly specify what this product will make profit of and why.
Product Roadmaps	A clear plan of how the product will evolve in the future.
Risk Management	The ability to assess risks and work active with them.

The most important determinant of profitability is developing a unique, superior product with real value for the customer [10], [13]. It is during this part and this part only in the IPD framework that this issue should be addressed and it is vital for the whole company that it is done successfully. The market environment analysis is the main action that serves as the foundation for the information input to the company. It is important that the analysis covers all aspects; technology, competitors, the customer's future business and process, market and more. Market environment analysis is important since the sources of innovation are typically found among users, manufacturers, suppliers and others [14].

On average 70 percent of the product cost is fixed after the specification and design process [1]. The best way to handle this is to have frontloaded projects with adequate competence present when the important early decisions are made in the project. Success comes from improving the understanding and cooperation between different departments in a company, especially between R&D and marketing [15].

The *how and when* questions are more about utilizing a company's resources in an optimal way with project execution as the most important variable. The *how and when* questions in the IPD planning phase were considered to depend on the following aspects (again without mutual ranking):

Table 2. Factor for *how and when* to develop

Technology Roadmap	Develop the technology needed to support the product roadmaps.
Metrics	Different metrics assisting the decision making.
Organization	It shall have clear responsibility, mandate, culture, competence and roles to support the planning.
Ownership from Top Management	It is important that the CEO understands how the IPD process will generate future revenues and profit.
Planning Competence	Understanding all the aspects: technical, market, economic, production, purchase etc. needs and address them.

A key success factor for *how and when* is not to start the implementation project if the firm does not have the key resources available. If a new project is started in an already fully utilized organization it will only slow the other projects down [16]. Many companies start project after project without securing the key competence [17]. Technology planning that will support and speed the product implementation is also a key success factor [18]. The planning ends and the implementation start when the firm decides to launch the development project and realize the actual product.

3.2 Innovative product development implementation

The IPD implementation is all about realization of what is specified in the IPD planning. The ultimate success for the IPD implementation is to deliver exactly what is specified on time with the specified quality. If the key requirements cannot be met or the business case is jeopardized it is important to kill the project if necessary [4]. In the implementation stage there are several different parts involved. Figure 3 illustrates the four main factors influencing the success of the product realization according to our research. Figure 3 is the result of our analysis of the input from interviews and workshops.

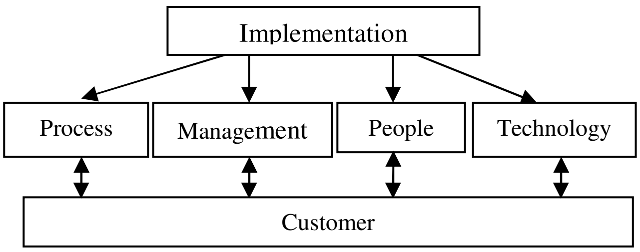

Figure 3. IPD implementation relies on: processes, management, people and technology, and their validation with the customer.

Our research indicates that the following aspect affects the different parts of the implementation stage:

Table 3. Factors influencing *Processes*

Process Quality	The maturity of the processes
Clear Development Process	That everyone in the organization understands and are able to follow
Tools	Updated tools that support the IPD work the best way possible.
Industrial Structure	Meaning that the right support systems are in place and can be used by the projects.
Clear Metrics	The use of metrics will improve the understanding the performance of the process.
Requirement Management	A structured way of handling requirements.

Table 4. Factors influencing *Management*

Professional Project Implementation	Important with skilled project leaders the enables effective project execution.
Multi Project / Portfolio management	The company must be able to handle multiple projects and maintain effective project execution.
Risk Management	All risks must be identified and assessed.
Handle Dependencies	Dependencies could involve business, resources, technical issues and project.
Global and Local Development	Find the right setting for what should be developed where.
Clear Objectives / Requirements	Management must be clear of what is expected from the people involved in the project.
Supplier / Partners	The ability to handle suppliers and partners during the development.

Table 5. Factors influencing *People*

Feedback	Feedback to the people involved in the project to further develop their competence.
Culture / Attitude	In the global world of today it is important to have every one work together as a team.
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 motivated and the right amount of resources 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.

Table 6. Factors influencing *Technology*

Technical Platform / Architecture	Makes it possible to share technology and thereby cost between projects /applications.
Predevelopment of Technology	Shall support the implementation to improve time to market and quality.

The IPD implementation is more of a production stage, since the best possible performance is to deliver what is specified during the IPD planning. In that sense IPD implementation could be compared with manufacturing, but for that to be reality an essential factor is that the *Technology* supports the project with predevelopment and re-use. For IPD implementation it is also vital that the *People* involved understand what is needed from them, because the ultimate success is all about time to market with sufficient quality. In order for *Management* to make the *People* most beneficial it is important that the project members find their assignments: professionally challenging, leading to accomplishments, recognition, and professional growth [19].

An illustrative metaphor to describe the IPD implementation is to relate it to the systems needed for railway transportation. It may be possible to run the train without tracks but it will be a lot smother using the track and it is the same thing with *Processes.* 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 *Management*. To be able to transport passengers the operator use trains representing the *Technology* and it is important that the train is able to keep the specified timetable. The train operator uses the signaling system to enable safe train rides and the possibility of running multiple trains, similar to handle multiple projects. For the train operator to be successful it needs skilled personnel that understand the passenger needs, in the same way skilled *People* are needed that understands the *Customer* requirements. The success for the train company is all about having the whole system working together, because when the train is moving in the right direction and the *Customers* are sitting comfortably they want to stay on the train and they will use the same train again.

A study by Booz Allan Hamilton reveals that most new products, from automobiles to washing machines, are over engineered as a result from not communicating and managing the customer need properly [20]. For management in the implementation phase it is important to continuously update and communicate organizational goals and project objectives. It is also important for management to illustrate the relationship and contribution of individual activities to the overall product development and business case [19].

3.3 Innovative product development marketing, sales and delivery

IPD marketing, sales and delivery are the third part in the proposed framework. It is during this stage that the company transforms its new developed products into revenues and profit. This gives a clear indication of the success not just of IPD marketing, sales and delivery, but also of the total IPD performance. This paper will not develop this part further since there are already well established theories [2], [21], but it is important for the completion of the overall IPD framework. Figure 4 illustrates the involved parts in this stage.

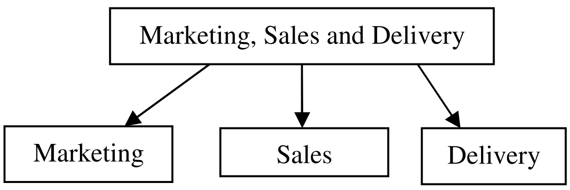

Figure 4. Marketing, Sales and Delivery stage involves marketing, sales and delivery of the developed product to the customer.

4. Innovative Product Development Productivity

As indicated earlier, all the three parts of the IPD framework are needed and it is important to separate and acknowledge what is important for success in each part individually. Especially the differences between planning and implementation must be supported and cultivated to create sustainable success. The productivity of the IPD process can only be established through efficiency in all the three parts. As a consequence a failure in any of the stages will lead to an overall failure off the total IPD process. It is important for a company to reflect on their weakest parts and acknowledge that they exist and secure future improvement. Conceptually the productivity of the IPD process can be expressed as

$$\eta_{IPD} = \eta_P \times \eta_I \times \eta_{MSD}$$

The equation expresses the productivity of the IPD process as a multiplication of the planning, implementation and marketing, sales and delivery efficiencies. As the equation illustrates is the productivity of the IPD zero if any of the three parts is zero, there cannot be any IPD productivity no matter the efficiency in the other two parts. The equation also acknowledges that an increase in the weakest part gives the best increase of the total IPD productivity.

4.1 Innovative product development and core competence and capability

In our opinion a competitive advantage arises when companies understand their strengths and weaknesses in the IPD framework. It is natural to compare the IPD framework with the work of core competence and capability; if it is managed well it provides customer benefits in the form of new products, it is hard for competitors to imitate since every organization is unique and it will be leveraged into all new products and thereby markets [22]. Core competence and capabilities constitute a competitive advantage for a firm; they have been built up over time and cannot be easily imitated [23]. If a company manages to turn their IPD framework into core competence and capability they will have the IPD process as a competitive advantage. If this is possible it will transform sustainable growth from an elusive goal to a natural veracity.

There are two fundamental principles when creating core competence and capability; the competence must steer the power structure in a company and the core competence strategy must be chosen by the CEO [24]. The first part is supported by the IPD framework but it must be used by management in that way. Also as we have pointed out in Table 2 support and understanding from top management including the CEO is a crucial success factor. The best approach for handling this would be to take an evolutionary approach involving implementation and coordinating dozens organizational efforts. This method is fruitful in the sense that it will deliver payoffs along the way even if there is only partial success [24]. Important to note here is that even if a firm initially is successful with IPD the work is not over. Working with the IPD framework is the work of small continues improvement steps and not something that is solved over night, it must always be in a company's focus.

5. Conclusion and Future Work

Since IPD is a complicated process it is essential to have a holistic framework to be able to understand the different aspects needed, because the IPD process is never stronger than its weakest parts. The IPD framework should be viewed as a foundation to reason about productivity and for improving the company's ability to successfully develop innovative products. We will in our future research attach metrics to this framework to identify and enable a better understanding of weaknesses and strengths in a company's IPD process and thereby make it possible for increasing the overall productivity.

References

[1] C. M. Christensen and M. E. Raynor, *Innovator's Solution: Creating and sustaining successful growth*. Boston: Harvard Business School Press, 2003.

[2] N. Slack, S. Chambers, and R. Johnston, *Operations Management*, 5 ed.: Pearson Education Limited, 2007.

[3] T. Hill, *Manufacturing strategy: The strategic management of the manufacturing function*, Second ed. London: Macmillan, 1993.

[4] R. G. Cooper, *Product leadership: Pathway to profitable innovation*, 2 ed. New York: Basic Books, 2005.

[5] R. Whitley, T. Parish, R. Dressler, and G. Nicholson, "Evaluating R&D performance using the new sales ratio," *Research Technology Management,* vol. 41, pp. 20-22, 1998.

[6] G. C. Hartmann, M. B. Myers, and R. S. Rosenbloom, "PLANNING YOUR FIRM'S R&D INVESTMENT," *Research Technology Management,* vol. 49, pp. 25-36, 2006.

[7] A. L. Page, "Assessing new product development practices and performance: Establishing crucial norms," *The Journal of Product Innovation Management,* vol. 10, pp. 273-290, 1993.

[8] P. F. Drucker, *Innovation and entrepreneurship*. New York: Harper and Row, 1985.

[9] J. Trout, "Tales from the marketing wars – Peter Drucker on marketing." vol. 2007, 2006.

[10] R. Luecke, *Managing creativity and innovation*. Boston: Managing Creativity and innovation, 2003.

[11] R. A. Burgelman, M. A. Maidique, and S. C. Wheelwright, *Strategic Management of technology and innovation*, Third ed. New York: McGraw-Hill/Irwin, 2001.

[12] K. T. Ulrich and S. D. Eppinger, *Product design and development* 3ed. Singapore: McGraw-Hill Education, 2003.

[13] R. G. Cooper, "Developing new products on time, in time," *Research Technology Management,* vol. 38, pp. 49-58, 1995.

[14] E. v. Hippel, *Sources of innovation*. New York: Oxford University Press, 1988.

[15] A. Griffin and J. R. Hauser, "Integrating R&D and Marketing: A Review and Analysis of the Literature," *Journal of Product Innovation Management,* vol. 13, pp. 191-215, 1996.

[16] R. Seider, "OPTIMIZING PROJECT PORTFOLIOS," *Research Technology Management,* vol. 49, pp. 43-48, 2006.

[17] B. L. Goldense and J. R. Power, "Developmental Overload," *Mechanical Engineering,* vol. 127, pp. 13A-13A, 2005.

[18] S. C. Wheelright and K. B. Clark, *Revolutionizing product development: Quantum leaps in speed, efficiency, and quality*. New York: Free Press, 1992.

[19] K. B. Kahn, *The PDMA handbook of new product development*, Second ed. Hoboken: John Wiley & Sons, 2005.

[20] C. Koehler and R. Weissbarth, "The Art of Underengineering," in *Strategy+Business Magazine*, 2004.

[21] P. Kotler, *Marketing management: Analysis, planning, implementation and control* 9th ed. Englewood Cliffs: Prentice Hall, 1996.

[22] C. K. Prahalad and G. Hamel, "The Core Competence of the Corporation," *Harvard Business Review,* vol. 68, pp. 79-92, 1990.

[23] D. Leonard-Barton, *Wellsprings of knowledge: Build and sustaining the sources of innovation*. Boston: Harvard Business School Press, 1995.

[24] K. P. Coyne, S. J. D. Hall, and P. G. Clifford, "Is your core competence a mirage?," *The McKinsey Quarterly,* 1997.

PAPER B

PMEX – A Performance Measurement Evaluation Matrix for the Development of Complex Products and Systems

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Abstract

A key aspect in a sustainable economy is to be able to do more with less by making better use of resources. Within the development of complex products and systems, a continuous need to improve performance exists, i.e., making better use of a company's resources. In this improvement process it is important to measure the performance of the product development process. Previous research mainly focuses on the design and implementation of new performance measurement systems, not on evaluating the measures currently used. The research question in this paper is how to evaluate a company's performance measurement systems from a manager's perspective. To answer this question, a performance measurement evaluation matrix (PMEX) is developed. The PMEX has the different phases of the Stage-Gate process as one dimension and important success factors in the development of complex products and systems as the other dimension. Furthermore, a multiple case study has been conducted as a first verification of the PMEX. The first results of the study indicate that the PMEX enables managers to overview what is and what is not measured. The PMEX can therefore function as a conceptual tool in the discussions for setting the scope of the performance measurement system.

I. Introduction

There is a consensus in that the market has never been more competitive than today. Technological advances, intensified global competition, changing customers and needs are some of the characteristics of the market of today [2], making the need for an effective and efficient product development (PD) process greater than ever. An important tool in the quest for a high performing PD process is the ability to measure performance. Measuring performance within a process is a classical research problem and also known as a complicated one. This paper studies performance measurement systems within the development of complex products and systems. A complex system e.g., a system comprised of interconnected simple parts, that together exhibit a high degree of complexity from which emerges higher order behaviour. Moreover, no single person understands the complete system. Often is the system long-lived and has been evolved over generations of engineers. In [3] complex products and systems are defined as high cost, high technology, engineering intensive, and business to business capital goods used to produce goods and services.

This paper takes a PD manager's perspective on performance measures in the development of complex products and systems, thereby emphasizing a holistic system view of the PD process. The research question in this paper is how to evaluate a performance measurement system from a PD manager perspective. There is a vast amount of research within the area of performance measurements available, mainly focusing on design and implementation of a new performance measurement system. However, the development of a new performance measurement system is related with high costs and a time consuming implementation process. Furthermore, there are few research studies with focus on evaluating the existing performance measures of the PD process. To address this issue a method for holistically evaluating performance measures within this context is proposed. PD managers often know they have a less than optimal performance measurement system but lack the ability to pinpoint what is good and what is not with the current system. Keeping measurements relevant to the changing business and organisational context is a problematic area, as "old" measurements are often not discarded and the new measurements are merely added to the confusion [4].

The outline of this paper is as follows: in Section II a brief presentation of the method and methodology used in presented research and continues in Section III with a short overview presenting previous research within PD and performance measurements. In Section IV a categorization of the PD process is proposed and the success factors identified in this research within the development of complex products and systems are presented. Moreover, Section IV then continues with a presentation of the proposed Performance Measurement Evaluation Matrix (PMEX). Further, in Section V a first verification of the PMEX is performed. The verification begins with a mapping of the, in this research identified, success factors with the success factors within PD, identified in the literature. Two case studies continue the verification, where the PMEX is applied to two sets of performance measurement systems currently used by two Fortune 500 companies developing complex products and systems. The paper ends with conclusions and future research in Section VI.

II. Method and Methodology

To deal with the complexity of measuring PD performance, a systems theory combined with an actors' approach has been adopted, in accordance with the views of [5]. Increased complexity stresses the need for models that could be used by teams to develop a shared understanding [6]. Systems theory is a promising effort to deal with this problem, where an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [7].

In presented research a method is proposed, to evaluate the performance measures within the PD process based on the PMEX. The success factors and the classification of them into a conceptual framework for performance in PD were done based on the results from interviews and a workshop where senior PD managers from seven different industrial companies developing complex products and systems participated. The participating companies are all international companies, based in Sweden. They all have extensive experience in developing complex products and systems within telecommunications, automotive, heavy vehicles, and automation. In the workshop the participants were asked for factors important for an effective and efficient PD process. The classification of success factors and the identification of gaps in existing literature gave rise to the PMEX. Moreover, the PMEX has been verified through two case studies with the aim of verifying how the PMEX can be used at a company developing complex products and systems within the area of industrial automation and heavy vehicles. The case companies are both divisions within two fortune 500 companies with a high R&D intensity in comparison to revenues. A total of 29 semi structured and open interviews were held at the two case companies to identify how they perceive performance and how it is measured at different levels of the organizations. These results were then incorporated into the PMEX. Furthermore, the authors professional work experience within complex PD was also used for reasoning during the development of the PMEX.

III. Related Work within Product Development and Performance Measurements

Turning an idea for an innovation into a successful product is by definition a unique experience and as such cannot be treated as a purely bureaucratic process. It must be treated as a project: a finite activity with its own objectives and resources, and above all its own leadership [2]. Measuring PD performance over time is complex due to inherent uncertainty [8]. The area of performance measurement has interested scholars with different functional backgrounds. A vast amount of research is available both within the area of performance measurements and within PD. Still, few studies analyze the PD processes from the performance measurement system perspective [9]. Nevertheless, the model proposed in [10] establishes the main guidelines for developing such an analysis. This model presents the PD process as a complex system consisting of two independent and parallel processes: the PD process itself and the evaluation process, i.e., the evaluation of the implemented performance measurement system.

The product development process

The term PD is often used without a proper definition. The research presented in this paper emphasizes a holistic view on PD by proposing the following definition:

"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."

In this research a PD project is to be considered successful if its products not only fulfils the needs and requirements of its customers, but also generates profits to its shareholders, and creates value to its stakeholder at large. Furthermore, the proposed definition of the PD process implies it spanning several different functions within a company, not just the R&D organization. In [11] a generic process is suggested for PD including: planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. This generic PD process is depicted below in Fig. 1.

Figure 1. The generic phases in the PD process involve planning, concept development, system-level design, detail design, test and refinement, and production ramp-up [11].

The process of PD within industry is diverse, both in the sense of novelty and type of products being developed. In this research, organizations developing complex products and systems are the unit of analysis. Complex products and systems are customised, high valued, capital goods, products, systems and networks, usually produced as one-off projects or in small batches [12]. Typical characteristics for this type of development projects; they are often executed by large organizations with a large network of contractors, subcontractors, suppliers and users [3]. A successful implementation is dependent on this network working well together.

The reputable Stage-Gate process [10], based on Booz, Allen and Hamilton's model (BAH), is both a conceptual and an operational model intended to move a new product from the idea stage through to market launch and beyond [9]. The generic Stage-Gate process [1] shown in Fig. 2, include stages and gates. There are strong similarities between the generic phases in the PD process and the stages in the Stage-Gate process. It is during the stages where the development work occurs; the project team completes activities to reduce business risks and advance the project to the next gate. The different stages are cross-functional and each activity is undertaken in parallel to accelerate speed [1]. Since each stage costs more than the preceding, an incremental commitment is achieved with each stage [13]. As uncertainties decrease, expenditures are allowed to rise and risk is managed. Gates are where the Go/Kill and prioritization decisions are made [1]. Mediocre projects may be culled out and resources could be allocated to the most promising projects of the portfolio. The focus during the gate decisions should be on three key issues: quality of execution, business rationale, and the quality of the action plan [13]. Often, different scorecards

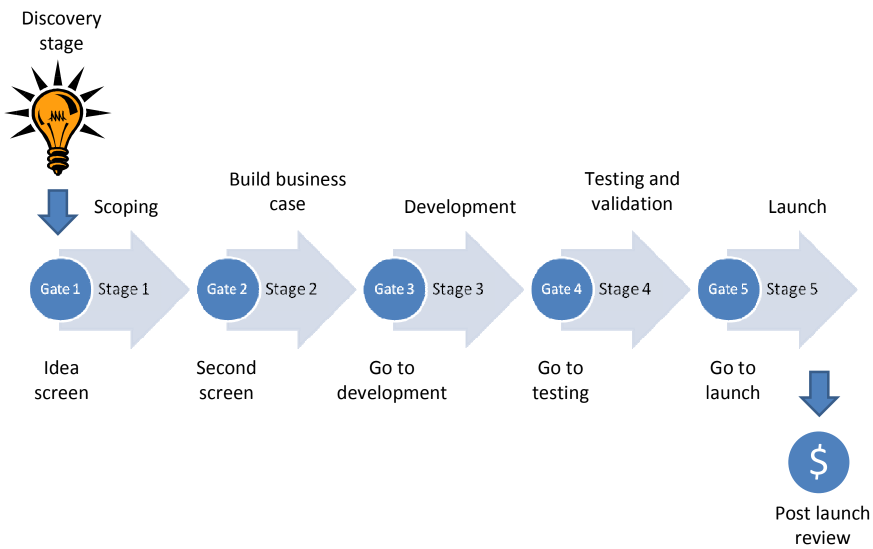

Figure 2. The generic Stage-Gate process [1].

and criteria are used to evaluate a project's potential for future success.

A study conducted by [14] shows that 60% of profit organizations are using a Stage-Gate or similar process for PD, whereas 39% indicated no formal development process in the PD at all. Further, results indicate that companies modifying their formal PD process improve efficiency while not significantly sacrificing product novelty [15]. Stage-Gate usage has also proven to be significantly related to PD process improvements and has indirectly but significantly been related to new product profitability [15]. Usually the Stage-Gate process involves four to eight stages and gates in a by the company modified process [9].

Performance measurement

The area of performance measurement has inspired numerous scholars. Researchers with functional backgrounds as varied as accounting, operations management, marketing, finance, economics, psychology, and sociology are all actively working in the field [16]. Performance measurement within PD belongs to the broader area of business performance measurement. There are several motives why it is important to measure performance. In [17] four different reasons for measuring performance are proposed: *check position, communicate position, confirm priorities,* and *compel progress*. This illustrates an important fact: measurements alone is not a direct value adding activity, value is achieved when the result of the performance measurement system is actively and adequately used by management.

The most wide spread and cited performance measurement system is the Balanced Scorecard [18], introduced by Kaplan and Norton in 1992 [19]. The literature reveals that the Balanced Scorecard still prevails as the dominant performance measurement system [4]. Financial measures alone cannot adequately reflect factors such as quality, customer satisfaction, and employee motivation [20]. 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. Successful implementations of the Balance Scorecard, however, are much less prevalent and translating the Balanced Scorecard into concrete action is still a problematic area. In [8] a framework to integrate the Balanced Scorecard in R&D management is presented. However, the Balanced Scorecard has not reached the same success within PD as it has within the more general business performance measurement system. Balanced measurements are designed to provide a balance by including measures of external success as well as internal performance, together with measures designed to give an early indication of future business performance as well as a record of what has been achieved in the past [21]. Leading indicators includes measures affecting the process, while lagging indicators measure the result of already performed processes. There are several other different classifications of performance measurements. Two common basic distinctions are *quantitative* and *qualitative measures*. For example computational methods clearly leads 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" [22]. Further, quantitative measures are often divided into financial and non-financial measures.

Research within performance measurements is often focused on the design and implementation of a performance measurement system. Still, little attention has been paid to the implementation of a complete performance measurement system covering the whole PD process [9]. There are several models and frameworks other than the Balanced Scorecard available but few of them have explicit focus on the PD process. A newly developed framework is the Performance Prism [23] that emphasizes a more holistic approach to the stakeholder perspective of performance measurements, compared to the Balance Scorecard. Moreover, few studies within performance measurement involve a holistic evaluation of the currently used performance measurement system. Merely half of the ten performance measurement systems, identified in [24], have some kind of evaluation of the current performance measurement system in their process of designing the new system.

Performance measurements are important as an aid to determine priorities, e.g., within different activities, and as means of providing direction to teams by highlighting how they are performing and where improvements would be most beneficial. However, the performance measurements must be kept in perspective; they must support the PD process and goal attainment [25] based on the business strategy. This implies the importance of continuously evaluating the performance measurement system. Process management theory suggests that one should not only implement the correct processes, one should also monitor how well the process is operating and, if necessary, intervene in a timely manner [26].

IV. The Performance Measurement Evaluation Matrix

In this paper a method for evaluation of a performance measurement system based on a Performance Measurement Evaluation Matrix (PMEX) is proposed. The PMEX provides PD managers with a tool to evaluate their currently used performance measurement system. Without a structured method, as the one proposed, it is difficult to assess what is measured and, maybe more important, assess what is not measured by the current performance measurement system. As described in Section III, PD is a dynamic and diverse task involving many different competencies and functions within a company. As a result, the process of PD differs between companies and domains of industries. This research focuses on evaluating the performance measures used by companies developing complex products and systems. Therefore, this research started with identifying important success factors within the development of complex products and systems. The first result of this research, a framework for performance in complex PD has been presented in a previous paper [27]. In the PD literature there are several studies identifying success factors but within the explicit area of developing complex products and systems such studies seems to be missing or their result have not reached a wide acceptance.

Conceptually, we have divided the PD process into three different categories based on our findings: *Planning*, *Implementation*, and *Marketing, sales and delivery* see Fig. 3. This categorization is in line with the definition of PD previously presented in Section III. The *Planning* activities typically involves decisions regarding what product to develop, especially the planning and concept development of the generic phases of the PD shown in Fig. 1. The *Implementation* activities are more operational in designing and constructing a product, typically involving system level design, detail design, test and refinement and the production ramp up, as shown in Fig 1. The final part *Marketing, sales and delivery* is important for the completeness of the PD process and in securing the overall success of the PD process. All the three parts of the PD process require unique specific competence and objectives if success is to be achieved. The PD process cannot be considered successful until the targeted customer needs are fulfilled and the new product generates profit. The reason for this categorization is to emphasize the different functions in a company needed in the PD process; it is not just a task involving R&D. Moreover, it is important to acknowledge the different competencies needed in the *Planning* compared to the *Implementation* activities of the PD process. In a performance perspective it is vital to differ between *Planning* and *Implementation*, since their objectives differ. *Marketing, sales and delivery* will not be further developed in this paper.

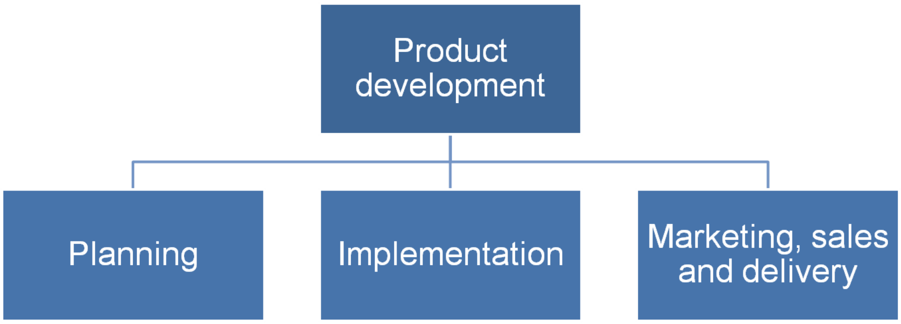

Figure 3. PD can, for performance evaluation reasons, be divided into Planning, Implementation, and Marketing, sales and delivery of a product.

When a performance measurement system is to be evaluated, it is important to address *what* is measured and *when* it is measured. The motivation for a particular metric, the *why*, is also a central question in the process of evaluating a performance measurement system, especially since every measurement is inherent with a cost. To address *what* is measured, an analysis of success factors in the PD process within the seven participating companies has been performed. The result of this study was then categorized and the result is presented according to the PD Planning and Implementation sub-sections below.

Product development: Planning

The first part of the PD process, and unrelentingly the most important activities, is to decide why and what something needs to be developed. It is during the PD planning the upper boundary for overall success and profitability of the PD is set. The overall objective in the PD planning activities is to decide on customer needs and transform them into something that utilizes a company's resources the best possible way i.e., generate the best possible future cash flow. Two main questions emerged during this study as important, needing their answer during PD planning. The first questions are w*hat* to develop and *why*, the second set of questions are *how* and *when* to develop it, see Fig. 4. *What* and *why* are vital questions, since they set the boundaries for both the technical specification and the future cash flow. In a value creation perspective; once a company has decided *why* something needs to be developed and *what* product to develop, the future value of the PD investment is limited since the decision of technical solution and targeted market is made. Therefore, this is an important aspect of the PD process that needs to be managed accordingly in order to make the best possible use of a company's scarce resources.

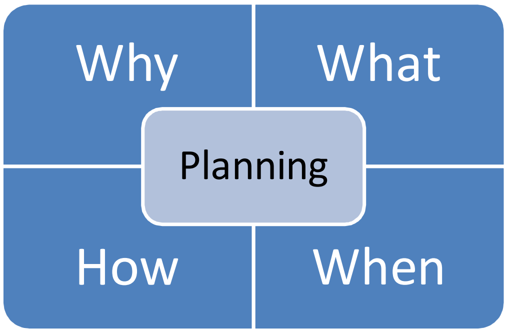

Figure 4. Successful PD planning especially involves the following questions: *why*, *what*, *how*, and *when* to develop a product.

The *how* and *when* questions in the PD planning focus on utilizing a company's resources in the best possible way with efficient project execution as an important objective. A key success factor for *how* and *when* is not to start PD implementation activities if the key resources are not available. If a new PD project is initiated in an already fully utilized organization it will only slow the other projects down [23]. It is common for companies to initiate project after project without securing the key competence [4], in the quest for achieving higher performance. Further, technology planning that support and speed up the product implementation activities is a vital success factor [24]. The planning ends and the implementation starts when the firm decides to execute the PD project, i.e., implement the planned product. Table 1 illustrates the success factors that PD managers in our studies consider most important in the PD planning activities.

Table 1. Important success factors for performance in the PD planning [27].

Why & What		How & When	
Market Environment Analysis	Involves different aspects: technology, competitors, the customers' future business and processes, market knowledge etc.	**Technology Roadmap**	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 this product will make profit of and why.	**Organization**	It shall 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 PD process will generate future revenues and profit.
Risk Management	The ability to assess risks and work active with them.	**Planning Competence**	Understanding all the aspects: technical, market, economic, production, purchase etc. needs and address them.

Product development: Implementation

The PD implementation activities are all about project execution and to produce what was specified in the PD planning, as efficient and effective as possible. The ultimate success for the PD implementation is to deliver exactly what is specified within budget, on time, and with the specified quality. In the implementation activities there are several categorize of factors affecting the performance, shown in Fig. 5. The factors have been divided into four main categorize of success factors influencing the success of the product creation according to the analysis of the interviews and workshops: *management*, *process*, *technology*, and *people*.

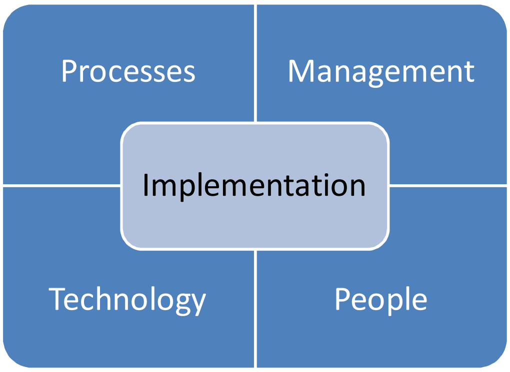

Figure 5. Successful PD implementation especially involves: *processes*, *management*, *people*, and *technology*.

The PD implementation activities of the PD process could be looked upon as a manufacturing process, since the best possible outcome is to deliver exactly what was decided in the PD planning. However, for this to be reality it is essential that the technology supports the project with pre-development and re-use. Furthermore, it is important to have a properly planned project e.g., a front loaded project in order to achieve an efficient and predictable implementation process. It is also vital for the PD implementation to involve people in the project with an understanding of what is needed from them. The ultimate success during the PD implementation is all about time to market with sufficient quality. In order for management to make use of the resources in the most beneficial way, it is important that the project members find their assignments: professionally challenging, leading to accomplishments, recognition, and professional growth [1]. A study presented in [6] reveals that most of the new products, from automobiles to washing machines, are over engineered as a result of not communicating and managing the customer needs properly. In the implementation phase it is important for management to continuously update and communicate organizational goals and project objectives. Management also needs to illustrate the relationship and contribution of individual activities to the overall PD process and business case [1]. Table 2 and 3 illustrate the result from workshop and interviews with respect to success factors in the product implementation activities.

Table 2. Important success factors for performance in the PD implementation [27].

Processes		People	
Process Quality	The maturity of the processes	**Feedback**	Feedback to the people involved in the project to further develop their competence.
Clear Development Process	That everyone in the organization understands and are able to follow	**Culture / Attitude**	In the global world of today it is important to have every one work together as a team.
Tools	Updated tools that support the PD work the best way possible.	**Organization**	Important that the organization evolves with the changes that occur in the firm and thereby support projects the best way possible.
Industrial Structure	Meaning that the right support systems are in place and can be used by the projects.	**Resources**	Important to have motivated and the right amount of resources available for the project.
Clear Metrics	The use of metrics will improve the under-standing the performance of the process.	**Competence**	Involves securing a diverse and excellent competence in the company
Requirement Management	A structured way of handling requirements.	**Incentives**	Could be in the form of bonuses and other carrots.

Table 3. Important success factors for performance in the PD implementation [27].

Management		Technology	
Professional Project Implementation	Important with skilled project leaders the enables effective project execution.	**Technical Platform / Architecture**	Makes it possible to share technology and thereby cost between projects /applications
Multi Project / Portfolio management	The company must be able to handle multiple projects and maintain effective project execution.	**Predevelopment of Technology**	Shall support the implementation to improve time to market and quality
Risk Management	All risks must be identified and assessed.		
Handle Dependencies	Dependencies could involve business, resources, technical issues and project.		
Global and Local Development	Find the right setting for what should be developed where.		
Clear Objectives / Requirements	Management must be clear of what is expected from the people involved in the project.		
Supplier / Partners	The ability to handle suppliers and partners during the development.		

The Performance Measurement Evaluation Matrix

To be able to evaluate performance measurements within the PD process, not only why and what is measured are important, but also when they are measured is an essential question. In this research the previously presented Stage-Gate process is proposed to address the *when* to measure *what*. Since the Stage-Gate process represents the different phases of a PD project it is convenient to have it representing the timeline of the sampled measures. The PMEX, shown in Fig. 6 below, has the different phases of the PD process as one dimension of the matrix and the categorization of important successes factors for developing complex products and systems, as identified in this study, as the other dimension.

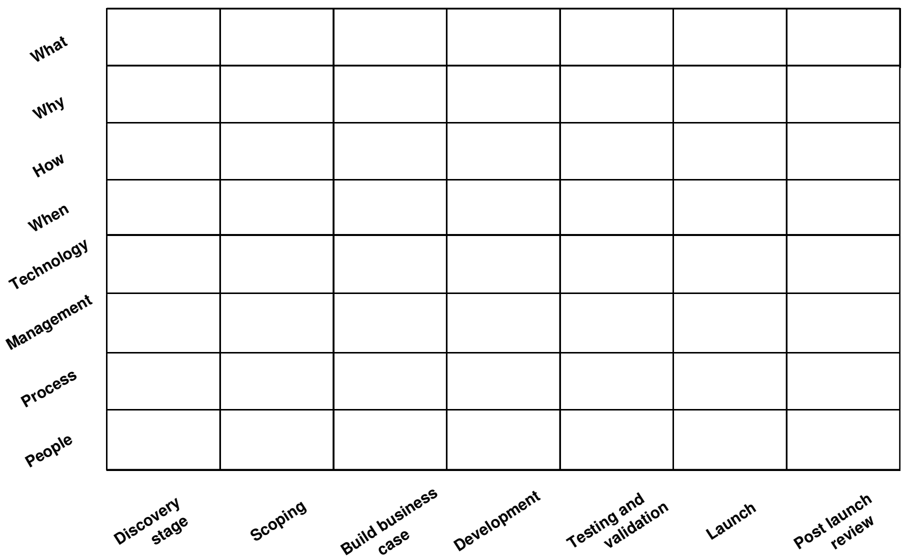

Figure 6. Illustrates the PMEX including the Stage-Gate process and the categorization of success factors important for performance in PD.

The success factor categorization included in the PMEX represents what is important to manage in order to enable a high performing PD process. 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 probably would be difficult to make use of all the information. Instead, the PMEX should be viewed as a conceptual tool for PD managers to discuss the performance measurement system, in the sense of what needs to be measured, why it should be measured, and when it should be measured. In Section V, an initial verification of the PMEX is performed.

V. Verification of the PMEX

An initial verification of the PMEX is performed in this paper, involving two steps. The first step includes a brief presentation of critical success factors from the literature. These success factors are mapped against the success factors identified in this research. The second step of the verification includes a multiple case study within two companies developing complex products and systems. From the multiple case studies, the two organizations' different performance measures were identified and mapped into to the PMEX.

Critical success factors in product development in the literature

The research literature and industry best practices report a vast number of success factors that contribute to successful PD [28]. The thought of having a limited amount of factors that directly affect the outcome and underlie excellent performance of the PD process is appealing for every manager. As a result there is a vast amount of research available within the area of success factors within PD [29]. 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 a less successful, success factors are identified.

In [28] a distinct set of success factors for PD that are statistically accurate predictors of the specific project outcomes of profit, market share, customer satisfaction, organizational effectiveness, and product quality. Moreover, the following categories are identified: *Leadership, Organizational culture, human resources, information, Product strategy, Project execution, Project execution, product delivery, and results*, Leadership involves key characteristics of the project leader, the power delegated, and whether there is clear strategic direction for the project. The organizational culture, engages the extent to which management has taken advantage of the established values of the people to improve project outcomes. Human resources, involves management's actions to improve the skills and the work environment. Information is concerned with the treatment of information as a valuable asset, their quality, and whether it is systematically collected, shared, analyzed. Product strategy includes the product planning processes and the extent to which they promote readiness for PD and product delivery. Project execution involves the key issues of the PD process. Product delivery consider to what extent manufacturing, sales, service and support are considered; or whether the product is just "tossed over the wall". 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 in [29] the following categorization, as previously developed in [30], was adopted: *customer integration, organization, culture, role and commitment of senior management* and *strategy*. In [31] another review drawing on a wide body of the product innovation literature, the following seven categories is identified as important in the product innovation process: *inputs management*, *knowledge management*, *innovation strategy*, *organizational culture and structure*, *portfolio management*, *project management*, and *commercialization*. Further, [32] argue for the following success factors in PD: *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 high performance-to-cost ratio. *Market knowledge* i.e., customer and user needs assessment and understanding is critical. A *clear product definition* by defining target markets, clear concept definition and benefits to be delivered before the development begins. 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 the end. *Project resources* including financial, 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 PD process. *Top management support* is important through the complete PD process from concept to launch. Table 4 below, illustrates how the in this research identified categorization of success factors, presented in table 1-3, maps to the success factors identified in the literature presented above.

Table 4. Illustrates how the in this research identified categorize of success factors maps to the success factors identified in the literature.

	Tang [28]	Ernst [29] / Cooper [30]	Adams [31]	Bessant [32]
What	Product strategy	Customer integration, Strategy	Portfolio management Innovation strategy Commercialization	Market knowledge Clear product definition, Product advantage
Why	Product strategy	Strategy	Portfolio management Innovation strategy Commercialization	Market knowledge, Product advantage Clear product definition
How	Product strategy	Strategy		Market knowledge Clear product definition
When	Product strategy	Strategy	Portfolio management Commercialization	Market knowledge
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
Process	Project execution, Information, Product delivery Results	PD process	Input management Knowledge management Project management	Risk assessment, Proficiency in execution
People	Information	Organization, Culture	Organizational culture Input management	Project resources, Proficiency in execution

It is difficult to directly compare success factors from the literature with the ones identified in this research because they are defined with different levels of abstractions. One example of this difficulty is strategy, identified in [29] and in [30] as an important success factor, that is mapped into the *why*, *what*, *how*, and *when* categorizes. In this initial verification of the success factors identified in this study, the main objective is not to highlight the detailed variations instead the major differences are important. With this in mind a first analysis of the mapping in Table 4 shows that the technology category is not directly addressed by any of the other studies found in the literature.

This is an interesting finding that might be explained by the other previous studies focusing on a wider set of companies and products while this research explicitly focus on the development of complex products and systems. In the context of developing complex products and systems, technology is per definition an important aspect of PD performance. The technology aspect 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 sharing cost between products and applications. Pre-development of technology supporting the PD implementation is another factor will have effect on time to market and quality of the developed product. Moreover, the technological infrastructure, e.g., a systems' architecture can have both positive and negative effect on the PD performance. The architecture may exhibit different levels of inner-quality attributes such as evolvability, flexibility, testability which have effect on the performance when evolving a long-lived system. In [33] a thoroughly conducted study within the disk drive industry highlights the importance of this issue. Both the rate of a technology's performance improvement and the rate at which the technology is adopted in the marketplace, has repeatedly shown to conform to a s-shaped curve [34]. The ability to assess when, the currently used technology reaches the end of such an s-curve, and hence is in need for e.g., improving inner-qualities in the architecture, would clearly be beneficial especially for the efficiency aspect of PD performance.

The *how* and *when* questions in the PD planning are less emphasized compared to questions of *what* and *why* in Table 4. The aspect *when* is important since it is a common phenomenon to overload the PD portfolio in the search for higher efficiency. However, such an overload often results in an increased PD project lead time. In a PD manager perspective the success of the overall portfolio is of more importance than the performance of an individual PD project. Studies focusing on the success of an individual PD projects is likely to miss out on the importance of the *when* perspective of the PD portfolio performance. In the PD implementation it is *management* that is by all the studies highlighted as the most important success factors.

Two case studies within the development of complex products and systems

To be able to verify the PMEX, two case studies were conducted within the automation domain, and the heavy vehicle domain. The first result from these case studies was to extend the PMEX to also include time, cost and quality. Not because they are success factors of the PD process, but because of many measures involves time, cost and quality. It is interesting that time, cost and quality was never mentioned in the workshop when the success factors where elicited and analysed by the senior managers in our study. The proposed PMEX, with an indication of what is measured by the two case companies, is shown in Fig. 7. The gathered performance measures within the two case companies were successfully structured into the modified PMEX. The stars represent the metrics used by the automation case company and the circles represent the measures of heavy vehicle case company. It was decided to map the measures into the matrix in order to emphasize the presentation and usage of the PMEX as an evaluation method, rather than focusing on the specific metrics used by these two case companies.

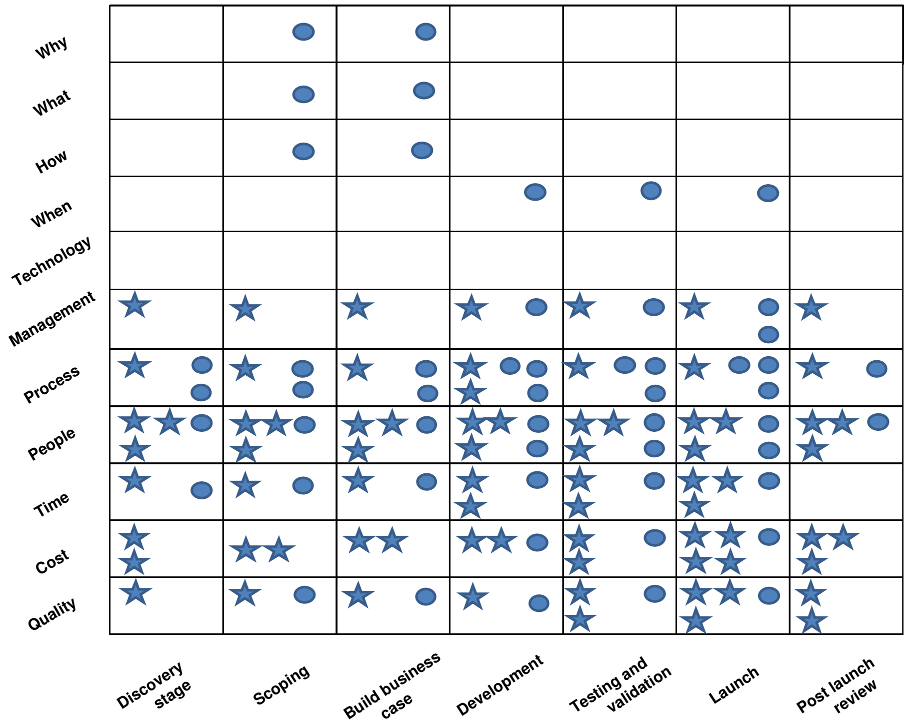

Figure 7. The PMEX illustrates what and when there are measurements present in the PD process for the two companies. The star represents case company 1 and the circle represents case company 2. Stars and circles were chosen instead of the real measurements in order to keep the focus on the PMEX and not on the measurements.

It should be noted that a star or a circle is not equaled to a unique measure. It could be that the same measure is used in multiple squares of the PMEX. An example of this is the circle in the why, what, and how measured during the discovery and build business case is the same measure. It is a measure of how the prescriptive process of early stages in the PD process is followed. When there are multiple entries of stars or circles it represents multiple measures applied to the same area. A further result of the analysis is that the two case companies seem to measure what is easy to measure and not what managers emphasize to be important. If the measure of fulfillment of the early stages of the PD process is disregarded, there are hardly no measures at all within the planning activities (why, what, how and when) or the technology aspects of the PD process. This may be negative in the important effectiveness perspective of the PD process. It may be the result of companies focusing on the efficiency and not the effectiveness of PD. Another interesting finding is that none of the two case companies measure the aspects related to technology. In spite the potential big influence it may have on particularly PD efficiency. Since both the studied companies are successful, and have an interest in increasing their PD performance, it could be that this information is managed as tacit knowledge. Tacit knowledge is defined in [35] as knowledge that cannot be articulated or verbalized; it is a knowledge that resides in an intuitive realm. Since the subject of tacit knowledge transfer, content and process, is poorly understood [35] it may be a substantial risk to treat the technology and planning aspects of the PD process this way. If that is the case it may be difficult to manage the planning phase as a process and thereby enable continues improvements.

Experiences from the first verification of the PMEX

The first indications from the verification of the PMEX show promising results. The PMEX has so far only been tested at the two case companies. However, within these companies the PMEX has been received as a novel way of evaluating the current performance measurement system. In both the studied cases the PMEX clearly illustrate what is and what is not measured. The problem still remains; how to design performance measures that addresses this issue. However, with the use of the PMEX this phenomenon is clearly shown; there are important aspects missing in the current performance measurement system of the PD process. The main idea of the PMEX is to holistically evaluate the performance measurement system and use it as a conceptual tool when performance measures are discussed.

Moreover, both case companies have a clear potential to further develop their performance measurement system since the success factors identified by the participating companies are almost disregarded, especially the planning activities. Furthermore, the findings that technology is not explicitly perceived as an important success factor in the PD literature and at the same time disregarded by the performance measurement system are both interesting findings. Especially since the majority of the PD within companies developing complex products and systems are incremental development of long living systems rather than development of completely new products. Often, are product-line architectures or platforms used and shared between products. It is our experience that the important inner quality of such architectures decreases over time if quality is not actively managed by the R&D organization and PD management. Reasons for this are, for instance, poor communication of important architectural decisions and constructs leading to architectural falling apart when new features are implemented in ways that violates the rules set by architecture, the introduction of new features that do not fit the current architecture, changes in business context that is not supported by the current architecture, turn-over of engineers resulting in the loss of knowledge. For a company developing complex products and systems it is therefore a clear competitive advantage to have the technology evolving in line with the business context and thereby support an efficient and effective implementation of new features and applications.

VI. Conclusions and Future Research

In this paper, a method for how a company's performance measurement system can be evaluated from a product development (PD) manager's perspective has been suggested. The first conclusion of presented research is that previous literature within both PD and performance measurement is vast. Despite this fact, there is a lack of research focusing on evaluating the performance measures used within the development of complex products and systems. The research of evaluating the performance measurement system is scarce or even missing, especially within this context. A second result from presented research is the Performance Measurement Evaluation Matrix (PMEX), a conceptual tool to holistically evaluate the performance measurement system used by companies developing complex products and systems. The PMEX has the success factors within the development of complex products and systems as one dimension and the phases of the Stage-Gate process, representing the timeline, as the other dimension. One benefit of the PMEX is the possibility, for a PD manager, to holistically evaluate what is measured and maybe more importantly, what is not measured within the PD process. The PMEX may also be used as a conceptual tool to reason about the performance measurement system, making it possible to initiate discussions of what is measured and why, and also when it is measured. Furthermore, the PMEX also illustrates what is not measured and can therefore be used when changes or new metrics are to be added, in order to ensure a performance measurement system that measures what is important in a company's perspective in the quest for a more successful PD.

A third conclusion based on the result of using the PMEX, is that the technology aspect of the PD process is not measured by any of the two case companies. This is especially interesting since both companies acknowledge the importance of technology as a success factor. Moreover, a literature study of different success factors within PD also disregards the technology aspect of PD performance. This is remarkable since there seems to be a gap both within the literature and within the current performance measurement system of the two case companies. Further research is needed, focusing on possible success factors and measures that can be used to address the technology aspects within the development of complex products and systems. An overall conclusion from the case studies is that there seems to be a mentality to measure something because it is possible to measure, rather than because it is important to measure. This would explain why there are few metrics measuring the planning and the technology aspects of the PMEX. Research is ongoing to formally verify the PMEX through five more case studies. The technology aspect together with its affect on the overall PD performance from a PD manager's perspective and possible ways of designing measures of technology's effect on efficiency and effectiveness will be further investigated.

References

[1] R. G. Cooper and E. J. Kleinschmidt, "www.stage-gate.com." vol. 2008: Stage-Gate Inc, 2008.

[2] K. Goffin and R. Mitchell, *Innovation Management: Strategy and Implementation Using the Pentathlon Framework*. London: Palgrave MacMillan, 2005.

[3] M. Hobday, "Product complexity, innovation and industrial organization," *Research Policy,* vol. 26, pp. 689-710, 1998.

[4] B. Paranjape, M. Rossiter, and V. Pantano, "Performance measurement systems: successes, failures and future - a review," *Measuring Business Excellence,* vol. 10, p. 12, 2006.

[5] I. Arbnor and B. Bjerke, *Methodology for Creating Business Knowledge*. USA: Sage Publications, 1997.

[6] D. Katz and R. L. Kahn, *The Social Psychology of Organizations* 2ed. New York: John-Wiley & Sons, 1978.

[7] P. M. Senge, *The Fifth Discipline, the Art & Practice of Learning Organizations*. New York: Currency Doubleday, 1990.

[8] W. G. Bremser and N. P. Barsky, "Utilizing the balanced scorecard for R&D performance measurement," *R & D Management,* vol. 34, pp. 229-238, 2004.

[9] A. I. Jiménez-Zarco, M. P. Martínez-Ruiz, and Ó. González-Benito, "Performance measurement system (PMS) integration into new product innovation: A literature review and conceptual framework," *Academy of Marketing Science Review,* vol. 2006, 2006.

[10] R. G. Cooper, "Stage-Gate Systems: A New Tool for Managing New Products," *Business Horizons,* vol. 33, pp. 44-55, 1990.

[11] K. T. Ulrich and S. D. Eppinger, *Product design and development* 3ed. Singapore: McGraw-Hill Education, 2003.

[12] H. Rush, "Managing innovation in complex product systems (CoPS)," *EPSRC Technology Management Initiative (Engineering & Physical Sciences Research Council), IEE Colloquium on,* p. 4, 1997.

[13] R. G. Cooper, *Winning at new products: Accelerating the process from idea to launch*. Cambridge, MA: Perseus Books, 2001.

[14] A. Griffin, "PDMA research on new product development practices: Updating trends and benchmarking best practices," *The Journal of Product Innovation Management,* vol. 14, pp. 429-458, 1997.

[15] J. E. Ettlie and J. M. Elsenbach, "Modified Stage-Gate® Regimes in New Product Development," *The Journal of Product Innovation Management,* vol. 24, pp. 20-20, 2007.

[16] A. Neely, *Business performance measurement*, 2 ed. Cambridge: Cambridge University Press, 2007.

[17] M. Kennerley and A. Neely, "Measuring performance in a changing business environment," *International Journal of Operations & Production Management,* vol. 23, pp. 213-229, 2003.

[18] A. Neely, "The evolution of performance measurement research: Developments in the last decade and a research agenda for the next," *International Journal of Operations & Production Management,* vol. 25, pp. 1264-1277, 2005.

[19] R. S. Kaplan and D. P. Norton, "The Balanced Scorecard measures that drive performance," *Harvard Business Review,* vol. No. January-February, 1992.

[20] H. Driva, S. Pawar Kulwant, and U. Menon, "Performance evaluation of new product development from a company perspective," *Integrated Manufacturing Systems,* vol. 12, pp. 368-378, 2001.

[21] M. Bourne, J. Mills, M. Wilcox, A. Neely, and K. Platts, "Designing, implementing and updating performance measurement systems," *International Journal of Operations & Production Management,* vol. 20, pp. 754-754, 2000.

[22] I. C. Kerssens-van Drongelen, B. Nixon, and A. Pearson, "Performance measurement in industrial R&D," *International Journal of Management Reviews,* vol. 2, pp. 111-143, 2000.

[23] A. Neely, C. Adams, and P. Crowe, "The performance prism in practice," *Measuring Business Excellence,* vol. 5, pp. 6-12, 2001.

[24] K. F. Pun and A. S. White, "A performance measurement paradigm for integrating strategy formulation: A review of systems and frameworks," *International Journal of Management Reviews,* vol. 7, p. 22, 2005.

[25] B. Nixon, "Conference report: Performance measurements for R&D," *R & D Management,* vol. 27, pp. 87-90, 1997.

[26] A. Syamil, J. Doll William, and H. Apigian Charles, "Process performance in product development: measure and impacts," *European Journal of Innovation Management,* vol. 7, pp. 205-217, 2004.

[27] S. Johnsson, L. Cederblad, C. Norström, and A. Wall, "Productivity framework for innovative product development " in *5th International Symposium on Management of Technology*, Hangzhou, China, 2007, pp. 1655-1659.

[28] V. Tang, B. Liu, B. A. Kellam, K. N. Otto, and W. Seering, P, "Enabling factors in successful product development," in *International conference on engineering design* Melburne, Australia, 2005.

[29] H. Ernst, "Success Factors of New Product Development: A Review of the Empirical Literature," *International Journal of Management Reviews,* vol. 4, pp. 1-40, 2002.

[30] R. G. Cooper and E. J. Kleinschmidt, "Winning business in product development: The critical success factors," *Research Technology Management,* vol. 50, pp. 52-66, 2007.

[31] R. Adams, J. Bessant, and R. Phelps, "Innovation management measurement: A review," *International Journal of Management Reviews,* vol. 8, pp. 21-47, 2006.

[32] J. Bessant and J. Tidd, *Innovation and entrepreneurship*. Chichester: John Wiley & Sons Ltd, 2007.

[33] C. M. Christensen, *The Innovator's Dilemma: The Revolutionary Book that Will Change the Way You Do Business*. New York: Collins 2003.

[34] M. A. Schilling, *Strategic management of technical innovation*, 2 ed.: McGraw-Hill, 2006.

[35] T. Foos, G. Schum, and S. Rothenberg, "Tacit knowledge transfer and the knowledge disconnect," *Journal of Knowledge Management,* vol. 10, pp. 6-18, 2006.

PAPER C

Modeling Performance in Complex Product Development – A Product Development Organizational Model

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Abstract

The area of performance has challenged scholars from different functional backgrounds resulting in rich and deep streams of functionally specialized research, with little cross-fertilization. As a result, it is difficult for researchers to build on previous work. Further, succeeding with new products is vital in today's changing business environment. Product development (PD) is therefore considered an important process, making performance in PD of even greater importance. The contribution of this research is the Product Development Organizational Performance Model (PDOPM), making it possible for managers to reason about performance in PD. The model consists of three generic levels of activities: product strategy, project management and product activities. Each level of activity uses resources to transform input to output under the direction of goals and constraints. This view of an activity is based on the familiar IDEF0 concept. The goal of the product strategy activity is related to the business strategy and the output of the activity is the goal for the project management activity. Project management translates the goal into outputs that become goals for the product activities. This way of modeling the product development (PD) process with three generic levels of activities makes it possible to analyze performance from the three perspectives. Effectiveness, efficiency and uncertainty are defined for the three generic levels of activities. Effectiveness can be expressed as how the output relates to the goal of the activities whereas efficiency can be defined as the difference between output and input divided by the used resources. The uncertainty can be viewed as the difference between the goal and the input. A first verification of the PDOPM has been performed by a root cause analysis of three problem areas selected from the result of a previously conducted case study. Furthermore, the PDOPM can be used as a way of discussing the effect which these three levels of activities have on PD as a whole (i.e. from a holistic view, aligning product strategy, project management, and product activities).

Keywords: Performance, decision-making, uncertainty, complex product development, PDOPM, measurement

Introduction

Product development (PD) is, for every technology driven company, an important business process in order to secure future growth and sustained success in the marketplace. In today's changing business environment characterized by technological advances, intensified global competition, changing customers and needs [1], the need for a successful PD is greater than ever. PD is a process and like any other management process, it can be improved to achieve better results [2]. Unfortunately, while the academic literature has made numerous contributions to the understanding of how PD should work, less attention has been paid to the question of why organizations so often fail to execute their PD processes as desired [3]. This paper study complex product and systems (CoPS), defined by Hobday [4] as high cost, high technology, engineering intensive, business to business capital goods, used to produce goods and services. The PD process itself is known as being complex, often characterized by non-programmed decision situations and uncertainty. The stock market's obsession with quarterly earnings forces companies to minimize cost and time to market, often at the expense of the value creation [5]. As a result, performance measures tend to focus on cost and time delays instead of the value progress. This could be the reason why performance may be considered equal to efficiency. Focus, in the PD process, tends to be on finishing the project and not in creating the best possible product. Consequently, early phases of PD are frequently mistreated because of fire fighting activities within in old projects [3].

It could be argued that performance measurement is not and never can be a field of academic study because of its diversity [6]. With this in mind, this research views the PD process from three different perspectives: decision making, uncertainty, and performance to manage this diversity. The research question to which this research ultimately will try to contribute to is: How can performance in PD be improved? This research however, takes a PD manager's perspective by emphasizing a holistic system view of the performance in the PD process. Thus, the research question in this paper is:

How can performance be modeled in the product development process?

To address this research question, a conceptual PD model involving decision making, uncertainty and performance has been developed. The proposed Product Development Organizational Performance Model (PDOPM) can be used as a tool for further research, but also as a conceptual model for PD managers to reason about performance. Further, this paper aims at developing a general syntax within PD performance that allow companies to define their own performance measures, according to their specific needs.

Methods and Methodology

This paper is the first in a series of several, aiming at describing the ongoing development of the PDOPM. Blessing's [7] Design Research Methodology (DRM) is the base for the research and this paper is a result of the research clarification stage of the DRM.

To deal with the complexity of PD, a combined systems theory with an actors' approach has been adopted, in accordance with the views of Arbnor and Bjerke [8]. Increased complexity stresses the need for models that could be used for teams to develop a shared understanding [9]. Systems theory is a promising effort to deal with this problem, where an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [10]. Instead of adopting a rational approach, where only one correct explanation for how data is connected to theory, a systems approach is adopted where knowledge is built up from the studied indicator effects. This means that the forces influencing the system are important. Further, the relationships are not necessarily deterministic or stochastic. It is also important to see the processes of change for the system, rather than taking snapshots.

Several extensive studies on uncertainty management, part of one of the authors PhD [11], has served as a foundation for this research. The starting point of this research was first developed through a workshop together with senior PD managers in seven different high-tech industrial companies. The companies are all international companies, based in Sweden. They all have extensive experience in developing CoPS within telecommunications, automotive and automation. This formed the initial ideas and problem statements on PD, including factors affecting performance. This research then continued through identification of gaps in literature by reviews within decision-making theory, uncertainty management, and PD performance. A total of twenty semi structured and open interviews was held at 4 companies to identify the need for change within the management of PD at different levels in the organizations. These results were then incorporated into the PDOPM. Further, the authors professional work experience within complex

PD was also used for reasoning during the development of the PDOPM. The first results are presented in this paper.

Theoretical Foundation

The body of knowledge within the area of PD and performance is vast but diverse. Clark and Fujimoto [12] argue that PD is critical because new products are becoming the nexus of competition for many firms. Thus, PD is among the essential processes for success, survival, and renewal of organizations, particularly for firms in either fast-paced or competitive markets [13]. The importance of PD and its interdisciplinary nature has attracted scholars from different research communities; contributing to the body of knowledge within PD. Krishnan and Ulrich [14] argue for at least four common perspectives of PD in the literature: marketing, organization, engineering design and operations management.

Different aspects of product development

The following definition of PD by Ulrich and Eppinger [15] has found broad acceptance within the research community:

"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."

This research acknowledges this definition; however it is suggested to include the tools and methods that are used to perceive the market opportunity. A PD project is successful if its products not only fulfills the needs and requirements of customers, but also generates profits to its shareholders, and creates value to its stakeholder at large. Successful PD is fundamentally a multidisciplinary process. Olson *et al.* [16] show especially that higher project performance is demonstrated when cooperation between marketing and R&D, and cooperation between operations and R&D is high during early stages of PD. With the definition of PD in mind it is suggested to view the PD process as three generic levels of activity; product strategy, project management, and product activities. These generic levels of activities require different capabilities of an organization in order to be successful. There has been extensive research within each of these generic levels of activity. Instead of bringing them together in a system view of the complete PD process, a tendency to divide and separate them from each other is common. However, a few authors ([17]; [18]; [19] argue for a change of the view of PD, from a problem-solving activity based view to a decision-making view. The decision-making view is commonly focused on the relations between decision and their impact on several aspects of overall PD performance. The decision-making view is aimed at supporting non-programmed decision situations. It aims at enabling decision-makers to consider the decision at hand in a holistic PD context, resulting in less sub-optimizing decisions. In the following sections the literature in strategy, project management, and product activities is briefly reviewed.

Strategy in product development

The basis for a strategy in the PD process may be the business strategy. A business model is defined by Zott and Amit [20] as a structural template of how a focal firm transacts with customers, partners, and vendors. It captures the pattern of the firm's boundary spanning connections with product markets and other factors. Peter Drucker is recognized as a pioneer in business strategy and one of the first to recognize that the purpose of a business is external in creating and satisfying customer needs [21]. By aligning the strategy of PD with the business strategy, it may be easier to get senior management support. Senior management support has been identified by many authors as an important success factor in PD (See e.g. [22] or [23].

Zott and Amit [20] argue product strategy to be the pattern of managerial actions that explains how a firm achieves and maintains competitive advantage through positioning in product markets. It could be argued that the role of the product strategy is to identify the needs of the chosen market and decide which products to develop in order to satisfy those needs. According to Krishnan and Ulrich [14] there are five generic questions at the product strategy level; What is the market and product strategy to maximize probability of economic success?, What portfolio of product opportunities will be pursued?, What is the timing of PD projects?, What assets (e.g. platforms), if any, will be shared across which products? Which technologies will be employed in the product(s)?

An example of a strategic decision within PD is of becoming a first mover or a fast follower. A first mover to the market may face considerable uncertainty about what product features customers will ultimately desire and how much they will be willing to pay for them [24]. Mechanisms that promote first mover advantages include proprietary learning effects, patents, preemption of input factors and locations, and development of buyer switching costs [25]. Porter [26] distinguishes between operational effectiveness which means performing similar activities better than rivals perform them and strategic positioning which means performing different activities from rivals or perform similar activities in different ways.

The PD portfolio should have a strategic focus which gives an overall direction to individual PD projects [23]. In Cooper and Kleinschmidt's [27] study, the construct of 'new product strategy' is the second most important success factor for the PD program. Firms that include an explicit strategy step in their PD process are more likely to produce successful new products [28]. It is also essential to keep the product strategy updated, to balance the tendency of just focusing on finishing the current active PD projects. This phenomenon is acknowledged by many authors as their focus turn from the project level to a more strategic view. Kaplan and Norton [29] introduced the Balanced Scorecard and since then their focus shifted towards strategy with the introduction of strategy maps. Cooper [30] introduced the Stage Gate model and today he emphasizes the importance of strategic buckets.

Project Management in product development

Requirements and product complexity are increasing, PD schedules are shrinking, and the competitive environment among customers and suppliers is on the rise. As a result, projects become more complex. In addition, higher demands are placed on the performance of projects both internally and externally. Expressed basically, project management is the process by which a project is completed successfully. However, there are several aspects of project management to consider. In order to better understand project management, it is important to understand what a project is. Obviously, several definitions of a project exist. PMBOK [31] defines project as *a temporary endeavor undertaken to create a unique product, service, or result*. A frequently referenced definition is the one of Turner [32]:

An endeavor 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 states some characteristics that need to be further explained. First, the project is organized in a novel way, hereby 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 differs depending on 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 the more standard operations. We undertake projects because we cannot produce, or achieve the benefit, by doing routine things, and the expected benefits from doing the project outweigh the risk [32].

Product activities in product development

When studying PD at a product activity level the analysis is often focused upon engineering design and the activities that directly impact the design of the product. There is a vast amount of PD activity models (See e.g. [33], [15] or [34]. These models vary their approaches depending on what is being developed. Other authors argue for the importance of different aspects of PD, e.g. integration of work procedures, information management and support tools so the complexity of PD can be managed in an effective and efficient way [35]. Ottosson [36] argues for Dynamic PD (DPD) which aims at supporting real time communication of qualitative information. DPD also facilitates control and guidance in real time, reducing unwanted events [36].

However, designing is not the only activities on a product activity level adding value to the overall performance of a PD organization. In a PD project there are several aspects which contribute to the success of a product and its overall goal, e.g. revenue and market share. These aspects are impacted through decisions being made on a product activity level. Hansen and Andreasen [17] 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.

Uncertainty versus risk

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. There are several attempts to classify what uncertainty is. Frank [37] describes uncertainties as either aleatory or epistemic. Aleatory uncertainty cannot be foreseen (from the Latin alea, meaning die (pl. dice), having to do with chance). Epistemic uncertainty, on the other hand, is defined from a lack of knowledge (could have been foreseen given more knowledge). Hillson and Murray-Webster [38] assert that the two aspects of uncertainty are variability and ambiguity. Here, variability means when a measurable factor can have one of a range of possible values.

Such uncertainty is, as described by Frank above, known as aleatory. 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 whether or not a particular event will happen at all, or whether something else unforeseen might occur. Also here, this type is described as epistemic uncertainty since there is incomplete knowledge about the situation under consideration. Pender (2001) argues that uncertainty applies when there is no prior knowledge of replicability and future occurrences defy categorization (i.e. aleatory uncertainty). In decision modeling, uncertainty is defined as the amount of lacking information that can become knowledge (i.e. epistemic uncertainty). It is not possible to see the link between uncertainty, risk, and opportunity from this. Instead Hillson [39] attempts to link risk with uncertainty based on the distinction between aleatory and epistemic uncertainty in the following couplet: *Risk is measurable uncertainty;Uncertainty is unmeasurable 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 [40], 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 paper, therefore, it is argued to view risk and opportunity as being derived from uncertainty.

Performance in product development

In organizations, project and process metrics are measured and acted upon. Since some activities are far too complex to measure, processes, models and other simplifications provide the possibility to measure performance. Often, performance is perceived primarily in terms of dimensions that can be measured, such as time and cost, or particular aspects of quality [41].

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. Different objectives of processes, both transactional (strategy processes, risk, and opportunity management for example) and operational (manufacturing for one), imply differences in difficulty to measure their performance. Although most processes have some type of metric to measure performance, their interaction on the overall PD performance would be 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, several sources of uncertainty are present which would 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 PD 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).

There is a lack of consistency in the definition of performance in the literature [42]. Within PD, effectiveness and efficiency is often a common denominator in the various definitions of performance. Sink and Tuttle [43] describe effectiveness as doing the right things at the right time, with the right quality. Efficiency is similarly described as doing things right, 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. The most commonly cited article and the most widely accepted performance measurement system is of the Balanced Scorecard [44]. A more recently introduced performance measurement system is the Performance Prism. This system is organized around five distinct but linked perspectives on performance; stakeholder satisfaction, strategies, processes, capabilities and stakeholder contribution [45].

In manufacturing, as an example, inventory turnover and gross margin percentage can be used as metrics of the manufacturing process [46]. However, PD is more difficult to measure than other business processes. Thus, there are no broadly accepted performance metrics as there are for other business processes. O'Donnell and Duffy [42] have developed a design performance model, based on IDEF0 [47], which tries to clarify the performance syntax. A basic but general activity model is shown in figure 1.

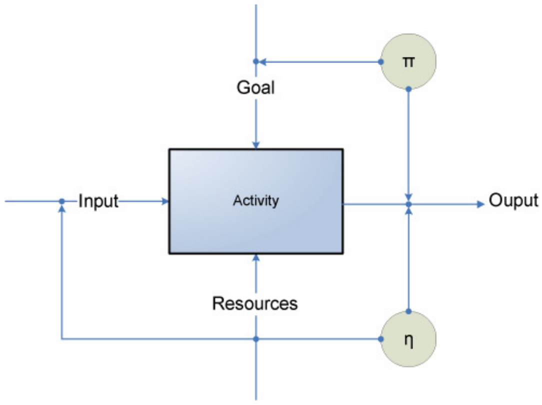

Figure 1. An activity uses resources to transform input to output under the direction of the direction of goals and constraints. The relation of effectiveness (Π) and efficiency (η) to the input and output variables is also shown. (O'Donnell and Duffy, 2002)

An activity uses resources to transform input to output under the direction of goals and constraints [42]. Input refers to the initial state of knowledge while output is the final state of the performed activity. Resources is not just the people involved in the activity but also other resources 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 [42] use this model of an activity to define efficiency (η) and effectiveness (Π).

The Product Development Organization Performance Model (PDOPM)

In this paper the PDOPM is introduced, see figure 2. The PDOPM is a holistic model based on three generic levels of activities in the PD: product strategy, project management, and product activity. Each of these generic levels can be modeled as an activity according to the IDEF0 [47].

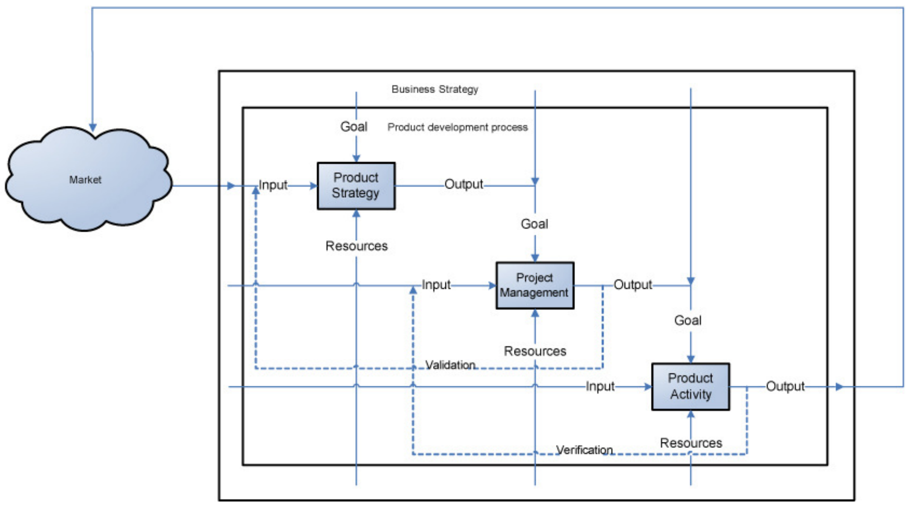

Figure 2. The proposed PDOPM model with the three generic levels of activities: product strategy, project management and product activity. The validation and verification illustrate the knowledge fed back to the product strategy and project management.

Each one of the three generic levels of activities uses resources to transform input to output under the direction of goals and constraints. In the product strategy, the decision of what product to develop is made and a PD project is initiated, realizing the selected customer needs. The project management activity then translates the selected customer needs into a product specification, serving as a goal for the product activities. In the product activity a product, according to the specification, is created. As for every activity, it is important to acknowledge the associated uncertainty. The PDOPM appreciates the inherent uncertainty in PD, as well as the uncertainty in activity input and in the decisions on output. In the next section, this paper will be further detailed on the different generic levels of activities and how performance, including uncertainty, can be modeled in the PDOPM.

Three Views on PDOPM

The PDOPM is based on three generic levels of activity identified in the PD process. These are further described below.

Product strategy in PDOPM

Within military strategies it is common knowledge that a strategy and its goals and objectives (i.e. output) does only survive until the first contact with the enemy. This reasoning and understanding stems from the experiences gained in warfare. This shows that although a comprehensive and, at the time, accurate plan is developed, uncertainty affects the strategic planning in such a way that it cannot be disregarded. Thus, the effect of uncertainty in PD performance must be appreciated in goal setting and in the input needed to create an efficient and effective output.

In business, value creation is typically measured by profitability and long term growth. In order to achieve those goals, a company must establish a continuing process for developing and delivering a steady stream of products, based on its business model, which offers unique and differentiated benefits to a chosen set of customers [48]. The objective of the PD portfolio needs to be defined and the meaning of their attainment for the overall goals of the organization must be clearly communicated [23]. The first step in the product strategy is to overview all the current stakeholders. Neely *et al.*, [45] propose a broad perspective, in contrast to the Balanced Scorecard, on stakeholders encompassing employees, suppliers, regulators, alliance partners, and intermediaries e.g. all parties that can have a substantial impact on the performance and success of the PD process. Product strategy is in this research 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.

Goal: To fulfill the business strategy, is the primary objective of the product strategy activity. It is important that the product strategy is aligned with the business strategy since it is the chosen path for overall company success. The goal of product strategy is to realize 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 PD process.

Input: 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 internal, within the company, and external, outside the company, is an important factor in deciding what product should be developed.

Resources: The main resource and responsibility of this activity is of the product manager. In many companies there is a steering committee assisting the product manager with this activity. Normally, senior management from marketing, sales, manufacturing, finance, etc is involved in the product strategy.

Output: The chosen market needs, are the output from the product strategy. The output of the product strategy activity serves as goal 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 PD process. In this paper, the PDOPM is simplified by covering 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 PD project is initiated. Once a new project is started, product management should secure that the right product is developed and monitor that the targeted customer needs still are of interest. Both of these tasks are important in securing a successful PD process.

Project management in PDOPM

PMBOK [31] describes an objective as *something toward which work is to be directed, a strategic position to be obtained, or a purpose to be achieved, a result to be obtained, a product to be produced, or a service to be performed*. The objective of a project can be described in different ways. The most common manner is by using the iron triangle of time, quality and cost. Turner [32] defines five project objectives: managing scope, managing organization, managing quality, managing cost and managing time.

When the product strategy activity output is decided, a PD project is initiated to carry out and ensure that the selected customer needs are realized in an efficient and effective way. The responsibility of managing the design 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 developed by Cooper [30] is a tool, commonly used by product managers to supervise and secure that the right product is developed. The role of the project manager is to be the catalyst between the output from the product strategy and the resources involved in the product activity. The project management activity should be performed in an iterative way, in close interaction with the product activities.

The essential purpose of uncertainty management is to improve project performance via systematic identification, appraisal, and management of project-related uncertainty [41]. All in all, the management of uncertainty does not in itself, as a process bring value to the project. However, it assists other processes to bring value to the PD process. The input, goal, resources and output of the project management activity, as modeled in figure 2, are further discussed below.

Goal: The goal is represented by 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 a schedule for when the product should be realized by the project. One important task for the project management is to agree and clarify the goal of the initiated PD project with the product manager. There should be an agreement between product managers and project mangers on the PD project's objective in the beginning of the project.

Input: 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 CoPS normally use some type of platform or architecture that can be used by the project. Knowledge about the 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 for a more radical one [49].

Resources: For smaller projects it is common to only include the project manager. In more complex PD projects there is often a project core team to assist the project manager in managing the project.

Output: Is a project requirement specification with concrete activities that will function as goal for the product 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 all activities that will be performed in the product activities.

The project management activity serves as a bridge between the product strategy and the product 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 for designing the wrong product.

Product activities in the PDOPM

It is during the product activities the product is being designed. The product activity includes all activities requested by the project management. The role of the product activities is to solve and realize the initiated activities as efficient and effective as possible. The product activities should be performed in close cooperation with the project management since it is an iterative process. The product activity, as modeled in figure 2, with a goal, input, resources and outputs is further discussed below.

Goal: Is the requirement specification that is developed in the project management activity. The objective with the product activity is to realize the specified requirements.

Input: Includes e.g. knowledge about prior project and product activities, development processes and working tools. Often is a new product not developed from a blank paper but instead starting from a previous product or architecture. Therefore, it is important that the people involved in the product activities are familiar with this previous knowledge.

Resources: All resources used by the product activities are included. Primarily this involves the people personnel but also computer tools, materials, techniques, and information sources.

Output: Is not just the finished product, it also consists of the deliverable, specified in the product requirement specification, which together make up the product. The finished product normally involves different parts that are integrated to a final product.

Within a PD 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 product 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 reason is to monitor the progress to make sure that the budget and schedule is kept. If there are deviations it is important to be aware of them early to be able to address them.

Product Development Performance in PDOPM

Performance in PD is seldom defined and there is no consensus of what performance is [42]. The proposed PDOPM makes it possible to define efficiency, effectiveness and uncertainty within the three generic levels of activity: product strategy, project management, and product activities.

Measurement, when done properly, i.e., linked to a purpose or goal that managers and employees have accepted, can drive and motivate performance improvement [43].

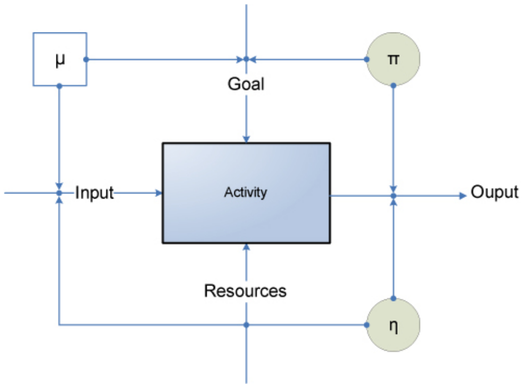

Figure 3. Illustrates the relation of uncertainty, effectiveness and efficiency to the input and output variables of an activity.

Performance and product strategy

Product strategy effectiveness (Π) is defined as how the output meets the goal. In this case, the goal is to fulfill the business strategy and thus, it is important that the output is clearly linked to the business strategy. In doing this, ownership from upper management is encouraged and it is as previously stated an important success factor. By achieving effectiveness in the product strategy, a foundation for successful PD is established.

Product strategy efficiency (η) is defined as the difference between output and input divided by the resources used i.e. the cost to realize the output. The output of the product strategy is what market needs the new product is satisfying and the input is the initial knowledge prior to the activity. Therefore, it is important that the difference is not too complex and can be managed by the resources, i.e. senior management, involved in the product strategy. Efficiency of the product strategy is often forgotten and not explicitly measured.

Product strategy uncertainty (μ) is defined as the difference between the goal and the input. This means that the uncertainty in product strategy is a measure of the new knowledge that is required in the PD project. This uncertainty measure could be used in the portfolio evaluation to make sure there is a mix between incremental and more radical PD projects. Within the

PD portfolio there should be a mix of uncertainty in order to get the most return of the investment.

Performance and project management

Project management effectiveness (Π) is defined as how the output meets the goal e.g., how the selected customer needs, output from the product strategy, is transformed to a product specification. Effectiveness within the project management is therefore a measure of how the project is realizing the scope of the project. Effectiveness is achieved when all the selected needs from the product strategy have been fulfilled. It is therefore important for the project manager to function as a bridge between the product strategy and the product activities.

Project management efficiency (η) 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, it is noticed in budget and time overruns as a result of product activities with to high complexity. Project managers tend to focus on finishing the specified activities on schedule and budget i.e. the efficiency aspect. It is therefore important to remember that if the effectiveness of the project management activity cannot be guaranteed, everything else is of minor importance.

Project management uncertainty (μ) is defined as the difference between the goal and the input. It is therefore a measure of what has to be created by the PD project. If there is a lot of new knowledge needed in the project, the product activities tend to be complex and will therefore affect both efficiency and effectiveness. Project management uncertainty can be viewed as a leading indicator of the effectiveness and efficiency.

Performance and product activities

Product activities effectiveness (Π) is defined as how the output i.e. the realization of the activity meets the goal for the activity. This is an important measure, often is focus turned to the output and the goal is forgotten. It is when the product activity effectiveness can be accounted for that focus can turn to measuring and securing the efficiency. An ultimate failure of the PD process would be to have product activities that are managed in an efficient way, on time and budget, but they do not meet the goal. It is therefore vital that a project manager within PD always focus on securing the product activity effectiveness by communicating a clear and well defined goal for the activity.

Product activity efficiency (η) is defined as the difference between output and input divided by the resources used to realize the output. Thus, efficiency in product activities may be used as a way to make sure that the invested resources are used the best possible way. Improving the product activity efficiency is often done by improving the PD processes or tools, development of competence etc. Often, the product activities do not begin with a blank piece of paper when developing a new product. A shared platform or architecture is often available for the product activity to use as base and starting point. Product activity efficiency is dependent on having a platform or architecture, supporting the realization of the specified product. It is a difficult task of knowing when a new platform or architecture should be developed in order to secure product activity efficiency.

Product activity uncertainty (μ) is defined as the difference between the goal and the input. It is therefore a measure of how complex the activity is and therefore what type of resources that is required for an efficient and effective realization of the activity. By measuring the product activity uncertainty, it is possible to manage the uncertainty and discover potential problems early when there still is time for changes without risking any substantial costs.

Performance in the product activity is achieved when uncertainty, effectiveness and efficiency are being managed. The objective of increasing performance may be accomplish by identifying weaknesses and address them early in the PD project.

Verification and Validation in the PDOPM

Every company seeks to fulfill the customer needs of the targeted market. As a result, the company needs to manage certain market specific constraints in order to be successful. Within the defense industry, for example, there may by a lead time of many years for a new PD project. This could be compared with, for example, the mobile phone industry where time to market is a deciding factor on the success of a new product. The time factor within the PDOPM is not explicitly shown in the model. However, there is strong time dependence in the PDOPM, which is incorporated in the verification and validation loop, see figure 2. The two feedback loops also represents the learning’s that can be made from each generic level of activity in the PD process. Validation and verification may be used by PD management to ensure that the correct activities are being performed and the different outputs match the specified goal.

Validation in the PDOPM

The validation loop represents the feedback from the output of the project management and it is modeled as an input to the product strategy. The validation represents the possibility for the product manager to see the progress of the PD project. Also, the validation could be viewed as a representation of the time to market constraint of the chosen customer needs. Often is the task of developing the right product taken for granted and therefore not questioned once a project is started. It is possible for customer needs to change during a PD 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 PD portfolio. The lead-time of the validation loop differs between markets and products. As mentioned, in the defense industry, a lead-time of many years for a PD 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 influence the verification loop since if there are changes in the customer needs it must be reflected in the PD activities.

Verification in the PDOPM

The verification loop in the PDOPM is modeled as the feedback from the output of the product activity to the input of the project management activity. By representing it this way, it shows the possibility for the project manager to view the progress and the output of the product activities. Through verification, it is possible to ensure that the produced output from the product 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 timeframe of the validation loop. If the chosen market is expecting new products every year, the PD lead-time within the company must be within that limitation. It is important to monitor the verification loop during the PD cycle to secure that the output from the PD project is aligned with the output from product strategy. If the selected customer needs have changed it is important to understand the change and act accordingly. The timeframe of the verification loop differs depending on the validation loop. The verification timeframe is linked to the validation loop. Since, changes in the market puts constraints on the verification loop in order to fulfill the validation time frame.

Applying the PDOPM in an Industrial Setting

As a first attempt to verify the PDOPM, it has been used to analyze some problem areas identified during a previously performed case study. The PDOPM can be used as a tool for identifying the root cause of problem areas within PD. To verify the PDOPM the following problem areas where selected from the result of the case study:

(i) Complicated solutions are often selected, even when there is no obvious reason. This prohibits reuse of known solutions and standard products. As a result, an unnecessary amount of, for example, special cables are used by the different products. A discussion to reduce the number of components has started but there is a lack of long-term thinking, everything is short-term oriented.

(ii) It is not unusual to have overload in the PD process, both in the PD project and in the project portfolio. As a result, overruns in budget and schedule is a recurring phenomenon. An illustrative quote from one of the respondents: *"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 in average."* The effect is that at the end of the PD project, requirements that have not been fulfilled 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 respondent expressed it: *"It is like obesity; we know it is not good but we keep eating anyway"*.

(iii) The view of PD performance is focused on shortening cycle-times, deliver on time, and reduce time to market. Looking at the NPV calculations in the business case it is clear; in order to receive a positive cash flow as quick as possible, reduced cycle-times and time to market are essential. Quality is also mentioned together with performance. The case company has substantial costs related to products delivered to customers not working properly.

Root cause analysis of the three identified problem areas

The first problem area is related to the product strategy activity in the PDOPM, see figure 2, but in the case company it is not managed as one. The necessary decisions are pushed away and end up in the project management activity. As a result, the decision has to be made by the project management activity within each project. The outcome is a PD project making decisions based on the knowledge and the needs of the projects. Sub-optimization in the perspective of the case company may be the result, when a PD project makes their decisions without clear and well defined goals from the product strategy. The lack of long-term product thinking is a natural phenomenon when the product strategy activity is not managing this issue properly. Expressed in terms of the PDOPM, the output from the product strategy is missing 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. Overload of the project in the early phases and running the company faster than it is possible, is a phenomenon that can be analyzed in the validation and verification of the PDOPM. The capacity of the resources employed by the PD project is vital input for the project planning, within the project management activity. Further, it may solve overload issues in the PD pipeline by thinking of the validation and verification loops and use the gained knowledge to initiate changes in the output of the product strategy activities. Discussion of project management uncertainty may also be useful in order to reason about the complexity required by the PD project. Overload of the project can be interpreted as failing to manage the product strategy and project management uncertainty since it represents the new knowledge needed to create the decided output from the product strategy.

The third problem area is of PD performance and the need for a holistic view. To improve performance, focus should also turn to the product and project management activities and not exclusively focus on the product activity output. It is of course important with; shorten cycle-time, deliver on time and shorten time to market, but when the complete PD process is managed accordingly, it may lead to incremental updates and PD projects characterized by low uncertainty. 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 time to market and cycle-time of PD 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 maximum potential. The performance of PD, illustrated in this issue, is focused on the efficiency aspect of performance in the project management and product activities of the PDOPM. If uncertainty and effectiveness aspects of these activities were included together with performance of the product strategy, the focus of maximizing the value contribution of the PD budget could be achieved.

Conclusion and Future Research

The PDOPM suggested in this paper enables PD managers to adopt a holistic view and to analyze the PD process from the perspectives of product management, project management, and product activities. The model can be used as a conceptual tool to reason about performance, thus making it possible to question the performance within each level of the PD process. It is argued, that by modeling the three generic levels as activities, it makes the often abstract activities in PD more understandable. This is done by reasoning about input, goal, and resources, not just the output. This applies particularly to the product strategy and project management activities. Further, the definitions of effectiveness, efficiency, and uncertainty for each generic level are useful ways of analyzing performance, even if there is no tangible output created. This may be especially useful, in the product strategy and the project management activity.

In industry it is common for management to look for easy solutions to boost performance of the PD. Focus is often turned to the efficiency of the product activities in order to improve the overall PD performance. In this research it is suggested that performance in the PD process is achieved through three steps. The first step is to manage the uncertainty, since it is the knowledge of what needs to be created to fulfill the goal. Next step is to secure effectiveness, in order to create the right product. Once the first two steps are established, focus on efficiency, e.g. developing the product right, becomes important. Performance is attained when uncertainty, effectiveness and efficiency is managed in all of the generic levels of activities in the PDOPM.

There is extensive research available within each of the generic levels of activities in the PDOPM. However, instead of bringing them closer together in a system view of the complete PD process, a tendency to divide them and separate them from each other exists. 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 in each of the generic levels of activities, but the ability to holistically manage the PD process. Only by adopting a holistic view, it is possible to identify the difficulties and limiting factors present in a company's PD process without sub-optimizing. By identifying and improving the weakest parts, the largest lever to overall performance, is achieved. Future research will focus at further verify and develop the model by case studies within the context of complex PD.

References

[1] K. Goffin and R. Mitchell, *Innovation Management: Strategy and Implementation Using the Pentathlon Framework*. London: Palgrave MacMillan, 2005.

[2] M. E. McGrath, *Next Generation Product Development : How to Increase Productivity, Cut Costs, and Reduce Cycle Times*. New York: McGraw-Hill, 2004.

[3] N. P. Repenning, "Understanding fire fighting in new product development," *The Journal of Product Innovation Management,* vol. 18, pp. 285-300, 2001.

[4] M. Hobday, "Product complexity, innovation and industrial organization," *Research Policy,* vol. 26, pp. 689-710, 1998.

[5] T. Koller, M. Goedhart, and D. Wessels, *Measuring and managing the value of companies*, 4 ed. New Jersey: John Wiley & Sons, 2005.

[6] A. Neely, "The evolution of performance measurement research: Developments in the last decade and a research agenda for the next," *International Journal of Operations & Production Management,* vol. 25, pp. 1264-1277, 2005.

[7] L. T. M. Blessing and A. Chakrabarti, "DRM: A Design Research Methodology," in *Proceedings of the Conférence Internationale Les Sciences de la Conception.*, INSA-Lyon, 2002.

[8] I. Arbnor and B. Bjerke, *Methodology for Creating Business Knowledge*. USA: Sage Publications, 1997.

[9] D. Katz and R. L. Kahn, *The Social Psychology of Organizations* 2ed. New York: John-Wiley & Sons, 1978.

[10] P. M. Senge, *The Fifth Discipline, the Art & Practice of Learning Organizations*. New York: Currency Doubleday, 1990.

[11] R. Olsson, "Managing Project Uncertainty by Using An Enhanced Risk Management Process." vol. Doctoral Västerås: Mälardalen University, 2006.

[12] K. B. Clark and T. Fuijimoto, *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*: Harvard Business School Press, 1991.

[13] S. L. Brown and K. M. Eisenhardt, "Product development: Past research, present findings, and future directions," *Academy of Management. The Academy of Management Review,* vol. 20, pp. 343-379, 1995.

[14] V. Krishnan and K. T. Ulrich, "Product Development Decisions: A Review of the Literature," *Management Science,* vol. 47, pp. 1-21, 2001.

[15] K. T. Ulrich and S. D. Eppinger, *Product design and development* 3ed. Singapore: McGraw-Hill Education, 2003.

[16] E. M. Olson, O. C. Walker, R. W. Ruekert, and J. M. Bonner, "Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance," *The Journal of Product Innovation Management,* vol. 18, pp. 258-271, 2001.

[17] C. T. Hansen and M. M. Andreasen, "A Mapping of Design Decision-making," in *International Design Conference – Design 2004* Dubrovnik, 2004.

[18] T. Gidel, R. Gautier, and R. Duchamp, "Decision-making framework methodology: an original approach to project risk management in new product design," *Journal of Engineering Design,* vol. 16, pp. 1-24, 2005.

[19] J. W. Herrman and L. C. Schmidt, "Viewing Product Development as a Decision Production System," in *Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Montreal, Canada, 2002.

[20] C. Zott and R. Amit, "The fit between product market strategy and business model: implications for firm performance," *Strategic Management Journal,* vol. 29, pp. 1-27, 2008.

[21] R. Koch, *The financial times guide to strategy - How to create and deliver a winning strategy* 3ed.: Trans-Atlantic Publications, 2006.

[22] R. G. Cooper and E. J. Kleinschmidt, "Winning business in product development: The critical success factors," *Research Technology Management,* vol. 50, pp. 52-66, 2007.

[23] E. Holger, "Success Factors of New Product Development: A Review of the Empirical Literature," *International Journal of Management Reviews,* vol. 4, pp. 1-40, 2002.

[24] M. A. Schilling, *Strategic management of technical innovation*, 2 ed.: McGraw-Hill, 2006.

[25] M. B. Lieberman and D. B. Montgomery, "First-Mover Advantages," *Strategic Management Journal,* pp. 41-59, 1988.

[26] M. E. Porter, "What is strategy?," *Harvard Business Review,* vol. 74, pp. 61-79, 1996.

[27] R. G. Cooper and E. J. Kleinschmidt, "Benchmarking the Firm's Critical Success Factors in New Product Development," *Journal of Product Innovation Management,* vol. 12, pp. 374-391, 1995.

[28] A. Griffin, "PDMA research on new product development practices: Updating trends and benchmarking best practices," *The Journal of Product Innovation Management,* vol. 14, pp. 429-458, 1997.

[29] R. S. Kaplan and D. P. Norton, "The Balanced Scorecard measures that drive performance," *Harvard Business Review,* vol. No. January-February, 1992.

[30] R. G. Cooper, *Winning at new products: Accelerating the process from idea to launch*. Cambridge, MA: Perseus Books, 2001.

[31] PMBOK, *A guide to the project management body of knowledge*. Newton Square, Pennsylvania, USA.: Project Management Institute 2004.

[32] J. R. Turner, *The Handbook of Project-Based Management: improving the processes for achieving strategic objectives*. Berkshire, England: McGraw-Hill, 1993.

[33] G. Pahl and W. Beitz, *Engineering design: A systematic approach*. London: Springer-Verlag London Ltd., 2007.

[34] D. G. Ullman, *Mechanical design process*. New York: Mcgraw-Hill Education - Europe., 2002.

[35] M. Norell, "Stödmetoder och samverkan i produktutveckling: Advisory tools and co-operationin product development." vol. PhD Stockholm, Sweden: KTH, 1992.

[36] S. Ottosson, "Dynamic product development - DPD," *Technovation,* vol. 24, 2004.

[37] M. K. Frank, "Treatment of uncertainties in space nuclear risk assessment with examples from Cassini mission implications," *Reliability Engineering and System Safety,* vol. 66, pp. 203-221, 1999.

[38] D. Hillson and R. Murray-Webster, *Understanding and managing risk attitude*. Hants, England.: Gower Publishing Ltd, 2005.

[39] D. Hillson, *Effective Opportunity Management for Projects – Exploiting Positive Risk*. New York, USA: Marcel Dekker 2004.

[40] F. Lefley, "Approaches to risk and uncertainty in the appraisal of new technology capital projects," *International Journal of Production Economics,* vol. 53, pp. 21-33, 1997.

[41] C. Chapman and S. Ward, *Project Risk management – Processes, Techniques and Insights*. Chichester, England: John Wiley & Sons, 1997.

[42] F. J. O'Donnell and A. H. B. Duffy, "Modelling design development performance," *International Journal of Operations & Production Management,* vol. 22, pp. 1198-1221, 2002.

[43] D. S. Sink and T. C. Tuttle, *Planning and Measurement in your Organisation of the Future*. Norcross, GA: Industrial Engineering and Management Press, 1989.

[44] A. Neely, "The performance measurement revolution: why now and what next?," *International Journal of Operations & Production Management,* vol. 19, pp. 205-228, 1999.

[45] A. Neely, C. Adams, and P. Crowe, "The performance prism in practice," *Measuring Business Excellence,* vol. 5, pp. 6-12, 2001.

[46] M. E. McGrath and M. N. Romeri, "FROM EXPERIENCE The R&D Effectiveness Index: A Metric for Product Development Performance," *Journal of Product Innovation Management,* vol. 11, pp. 213-220, 1994.

[47] G. J. Colquhoun, R. W. Baines, and R. Crossley, "A State of the Art Review of IDEF0," *International Journal of Computer Integrated Manufacturing,* vol. 6, pp. 252-64, 1993.

[48] D. R. Spitzer, *Transforming performance measurement - Rethinking the way we measure and drive organizational success*. New York: Amacom, 2007.

[49] R. Foster, *Innovation: the attacker's advantage*. New York: Summit books, 1986.

PAPER D

What is Performance in Complex Product Development?

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Abstract

The process of developing new products is one of the key business processes in a company, especially technology intensive ones. In order to continuously improve the capability of developing new products it is important to be able to measure the performance in the product development process. The dilemma though is that there are no good performance measurements available within complex product development. One reason, as argued in this research, is the lack of a holistic perception of performance within the development process. Data from an explorative five case study including 49 semi-structured open interviews regarding performance indicate that performance is perceived in terms of time, cost, and quality i.e., what is measured. Thus, in order to develop better measurements of performance, the perception of performance needs to be changed first.

To meet this need, a Product Development Organizational Performance Model (PDOPM) is proposed, consisting of three generic levels of activities: product strategy, project management, and product activities. These generic activities are modelled in accordance with the IDEF0 framework making it possible to conceptually reason about uncertainty, effectiveness, and efficiency at each activity level. Product development effectiveness and efficiency are also defined for the complete process. Further, product development efficacy is introduced to describe the capability of identifying or creating a market opportunity and being able to develop and deliver a product fulfilling exactly what was identified as the market opportunity.

1. Introduction

One of the key corporate activities to differentiate oneself from competition, thus forming a fundamental part of the core competencies of a successful company, is the process of developing new products and services. Today, the market is more competitive than ever [1], thus, the demand for the product development (PD) process to continuously deliver sustainable value is greater than ever. PD is often organized in projects, which is suitable when a unique objective is to be achieved within a limited period of time. Traditionally, projects are evaluated using what is called the iron triangle or the triple constraint of quality, time, and cost.

In a recent study within a utility company, 72 percent of the PD projects failed against at least one of the goals of quality, time, and cost [2]. But surprisingly, 82 percent of the projects still ended up being financially successful. This interesting finding illustrates the weak link between what is measured in a PD project and how successful the developed product will become. What gets measured gets done [3] and you are what you measure [4] are two well known statements related to the use of measurements. Thus, if quality, time, and cost are the focus of the measurements, it may also be the only dimensions being managed.

In the literature, both within performance and PD, there is confusion in terminology. This may be the result of two research areas attracting scholars with various functional backgrounds. In a review of the PD literature [5], at least four common perspectives: marketing, organization, engineering design, and operations management were argued for. Moreover, to describe the process of developing new products, various terms like product innovation, innovation, engineering design, NPD, R&D, and PD are used. In this research the term PD is adopted to holistically describe the process of developing new products in a company, by proposing the following definition:

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

The proposed definition is an extension of the one argued for in [6].

Performance measurement is also a diverse subject, including researchers with functional backgrounds as varied as accounting, operations management, marketing, finance, economics, psychology, and sociology all actively working in the field [7]. A vast amount of research is also available within performance measurements and PD. Still, few studies analyze the PD process from a performance measurements system perspective [8].

Performance is often associated with effectiveness and efficiency. However, there are several different interpretations of effectiveness and efficiency in the literature. According to [9], effectiveness refers to the extent to which customer requirements are being met, while efficiency is a measure of how economically the firm's resources are used, when providing a given level of customer satisfaction. In [10] effectiveness is described as doing the right things at the right time, with the right quality. Efficiency is similarly described as doing things right, often expressed as a ratio between resources expected to be consumed and resources actually consumed. These examples clearly illustrate the diversity in the present terminology associated with performance. Moreover, PD is more difficult to measure than other business processes e.g., due to non-programmed decision situations and uncertainty. It is therefore not surprising that there are no broadly accepted performance measurements as there are for other business processes, e.g., manufacturing [11].

Since the area of performance and PD is a relatively young research area, it is natural that a common body of knowledge is missing. Hence, further research with a holistic perspective of performance in the PD processes is needed. The objective of this research is to explore how PD performance is perceived within the industry and to initiate a discussion of what performance in a complex PD context is. The outline of this paper is as follows. In Section 2 the methodology used in this research, including an explorative multiple case studies, is briefly presented. Further, in Section 3 a previously developed model of performance is presented and this model is used to analyze the perception of performance within complex PD identified in the case study. In Section 6 the term PD efficacy is introduced to holistically describe performance and the research is ended with conclusions and discussion in Section 7.

2. Methodology

To deal with the complexity of PD, a systems theory combined with an actors' approach has been adopted, in accordance with the views of [12]. Increased complexity stresses the need for models that can be used by teams to develop a shared understanding [13]. Systems theory is a promising effort to deal with this problem, where an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts. The real leverage in most management situations lies in understanding dynamic complexity, not detailed complexity [14]. Instead of adopting a rational approach where only one correct explanation exists for how data is connected to theory, a systems approach is adopted where knowledge is built up from the studied indicator effects. This means that the forces influencing the system are important. Further, the relationships are not necessarily deterministic or stochastic. It is also important to see the processes of change for the system, rather than taking snapshots.

Results from a multiple explorative case study on how performance is perceived and measured within large organizations developing complex products and systems within telecommunications, heavy vehicles, and automation are presented in this paper. The focus in this research is primarily on the parts of the case study involving the perception of performance. The explorative multiple case study was performed in accordance with the approach presented in [15]. A case study research strategy focuses on understanding the dynamics present within a single setting [16] and is therefore suited for exploring the perception of performance in complex PD. A total of 49 semi-structured interviews with open questions were held at the five case companies. The questions asked were stated in such a way that the respondents were encouraged to talk about what they thought important. The respondents were managers and decision makers at different levels of responsibility within the organization. Every interview lasted between 50 minutes and 2 hours.

3. The Product Development Organizational Performance Model (PDOPM)

In an attempt to clarify the confusion in terminology used to describe performance, [17] developed a performance model within engineering design, based on the IDEF0 framework [18]. A general model of an activity according to the IDEF0 is shown in Figure 1.

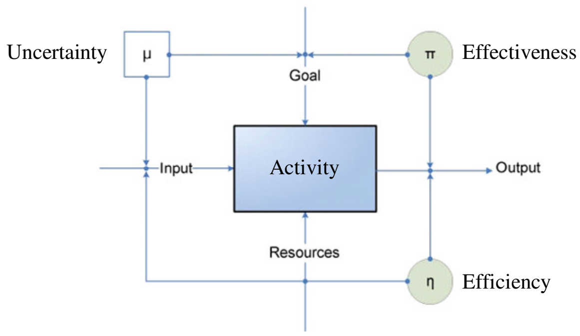

Figure 1. An activity uses resources to transform an input to an output under the direction of goals and constraints. The relation of uncertainty (μ), effectiveness (Π), and efficiency (η) to the input and output variables is also shown. The figure is inspired by (O'Donnell & Duffy, 2002)

An activity uses resources to transform an input to an output under the direction of goals and constraints. The input refers to the initial state of knowledge, 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 e.g., 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, [17] use this activity model to define effectiveness and efficiency. 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. Uncertainty is defined 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 [19].

With performance and the definition of PD in mind, we propose to divide the PD process into three generic levels of activities: product strategy, project management, and product activities. These generic activities are then related to each other in the PDOPM through the IDEF0 framework. In the following subsections the PDOPM, is presented (see Figure 2); in [19] a more detailed presentation of the model is given.

Product strategy in the PDOPM

In business, value creation is typically measured by profitability and long term growth. It is therefore important to establish a continuous process for developing and delivering a steady stream of products, based on its business model, which offers unique and differentiated benefits to a chosen set of customers (Spitzer, 2007). Aligning the product strategy with the business strategy is important for a successful PD process (Ernst, 2002).

In this research, product strategy is viewed as a pattern of decisions and actions performed today to ensure future success. In the product strategy, the decisions of what products to develop and why, to fulfill the business strategy are made. Further, within the product strategy it is important to balance the internal and the external perspectives e.g., the customer and market perspective with the perspectives of e.g., the internal capabilities and the performance of the current PD projects. If there are changes in the market or difficulties within a PD project, appropriate precautions need to be taken. Once it has been decided what is to be developed, it will serve as a goal for the project management activity to fulfill.

Project management in the PDOPM

The PMBOK (PMBOK, 2004) describes an objective as something toward which work is to be directed, a strategic position to be obtained, or a purpose to be achieved. Once the product strategy activity output is decided, the project management activity is initiated to ensure that the selected customer needs are realized in an efficient and effective way. The Stage Gate model is a tool, commonly used by product managers or similar persons responsible for the business effects of the project, to supervise and secure that the right products are developed (Cooper, 1993). The role of the project management is to make sure that the output from the product strategy is transformed into activities to be performed by the resources involved in the product activities.

Product activities in the PDOPM

The product activity includes all activities needed to fulfill what has been undertaken by project management to the product strategy, in order to design and implement the product. Within a PD project, it is important that the goals from project management are broken down into well-defined activities that can be realized in an efficient and effective way. To be successful in the product activity it is important that all activities are performed in close cooperation with the project management activity. This is especially important for two reasons, first, to ensure that the right product is being developed and second to monitor the progress in order to keep the budget and time plan. If there are deviations it is important to be aware of these early on in order to address them.

Effectiveness and efficiency in the PDOPM

By modeling the product strategy, project management, and product activities as activities in the PDOPM, it is possible to reason about how these activities relate to each other. Moreover, it is possible to explicitly define uncertainty, effectiveness, and efficiency for each activity, resulting in a holistic conceptual model of performance in the PD process. In [19] a more detailed description of uncertainty, effectiveness, and efficiency for each activity, is given. In this research effectiveness and efficiency are defined for the complete PD process.

PD effectiveness (Π_{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 from upper management is encouraged and it is an important success factor for the PD process (Ernst, 2002). Effectiveness in the PD process is the important foundation of a successful development process. However, there is no easy way to measure and no one factor to manage, in order to improve the PD effectiveness. Instead, PD 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. PD effectiveness is the aggregated result of the effectiveness for the three activities in the PDOPM.

PD efficiency (η_{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, PD efficiency is important to make sure that the invested resources are used in the best possible way. The PD efficiency can be improved by increasing the output or decreasing the cost for the resources consumed by the activities.

The PD process depends on both efficiency and effectiveness in the performed activities in order to be successful. The iron triangle is often used to evaluate projects, thus focus turns to the recourses and the output aspect of the product activities. Hence, the effectiveness and value perspectives of what is being developed are missing or taken for granted.

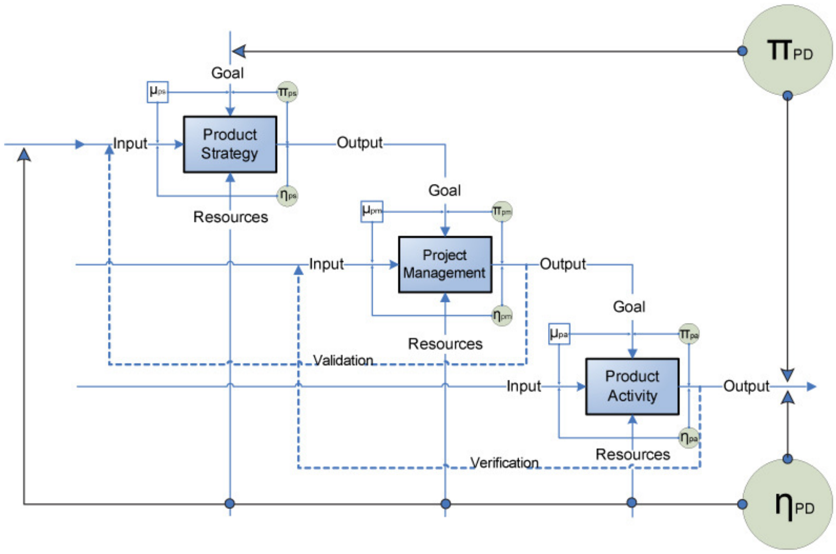

Figure 2. The proposed PDOPM model with the three generic levels of activities: product strategy, project management, and product activity. The relations of uncertainty (μ), effectiveness (Π), and efficiency (η) are also shown in the figure, both for each activity and for the complete PD process.

5. Perception of performance within five companies developing complex products and systems

In this section the findings from the explorative case study are presented through five typical citations of how the respondents perceive performance in the PD process. The selected citations are typical and illustrate how performance in the PD process is perceived from the respondents' own experience and their role within the organization. The perception of performance differs between respondents and no indications of a company specific view of performance could be identified.

Citation 1

Performance within PD is to do the right things, as quickly as possible, and with as low cost as possible.

This citation mainly relates to the product activity in the PDOPM. Both efficiency and effectiveness are related to this perception of performance. Effectiveness is emphasized through developing the right things. This citation clearly illustrates the common phenomenon of taking for granted what the right things are. Focus often turns to the product activities, while the product strategy and the project management activities are forgotten.

Citation 2

Performance within PD is to work with process improvements to shorten the lead time and make sure that the whole chain is involved at the right time.

This citation focuses on the efficiency of the processes used in the product activities. The importance of the implementation activities as well as the efficiency part of performance is being emphasised.

Citation 3

Performance within PD is to shorten cycle times, deliver on time, and reduce time to market. If you look at the calculations, the normal cash flow, cash in cash out, for a normal net present value calculation, it is clearly shown that it is important to reach a positive cash flow as quickly as possible. It is equivalent to having a short time to market. Quality is also important, we have high costs for everything that is delivered to a customer and not working properly.

This citation is similarly related to the product activities and the efficiency aspect of performance. The strategic aspect of what to develop and its effect on the cash flow is never mentioned; this perspective is similar to an efficiency perspective on manufacturing.

Citation 4

If it took three years to develop a new product a couple of years ago, I would want it to take 6 months today. The processes and steps that are required to develop a new product shall be more efficient to decrease the lead time. The pace should be higher and higher. You get more development per spent SEK.

This citation clearly implies the favouring of an incremental PD process and the citation is heavily related to the product activities in the PDOPM. Further, the efficiency aspect of performance is the obvious focus, on the expense of effectiveness.

Citation 5

Performance within PD is about managing the four dimensions time, product cost, project cost and quality within a project. Efficiency is about not having to redo things and focus on what creates value and doing things right. Effectiveness is about doing the right things and it is the product manager that decides what to develop. What to develop is seldom purely a R&D decision but more of a market strategy decision. This has a high effect on the performance of product development.

This citation relates to the product strategy, the project management and the product activities in the PDOPM as well as both the efficiency and the effectiveness aspects of performance. This citation is one of few that even mention value creation or adopt a holistic perspective to performance in the PD process.

Summary and discussion

To summarize, the perception of performance in PD almost exclusively focuses on shortening lead times, decreasing costs, and increasing quality. There seems to be a strong relation to the iron triangle of time, cost, and quality also within the perception of performance. This may be the natural consequence of having the PD organized in projects. From the citations it seems like it is taken for granted that the right product is being developed. Only ten percent of the respondents reflected on the product strategy and its effect on performance in the PD process. This may be the result of having large organizations developing complex products were no person can have a complete holistic view of the process.

One possible reason that time, cost, and quality are mentioned in practically every citation of performance may be that they are relatively easy to quantify and measure. Hence, it may be the case that the perception of performance has been influenced by what is measured. Ideally it would be the other way around i.e., to improve performance, a set of measurements are chosen to get management attention of what is important in order to achieve this objective. If the latter is true, there is a need for a change in the perception of performance within PD. This argument is supported by [20] who argue that performance is perceived primarily in terms of dimensions that can be measured. If that is the case, the perception of performance needs to be changed before any other more holistic ways of measuring the performance can be developed.

Validity

The validity of the presented results of the explorative case study is divided into construct validity, internal and conclusion validity, and external validity as well as reliability [15].

Construct validity concerns how the study relates to the research question. In this study the question asked to the respondents also is the one investigated. However, as revealed in the literature, the terminology is ambiguous and this may have affected the respondent's perception of performance. When the respondent's perception of performance in PD was asked for, it was not explicitly revealed what the interviewee's view of the performance and PD. The questions asked were stated in an open way in order for the respondents to interpret from his or hers experience and position within the case company. Further, all interviews were anonymous and it was made sure that it would not be possible to trace who said what.

Internal and conclusion validity aim to ensure that the conclusions drawn are correct. A representative selection of respondents was made by ensuring that the participants have different roles within the organization. Almost every selected respondent was able to participate in the interview, reducing the risk of mortality. Respondents not being able to participate were replaced by a person with a similar role within the organization. The possibility of "fishing" for answers i.e., asking leading questions during the interview was minimized by the use of open questions. Moreover, the interview ended by asking the respondent if anything important was left out.

External validity is about how the results can be generalized. This is a particular concern for a case study, where it always can be discussed to what extent the observations are particular to a certain environment, or whether they are examples of general phenomena. The conclusions are drawn from a multiple case study with respondents from five different organizations. Still, it cannot with certainty be said that this is the case, and to draw such conclusions, further studies are needed. So far only five organizations have been studied in Sweden.

Reliability involves the possibility of others to replicate the study and draw the same results. This study could easily be replicated by other researchers but the same result may not be achieved because an organization changes continuously and through the interviews only a snapshot of the current state was taken. It would be interesting to see the result from a similar study in other countries to see if there are any similarities.

6. Product development efficacy

The major finding from the perception of performance is the neglecting of the product strategy's effect on PD performance. It seems that it is taken for granted that the right product is being developed. One reason may be in the limitations and ambiguity in the words describing performance. Thus, the term PD efficacy is introduced.

In the Oxford Advanced Learner's Dictionary [21], efficacy is described as the ability of something, especially a drug or a medical treatment, to produce the results that are wanted. Moreover, in [22] product innovation efficacy is described as something reflecting the degree of success of an innovation. Efficacy is often used in the sense of capacity or power to produce a desired effect.

With the definition of PD presented in Section 3 in mind, PD efficacy is introduced to illustrate the capability to first identify or create a market opportunity and second, to fulfil this opportunity by developing a product fulfilling precisely this, by the product strategy identified, market opportunity. A report by Booz Allan Hamilton reveals that most new products, from automobiles to washing machines, are over engineered as a result of not communicating and managing the customer needs properly [23]. An important aspect in the quest for PD efficacy is the product strategy activity since it is where the balancing act between what is needed by the market and the capabilities within the organization is decided on. If this is not performed successfully, it cannot be corrected within the project management and product activities. By focusing measurements on time, cost, and quality, often in a lagging perspective, what to be developed is never questioned when the PD process is to be evaluated.

PD efficacy is also dependent on the project management and the product activities, once it is decided what to develop in order to avoid over or under engineering when designing and implementing what has been decided in the product strategy. Moreover, PD efficacy is to be viewed as the result attained through continuously managing the uncertainty, effectiveness, and efficiency in each of the three generic levels of activities in the PDOPM. If the customer needs changes during the development of a new product, it has to be reflected in the PD project in order to secure that the right product is developed. High performance in the PD process is achieved when there is efficacy in the complete PD portfolio.

7. Discussion and conclusions

Time, cost, and quality i.e., the iron triangle are common measurements of performance within projects. PD is often performed in a project setting, thus evaluated accordingly. A recent study within the utility industry shows that there is a weak link between the iron triangle and financially successful products. Moreover, the results from the explorative five case studies of how performance in complex PD is perceived clearly show that performance is perceived in terms of time, cost, and quality. The perspectives of value creation and if the right product is being developed were often missing when asking about PD performance. In this research it is therefore argued that a change in the perception of performance is needed, before there can be any changes in the development of new measurements. This may only be achieved by changing the mindset of the people involved in the PD process.

The explorative multiple case studies also showed that there is no common view of how performance is perceived within any of the five organizations. But, since all five case companies are successful, it could be that this information is managed as tacit knowledge. Tacit knowledge is defined in [24] as knowledge that cannot be articulated or verbalized; it is a knowledge that resides in an intuitive realm. Since the subject of tacit knowledge transfer, content and process, is poorly understood it may be a substantial risk if performance within PD is treated this way. Thus, it would be difficult to improve the performance in a structured way within large organizations.

To address the need of a more holistic view of performance, it is argued that the PD process, from a performance perspective, should be divided into three generic levels of activities: product strategy, project management, and product activities. These activities are related using the IDEF0 framework in the PDOPM. Thus, it is possible to reason about uncertainty, effectiveness, and efficiency for each generic activity level. Furthermore, PD efficacy is also introduced in this research to describe the capability of identifying or creating a market opportunity and being able to develop and deliver a product fulfilling exactly what was identified as market opportunity. PD efficacy is needed in order to change the mindset of how performance in PD is perceived within industry, to also include the product strategy activity. By using the PDOPM it is possible for managers and decision makers to conceptually reason about performance in the PD process from a holistic perspective and identify where improvements are needed in order to improve the performance.

8. References

[1] K. Goffin and R. Mitchell, *Innovation Management: Strategy and Implementation Using the Pentathlon Framework*. London: Palgrave MacMillan, 2005.

[2] M. Larsson, M. Arif, and D. Lundberg, "Do projects that fail, really fail?," in *The 17th International Conference on Management of Technology*, Dubai, U.A.E., 2008.

[3] T. Peters, "Tom Peters revisited: What gets measured gets done," *Office Solutions,* vol. 19, pp. 32-33, 2002.

[4] J. Hauser and G. Katz, "Metrics: you are what you measure!," *European Management Journal,* vol. 16, pp. 517-528, 1998.

[5] V. Krishnan and K. T. Ulrich, "Product Development Decisions: A Review of the Literature," *Management Science,* vol. 47, pp. 1-21, 2001.

[6] K. T. Ulrich and S. D. Eppinger, *Product design and development* 3ed. Singapore: McGraw-Hill Education, 2003.

[7] A. Neely, *Business performance measurement*, 2 ed. Cambridge: Cambridge University Press, 2007.

[8] A. I. Jiménez-Zarco, M. P. Martínez-Ruiz, and Ó. González-Benito, "Performance measurement system (PMS) integration into new product innovation: A literature review and conceptual framework," *Academy of Marketing Science Review,* vol. 2006, 2006.

[9] A. Neely, M. Gregory, and K. Platts, "Performance measurement system design: A literature review and research agenda," *International Journal of Operations & Production Management,* vol. 25, pp. 1228-1263, 2005.

[10] D. S. Sink and T. C. Tuttle, *Planning and Measurement in your Organisation of the Future*. Norcross, GA: Industrial Engineering and Management Press, 1989.

[11] M. E. McGrath and M. N. Romeri, "FROM EXPERIENCE The R&D Effectiveness Index: A Metric for Product Development Performance," *Journal of Product Innovation Management,* vol. 11, pp. 213-220, 1994.
[12] I. Arbnor and B. Bjerke, *Methodology for Creating Business Knowledge*. USA: Sage Publications, 1997.
[13] D. Katz and R. L. Kahn, *The Social Psychology of Organizations* 2ed. New York: John-Wiley & Sons, 1978.
[14] P. M. Senge, *The Fifth Discipline, the Art & Practice of Learning Organizations*. New York: Currency Doubleday, 1990.
[15] R. K. Yin, *Case Study Research: Design and Methods*, 3 ed.: Sage Publications, 2003.
[16] K. M. Eisenhardt, "Building Theories from Case Study Research," *Academy of Management Review,* vol. 14, pp. 532-550, 1989.
[17] F. J. O'Donnell and A. H. B. Duffy, "Modelling design development performance," *International Journal of Operations & Production Management,* vol. 22, pp. 1198-1221, 2002.
[18] G. J. Colquhoun, R. W. Baines, and R. Crossley, "A State of the Art Review of IDEF0," *International Journal of Computer Integrated Manufacturing,* vol. 6, pp. 252-64, 1993.
[19] S. Johnsson, J. Eriksson, and R. Olsson, "Modelling performance in complex product development - A product development organizational performance model," in *The 17th International Conference on Management of Technology*, Dubai, U.A.E, 2008.
[20] C. Chapman and S. Ward, *Project Risk management – Processes, Techniques and Insights*. Chichester, England: John Wiley & Sons, 1997.
[21] S. Wehmeier, A. S. Hornby, and C. McIntosh, in *Oxford Advanced Learner's Dictionary of Current English*. vol. 7: Oxford University Press, 2005, p. 1907.
[22] J. Alegre, R. Lapiedra, and R. Chiva, "A measurement scale for product innovation performance," *European Journal of Innovation Management,* vol. 9, pp. 333-346, 2006.
[23] C. Koehler and R. Weissbarth, "The Art of Underengineering," in *Strategy+Business Magazine*, 2004.
[24] T. Foos, G. Schum, and S. Rothenberg, "Tacit knowledge transfer and the knowledge disconnect," *Journal of Knowledge Management,* vol. 10, pp. 6-18, 2006.