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Product Platform Performance
Achieving internal effects

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Preface

This thesis is the result of a long and slightly winding process for me. I have had many great experiences and insights, both personally and professionally, that I highly value. It has involved a number of people, whom I would like to thank.

I want to thank my supervisor Prof. Niels Henrik Mortensen for giving me the opportunity to conduct the Ph.D., his ideas and feedback, positive support and enthusiasm and finally his patience.

Thanks to the many employees at LEGO who have worked with me in the different platform projects. They have been open, engaged and applied the results of my work. Special appreciation goes to Thomas Steen Jensen, who have contributed throughout the period and shared his insights in platform-based product development. The engagement from my LEGO colleagues provided the best circumstances for my study.

Also thanks to Henrik Priess Sørensen and Dorthe Kjærullf, who funded the project, took me into their departments and gave me the possibility to work with the interesting platform projects in LEGO. This opportunity was an important reason for me to engage in a Ph.D. study.

The representatives from the 12 companies in the industrial study I owe thanks for taking time and for their openness. Their experiences provided more insight than this thesis represents.

I would also thank my colleagues at DTU. Thanks to Sofiane Achiche and Giovanna Vianello who guaranteed a smile a day. Special thanks goes to my Ph.D. colleagues Ole Fiil Nielsen, Rasmus Pedersen and last, but not least, Morten Kvist. They were an important reason to engage in the Ph.D. study. Morten, of course, receives my final appreciation, for all the great experiences during the study and his fantastic help in every way.

Part 1

Part 2

Part 3

Part 4

Part 5

Part 6

Abstract

The aim of this research is to improve understanding of platform-based product development by studying platform performance in relation to internal effects in companies. Platform-based product development makes it possible to deliver product variety and at the same time reduce the needed resources, and the subject has gained increased attention in industry and academia the past decade. Literature on platform-based product development is often based on single case studies and it is sparsely verified if expected effects are achieved. This makes it difficult to put forward realistic expectations for companies engaging in platform-based product development. Similarly platform assessment criteria lack empirical verification regarding relevance and sufficiency.

The thesis focuses on

- the process of identifying and estimating internal effects,
- verification of performance of product platforms, (i.e. if the expected results are achieved), and
- reasons for possible deviations between these, comparing them to existing platform assessment criteria.

The research results are based on 8 comprehensive case studies of product platforms in LEGO Company in the period of 2004-2009 (involving participant observation, observation, interviews and data analysis) and are validated by a series of interview with representatives from 12 Scandinavian companies.

A descriptive model of the process of identifying and estimating internal platform effects has been developed. It involves analysis of past data and estimates from experienced representatives from the different life systems phase systems of the platform products. The effects are estimated and modeled within different scenarios, taking into account financial and real option aspects. The model illustrates and supports estimation and quantification of internal platform effects. The model empirically verifies findings in literature and received moderate support from industry in the validation study.

The research findings document that product platforms achieve significant internal effects in terms of

- reduced development time (often around 25 %),
- reduced number of components (often around 50%) and
- reduced production cost and investments (often around 25%).

This verifies a significant, general improvement potential, a verification which has lacked in the literature. These findings underline the potential in platform-based product development as a way of creating competitive advantage.

The findings also reveal that between half and two thirds of the platforms do however do not achieve the expected effects, despite that they do deliver some effects. This is mainly because of 1) lack of use of the platform assets, 2) technical reasons and 3) changed market conditions. These reasons are mentioned in literature, but only the two latter are addressed in platform assessment criteria. Hence a new platform assessment criterion is introduced, the platform user incentive criterion. Alongside with the introduction and recommendation of a platform user incentive criterion, recommendations are also made regarding focus on down-stream effects, modeling and viable estimation and quantification of effects, facilitation of performance tracking and goal-setting and finally to understand a product platform as an internal system in the company. A platform system model is introduced to support this understanding. Finally a categorisation of different approaches to platform-based product development is introduced, based on the companies from the industrial study.

Resumé

Formålet med denne forskning er at forbedre forståelsen af platformsbaseret produktudvikling ved at studere hvilke interne effekter, virksomheder opnår. Platformsbaseret produktudvikling gør det muligt at fremstille mange produktvarianter og samtidig reducere ressourceforbruget, og emnet har fået øget opmærksomhed fra både industri og det videnskabelige miljø det seneste årti.

Litteraturen om platformsbaseret produktudvikling er ofte baseret på enkelte case studier og det er ringe verificeret, om de forventede effekter opnås. Derfor er det svært at opstille realistiske forventninger for virksomheder, der ønsker at arbejde med platformsbaseret produktudvikling. På samme vis mangler der empirisk validering af relevans og tilstrækkelighed af kriterier, der anvendes til at vurdere produkt platforme.

Denne afhandling fokuserer på

- processen med at identificerer og estimere interne platformseffekter,
- verificering af produkt platformes performance (om de forventede effekter opnås) samt
- hvilke årsager der kan være afvigelser og sammenholder disse årsager med eksisterende platforms kriterier.

Forskningsresultaterne bygger på 8 dybdegående case studier af produktplatform i LEGO Company i perioden 2004-2009 (henholdsvis deltagende observation, observation, interviews og data analyse) og valideres af et interview studie med repræsentanter fra 12 skandinaviske virksomheder.

Der er opstillet en deskriptiv model, der beskriver en process med identifikation og estimering af platforms effekter. Processen indeholder analyser af historisk data materiale og estimater fra erfarne repræsentanter fra platform produkternes forskellige livsfase systemer. Effekterne bliver estimeret og modeleret ud fra forskellige scenarier og medtager finansielle aspekter og reelle optioner. Modellen illustrerer og støtter kvantificering af interne platformeffekter. Modellen verificerer resultater fra litteraturen empirisk og modtog moderat støtte i det industrielle valideringsstudie.

Forskningsresultaterne dokumenter at produktplatforme opnår signifikante effekter i forhold til

- reduceret udviklingstid (ofte ca. 25 %),
- reduktion i antallet af komponenter (ofte ca. 50 %), og
- produktionsomkostninger og – investeringer (ofte ca. 25%).

Dette bekræfter et signifikant, gennemgående potentiale, en verificering, der mangler i litteraturen. Resultaterne understreger potentialet for platformsbaseret produktudvikling i at skabe konkurrence fordele.

Resultaterne viser også at mellem halvdelen og totredjedele af platformene, selvom de opnår effekter, ikke opnår de forventede effekter. Dette er hovedsagelig pga. 1) manglende brug af platformene, 2) tekniske årsager og 3) forandringer i markedet. Disse grunde er nævnt i litteraturen, men kun de to sidste er adresseret i platformsvurderingskriterier. Derfor introduceres et nyt platformsvurderingskriterie, et incitamentskriterie for platformbrugere. Sammen med introduktion og anbefalingen af incitatmentskriteriet, opstilles der en række anbefalinger om fokus på effekter fra de senere faser, om at modellere og sandsynliggøre og kvantificere effektestimater, om at facilitere af platform performance opfølgning og målsætning og endelig om af opfatte en produkt platform som et internt system i virksomheden. Endelig introduceres også en kategorisering med fem forskellige typer af platformsbaseret produktudvikling, baseret på virksomhederne fra det industrielle studie.

Part 1
Introduction to the research

This introduction shortly describes the research object and aim of this thesis, the research questions that are sought answered and why they are worth pursuing. The research approach and conditions in terms of the core industrial case are described. The above issues are described in detail in the following chapters. Finally the potential audience the thesis is aiming at and the thesis disposition is gone through.

1.1 Research object and aim

This thesis studies the application and performance of platform-based product development and implemented product platforms in companies. Platform-based product development is a way of gaining competitive advantage and has shown its effect by reusing and sharing assets (physical elements, activities and knowledge [Simpson, 2004]) across products. The phenomenon has gained increased attention in industry and academia the past decade as an alternative to single product development, making it possible to deliver product variety and at the same time reduce resources spent internally in a company.

Platform-based product development differ from single product development by having a preparation phase, where the platform is developed and an execution phase, where products are developed, utilizing the established platform by reuse of its elements [Elgård,1998].

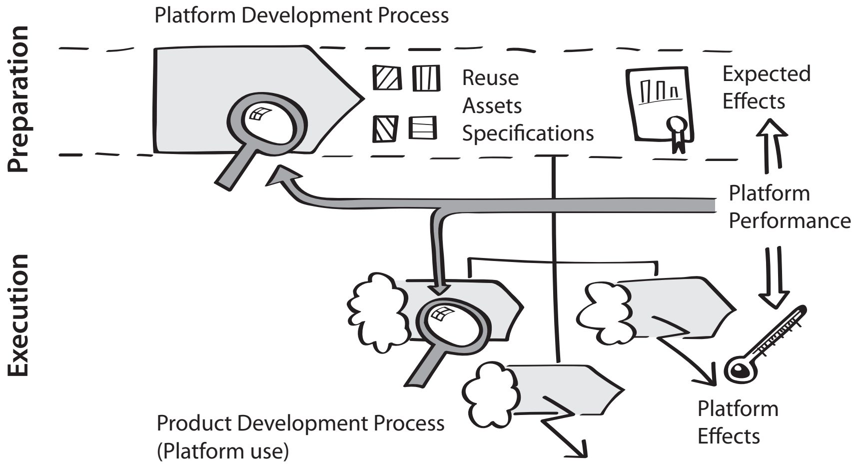


Figure 1.1: Platform-based product development, with the development split in a preparation and execution phase, where the product platform is respectively developed and utilized. This thesis studies both phases and the resulting effects of the product platform, symbolized respectively by the small magnifying glasses and the thermometer [inspired by Elgård, 1998].

This development split is illustrated in Figure 1.1, where the focus area of this thesis is described, being both the preparation phase, the execution phase and the expected compared to the achieved effects.

The aim of this thesis is to improve the understanding of how and how well companies apply platform-based development, focusing on how and if the platforms achieve the expected internal effects and what causes the possible deviations between performance and expectations. Hereby it seeks to point out areas of improvement, which can possibly improve product platform performance.

1.2 Research background and motivation

Platform-based product development is conducted in order to achieve different benefits. The cases in literature report of successful stories where the introduction of a platform yields great results: Up to 70

% reduction of costs, 30% reduction of development or production time, 50% higher level of quality etc. [Sanchez, 2000]. Typical potential benefits are (only representative sources):

- Increased revenue by enabling variety [Halman et al, 2003, Simpson 2004, Robertson & Ulrich, 1998]
- Time efficiencies: Reducing development time for derivative products ([Muffato, 1999)]
- Cost efficiencies: Reduce costs due economies of scale and less redundancy [Gershenson et al., 1999, Muffatto & Roveda, 2000]
- Product reliability and quality [Muffatto & Roveda, 2000, Andreasen, 2003, Meyer and DeTore, 2001, Sawhney, 1998]

Fewer examples of literature describes the risk of platform-based product development with cases where platform-based development is less beneficial [Kristjansson & Hildre, 2004, Krishnan & Gupta, 2001, Hauser, 2001], and meets challenges in the actual operation or use of the platform [Juuti et al 2004], or the resulting properties (like cost and time) are less advantageous than expected [Holmqvist & Persson, 2004] and that product platforms may be a major investment compared to single product development [Ulrich & Eppinger, 2001]. Typical potential risks are:

- Increased cost and time development time for the first product [Halman et al., 2003, Ulrich & Eppinger, 2001]
- Reduced revenue due to commonality and cannibalism [de Weck, 2006, Krishnan and Gupta, 2001]
- Sub-optimal Product Design [Meyer et al.1997, Ulrich 2007, Robertson and Ulrich, 1998].
- Increased Management Complexity [Holmqvist & Persson, 2004, Sanchez & Mahoney, 1996]

In general the researchers often highlight few isolated and successful empirical studies [Du et al, 2001] and hence there is a need for more empirical research on the subject [Andreasen et al, 2001, Thomas, 2009]. There is little empirical knowledge about how well platforms perform in industry after they have been developed [Gershenson et al., 2003] and little verification of the actual achieved effects. Due to the complex phenomena platform-based product development is, it is neither trivial to measure performance nor evident that the benefits are achieved.

Knowing how well platforms perform and what the reasons are for success or failure is however important to understand, so companies can get realistic expectations about the results product platforms produce and the necessary effort, resources and firm capabilities [Jiao et al., 2007], before they embark on a platform project. The importance of this is illustrated by the fact that many companies are hesitant to embrace product platforms and product families [Simpson, 2004], because they fear compromising the qualities of their products, and this risk must be outweighed by realistic expectations of benefits.

Academia presents several methods to develop platforms, e.g. Erixon [1998], Simpson et al [2006], Stone et al [2000], Ulrich and Eppinger [2000], which have been tested in individual projects. They mainly consider the platform development process and leave little attention to the actual use (execution phase) of product platforms and the long term success of them. The methods are often sparsely validated in industrial context, and there is little knowledge of whether they consider the relevant and sufficient assessment criteria.

Hence the reasoning behind this thesis both relies on a research background and on an industrial background as summarized in the following Figure 1.2.

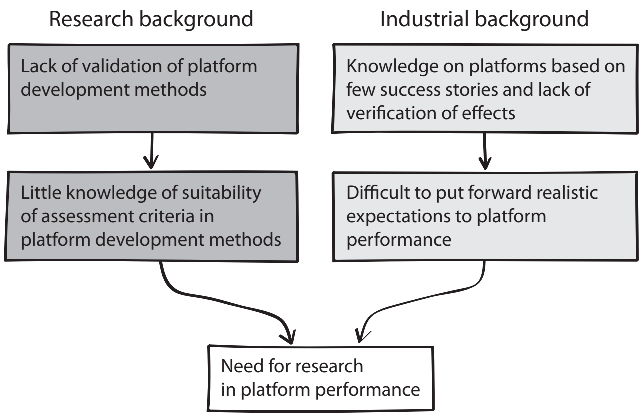


Figure 1.2: The background of this study is based on needs in both academia and industry

1.3 Research approach and industrial case

This research builds on engineering design science tradition. It means that the research will seek to describe a current situation and state of knowledge in academia and industry, analyze it from theoretical and practical perspective to identify problems and suggest possible improvements and recommendations and finally validate these. Several data collection methods and sources have been applied, from participatory research, document, product, production and economical analysis to interviews and observation.

This thesis is based on empirical studies from 2004-2010 of platform-based product development in the company LEGO Group, studied in depth with participant and direct observation, interviews, documentation and archival records [Yin, 1994]. LEGO saw potential in product platforms and have approached many different parts of their business with this strategy with success. Having already a few existing product platforms, these initiatives resulted in eight different implemented product platforms. Furthermore they have been focused on the viability of the product platform effects. This makes LEGO a unique and interesting case, when it comes to studying the performance of product platforms, which are comparable, yet different, more comprehensively.

This opportunity represents the core case in this thesis. This however means that this study focuses on and is limited to considering the desired (interrelated) benefits that were relevant in LEGO, namely:

- Reduced cost (production and investments)
- Reduced item numbers
- Reduced development time
- Reduced risk (obsolete goods and lack of production capacity)

These benefits are oriented towards the internal side on the business and the impact of the product platforms on the products have intentionally not been affecting the product offering as such. The platforms were aiming at minimizing the effect on the customers' perception of the products, lowering the risk of the product platforms. Hence the research results concern internal effects, as defined by Kristjansson & Hildre [2004]. Note that both potential internal and external effects must be considered in platform-based product development, but the cases in LEGO provided little substance on the external effects, and hence the research findings only address the internal effects.

Another consequence of basing the research on the cases from LEGO is the risk of the findings being product and company specific. To address the general validity of the findings and their relevance a validation study in Scandinavian industry has been conducted: Representatives from 12 Scandinavian companies was interviewed about how their company had engaged in platform-based product development and their results and was presented for and interviewed about the findings from the LEGO product platforms.

1.4 Research questions

Based on the above need for knowledge from industry and academia, this thesis will seek to answer three research questions concerning product platform performance, the expected and achieved effects and the process of identifying and estimating them in the platform development process:

In order to understand if the expected effects are realistic and the weight and relevance of them, the process of in which they originated is studied to answer the first contextual research question:

RQ1: How can a process of identifying and estimating internal effects of product platforms be described?

Knowing the impact of product platforms is relevant to decide whether it is worth embarking with. The second research question addresses the performance - the achieved effects compared to the expected - of the platforms, which indicates the impact of platform-based product development as approach:

RQ2: Do product platforms achieve the expected effects?

Due to the limitations of the LEGO case, the studied effects are: Reduced cost (production and investments), reduced item numbers, reduced development time, and reduced risk (obsolete goods and lack of production capacity).

To understand why the platforms do not always meet the expectations, the reasons for this are studied. Knowing if the reasons are already addressed by relevant criteria in literature or new ones appear, the final research question focus on the causes, which also make it possible to improve the product platforms and their development process:

RQ3: What are reasons for deviations between achieved and expected platform effects and are they addressed by platform assessment criteria in literature?

Figure 1.3 shows a reference model with the different elements that are considered relevant in this research and describes respectively success and the measurable criteria in the research. The research questions are shown where they hopefully will contribute to the research topic and identify new knowledge:

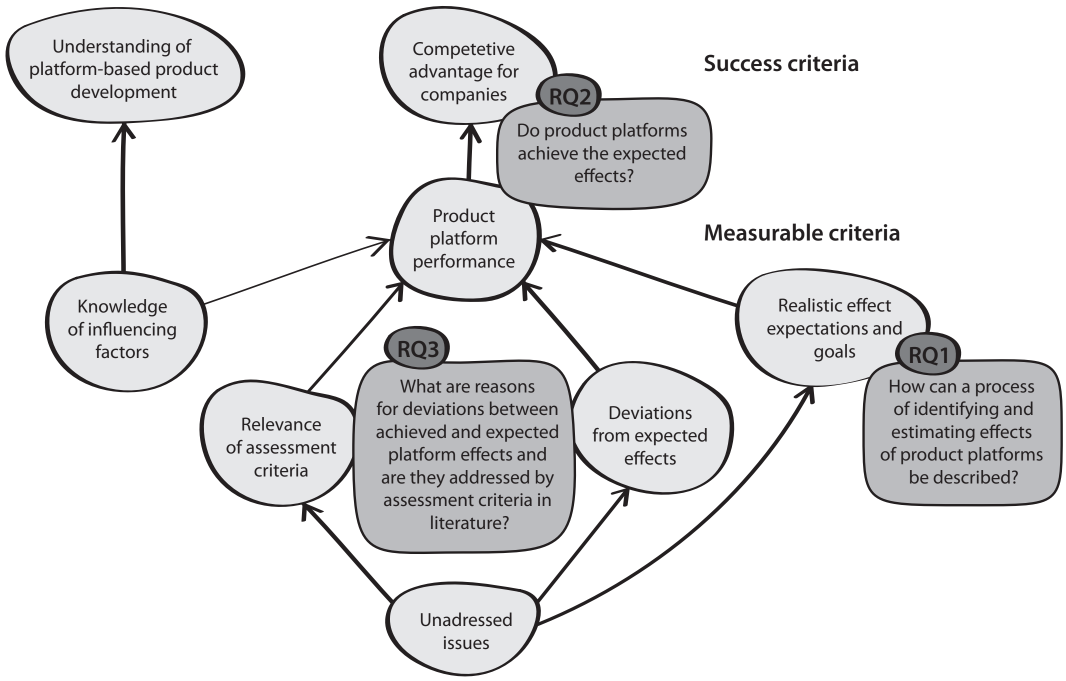


Figure 1.3: Reference model of this research: The relevant elements of this research are show in relation to each other and the research questions.

Answering the above research questions is aiming towards an improved understanding of what should be considered, what results can be expected, and what effort and prerequisites are needed for a company to perform platform-based product development successfully.

1.5 Potential audience

This thesis is intended to be of interest to both the academic as well as the industrial audience. The academic audience can hopefully gain an improved understanding of and new insight in the area of platform-based product development and its performance and application in industry and apply this in future research. The industrial audience can be both present as well as potential product platform designers, but also managers, who will learn about the potential. They can be inspired by the case studies, gain knowledge of what to expect from the phenomena and hereby be more confident when approaching platform-based product development.

1.6 Thesis disposition

To help the reader to through the thesis and follow its reasoning, the different elements in the disposition, will be described and illustrated in Figure 1.4.

Part 1, "Introduction to the research", introduces the research object and the motivation behind the subject and the research questions. It also shortly describes the research approach and the audience that may benefit from reading this.

Part 2, "Theoretical background", describes the research area and some of the fundamental theories and the research tradition this research is influenced by. These basic theories concerning technical systems, product development and organizational aspects are relevant to understand which perceptions the research builds upon.

Part 3, "Introduction to platform-based product development", introduces the basic concepts in platform-based product development, its benefits and risks, and reviews different platform design and development processes and methods.

Part 4, "State of the art and challenges:
Product platform performance", describes the state of the art of the literature within the specific areas, which will be used as reference for the later findings. This review identifies the gaps in the existing knowledge, leading to the research questions.

Part 5, "Research approach", describes how the actual research work has been conducted and the thoughts and theories behind it. It goes into detail with the theoretical framework of the research methods and behind the design of it. It also presents validation methods, and case selection approach.

Part 6, "LEGO ® Group and the platform cases", introduces LEGO and company's platform approach. It presents the case descriptions of the eight LEGO cases in a very detailed and rich way. The section does not include the raw data in form of interviews, full documents or database reports, since this is too comprehensive to present. The case descriptions have been written up based on these sources to establish an understanding and overview of the cases from where the research findings originate.

Part 7, "Analyzing and concluding on the LEGO platforms", analyses the cases and seeks to answer the three research questions based on the LEGO cases and recommendations are made. It also introduces a platform system model.

Part 8, "Validating the research results", describes the validation of the findings. An industrial validity study, based on interviews with 12 Scandinavian companies applying platform-based product development seeks to validate the answers of the research questions and relevant findings by comparison. A platform categorization is introduced, and the general validity of the findings are discussed.

Part 9, "Conclusion", concludes on the research results and recommendations, and dicuss the limitations and implications of the research contribution.

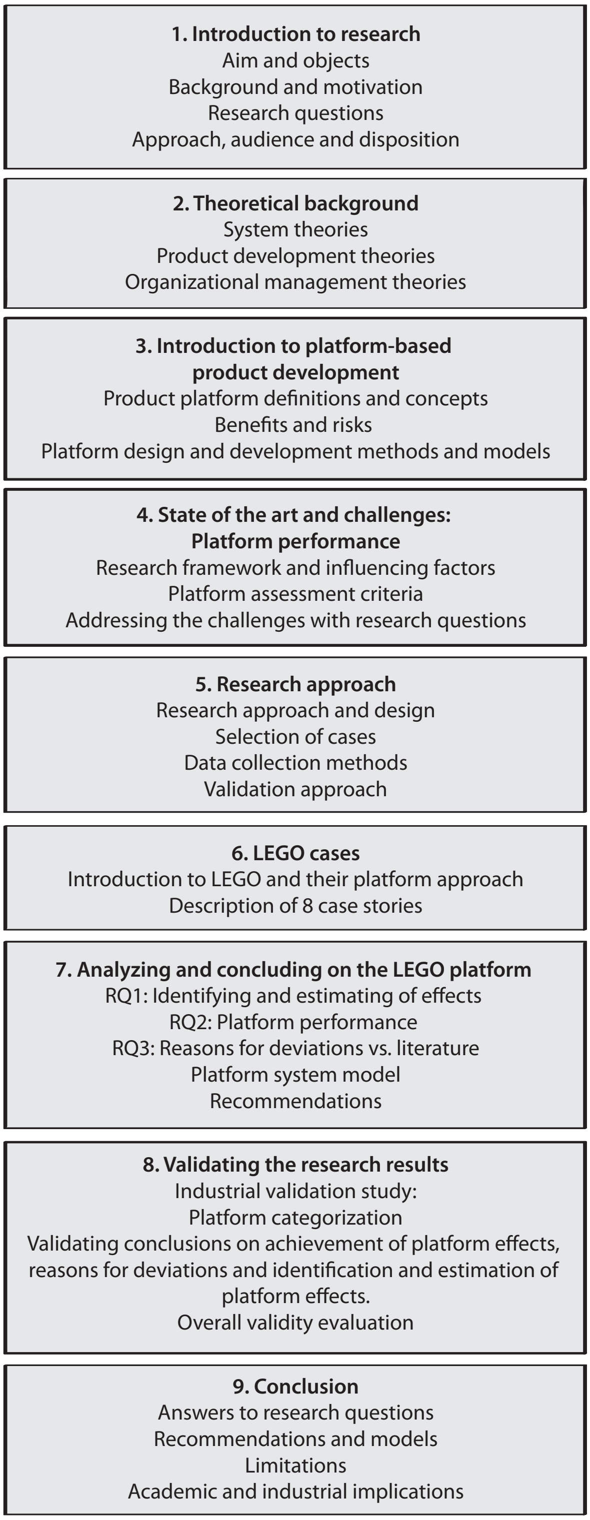


Figure 1.4: Overview of the thesis' disposition.

Part 2
Theoretical background

The theoretical basis is the fundamental viewpoints from which the research objects are perceived from. In this chapter we go through the fundamental and underlying theories this research is based upon. This includes system theories, engineering design/product development theories and organizational management theories. Altogether the presentation of these theories has the purpose of creating a mindset wherein this research is better understood.

This thesis is founded within engineering design science. It has a systems and engineering design or product development perspective on the phenomena of product platforms. During the study of product platforms it has however proved useful to include aspects of organization and management theories, since platform–based product development, being a process or system involving technology and humans, must take into account some human factors.

The methods and research results within platform-based product development generally build on these general theories. Hence they are presented to provide a basic understanding of the foundation of specific theories in platform-based product development and for the viewpoint of this research. The following section shortly describes this theoretical basis of the thesis

I present the theories within three areas:

- *System theories*
  A product platform and the use of it can be perceived as a system. Hence we use a system approach when exploring the subject of product platforms.
- *Product development theories and engineering design theories*
  Another viewpoint is that of platform-based product development as a development and design process making product development theories and models and the engineering design perspective relevant.
- *Organizational management theories*
  Introducing platform-based product development may be major change in the organization, and hence theories describing change management, motivation and goal setting theory are briefly discussed.

The three areas do somehow overlap and do in different way relate to the design object, the development process and the context of which it takes place, as depicted in Figure 2.1. The system theories consider both the design object (the technical system or product) and its context (the state, other operators and life phase systems), the management theories consider the process (motivation factors) and the context (organizational change), while the product development theories describe the design object (as the product) and the process (the product development process itself).

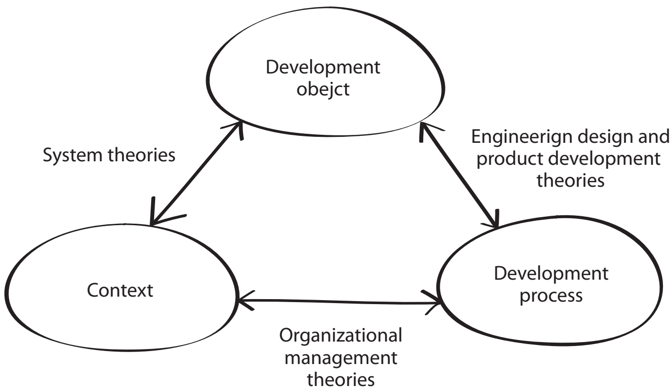


Figure 2.1: Relation between the different theories and their coverage of development object, development process and context.

2.1 System Theories

The systems perspective is dealt with by several engineering disciplines and is useful when describing and understanding how different elements work together transforming an input to a desired output in a product or another system.

2.1.1 The Theory of technical systems

Theory of technical systems (TTS) is a framework for understanding products and other artifacts as technical systems, described by Hubka & Eder [1988]. The theory describes how a Transformation of an Operand takes place between the technical system, the human system, the information system, and the management and goal system. The theory focus on elements within a defined boundary, creating one or more systems, and what happens with a system, when it is transformed with input and output. The operand is the part of the system that is the object of transformation, i.e. the object changes state during the transformation. Below the most important of the different elements in Figure 2.2 will be described:

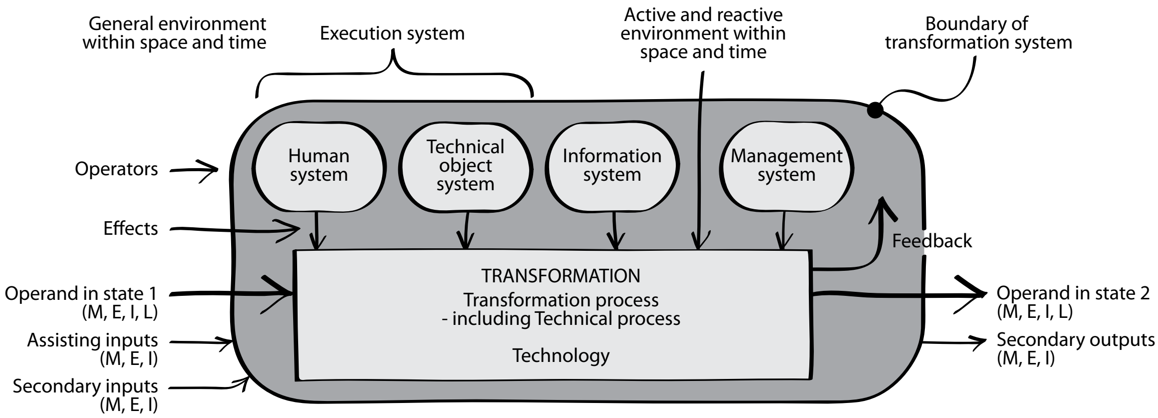


Figure 2.2: Overview of the different elements in the Theory of Technical Systems , i.e. the systems, environment, boundary and the different types of input and output.

Different specific systems (human, technical, information or management/goal system) deliver the necessary effects (as active participants in the process) to the operand to perform the transformation. Technology enables the operands transformation together with effects that are acting on the operand, including supply of the necessary materials, energy or information. Finally secondary inputs and outputs –both desired and undesired, depending on the context, must also be considered.

The transformation takes place in the interaction between the technical system and the above mentioned other elements in Figure 2.2, creating the desired state.

2.1.2 Relevance of Theory of Technical Systems

The Theory of Technical Systems provides a fundamental frame for the description and understanding of product platforms, because product platforms are systems of elements that create a desired effect. The theory provides the basis to describe the relations between elements in a technical system, and between a technical system and its operands, as well as other technical systems.

The technical system is focused on single products, but is in this context found applicable on platforms and other systems, consisting of not only physical elements. Hence the theory can be applied on many levels from parts of a product to product platforms, because the technical system view is applicable on subsystems as well as 'whole' systems. Therefore, the Theory of Technical Systems serves as the basic perception of a system in the thesis and is a fundamental underlying understanding of how different elements of different kinds operate together to create the desired state or solution.

2.1.3 Theory of dispositions

This theory by Olesen [1992] describes how one in the design of a product makes dispositions for the entire life cycle of a product: A product has different effects depending on the context in which it occurs. The product design and characteristics determine the products (desired or undesired) behavior within each of the later life phase systems. Olesen puts it this way:" By a disposition we understand the part of a decision made within one functional area that affects the type, content, efficiency or progress of activities within other functional areas". Functional areas refer to the different disciplines involved in bringing products to the marketplace, all the way from development, engineering design through production and distribution, during use, maintenance and scrapping & recycling and so on.

Dispositions are therefore decisions related to a product design that later create certain effects in the life phases. The overall performance of the product and life phase systems must be optimized by creating a fit between the dispositions and the life phases and a products performance can only be evaluated in the "meeting" with each life phase, as Olesen puts it, and how well it "fits" this phase. It may be performing successfully in one phase due to certain characteristics, while it fails due to the exact same characteristics in a different life phase. The various life phases of the Theory of Dispositions are illustrated in Figure 2.3.

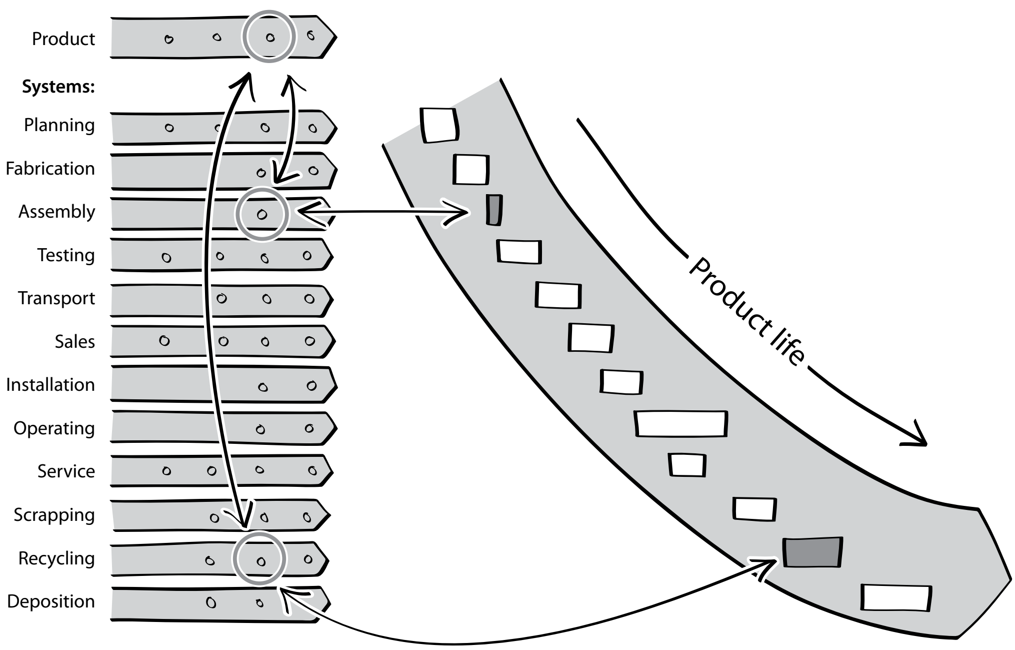


Figure 2.3: The early decisions in the development of the product regarding its' characteristics determine the effects in the rest of the products life. The effects occur in the products meeting with the systems of the different life phases, e.g. assembly, transport or sales.

The theory builds upon Theory of Technical Systems, but does not only focus on the meeting in the use phase (the intended transformations) but also on all the other transformations and effects that takes place during the life phases of a product.

An important aspect of the theory is the impact of the early or conceptual decisions in a product development, where the overall structure is decided. Therefore these phases need extra attention and many alternatives must be considered, as they are determining for the overall effects of the product (see Figure 2.4)

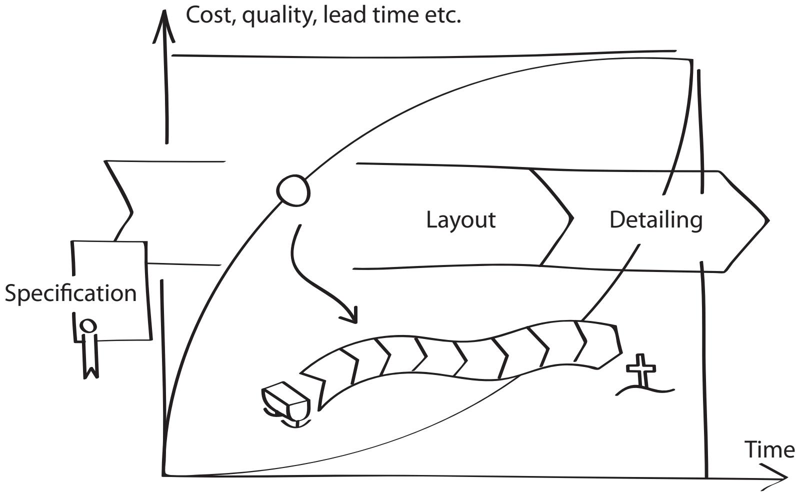


Figure 2.4: The consequence of theory of dispositions is that the most important and most influencing decisions are made in the concept phase, where the overall structures are decided.

The Theory of Dispositions can be related to Design for X (DfX), an extension of Design for Manufacturing (DfM), [Corbet et al., 1984], where the manufacturing productivity of products are improved by addressing manufacturability issues during the early concept phases of the product development. DfX extend this approach to other life phases, such as assembly, service etc., and can in this context be seen as the practical and operational side of Theory of Dispositions.

2.1.4 Relevance of Theory of Dispositions

In this context the theory is applied on product platforms (which also include products and their characteristics and does not only concern a single product, but a group of products that must "fit" the different life phase systems. Even though it is developed with products as object the theory is highly relevant because it conveys an understanding of the importance of having an object (or product) fitted to another system and that this fit is crucial to the performance of the object. The performance of a product platform often has to do with the production and specification/engineering/design/configuration phases. The consequence is that the performance of a product platform has to be fitted and evaluated in relation to something – in relation to the use phase, the production phase or other important aspects- and the desired effects that it creates in all the life phases.

2.2 Product development models

Product development methods can be described as addressing the issues around the design process. The development methods often describe the different issues of market, product and manufacturing, that companies consider, when developing a product. Compared to product design models, product development is often the more business oriented approach and also covers issues like gathering needs from the market place, planning the product portfolio, introducing new products in a certain sequence, designing the sales processes, together with the physical design of the products, the production processes, the distribution processes etc. There are multiple of models and concepts within product development, [Andreasen & Hein, 1985], [Clark & Fujimoto, 1991], [Pahl & Beitz, 1996], [Ulrich & Eppinger, 2000], [Otto & Wood, 2001], [Wheelwright & Clark, 1992, 1995, 2007],[Cooper, 2001], [INCOSE, 2007] of which hold many similar patterns.

In the following we go through three representative models, namely the stage-gate model by Cooper [2001], the model of Integrated Product Development [Andreasen & Hein, 1985], and the V-model [INCOSE, 2007] . The first has a conceptual and operational approach to the process and deliverables (business oriented) of product development process, whereas Andreasen & Hein's model has more focus on the technical product and the integration of the market and production/supply chain aspects, and it also includes the product synthesis (design) process and address issues of requirements, goals and criteria. Finally the V-model, which originates from the field of System Engineering, represents the different steps in the lifecycle of a development project, but with focus on systems and the integration of many different technical fields and their various criteria.

2.2.1 The Stage-gate model

The Stage-gate model by Cooper [2001] refers to the use of funnel tools in decision making when dealing with new product development projects. The "gates" are decision points in the product development process, placed where it is most beneficial to making decisions regarding continuance of the product development process. The common model consists of the following stages: ideation, preliminary analysis, business case, development, testing, launch, (see Figure 2.5). The stage-gate model is a conceptual and operational road map for moving a new project from idea to launch. It is the idea that different types of projects go through only the relevant steps, depending on their risk and size.

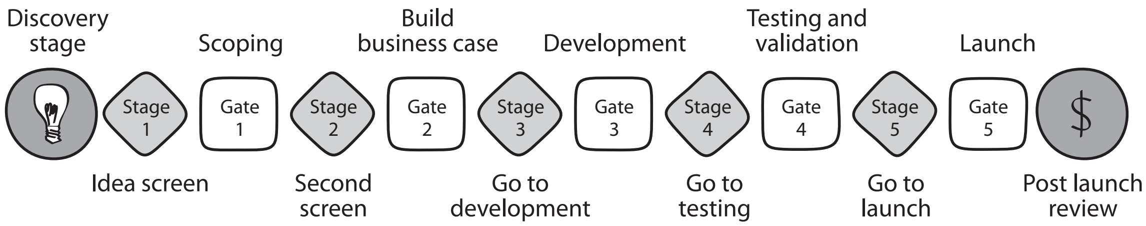


Figure 2.5: The different stages and gates in the stage gate model. The main content of the stages from discovery to launch are shortly described [Cooper, 2010].

Each stage consists of a set of prescribed, cross-functional and parallel activities undertaken by a team of people from different functional areas. Stages have a common structure and consist of three main elements: Activities, Integrated Analysis and Deliverables. Activities consist mainly in information gathering by the project team to reduce key project uncertainties and risks. An integrated analysis of the results of the activities is undertaken by the project team. Deliverables of stages are the results of integrated analysis-and are the input to the next gate

Similarly the gates have a common structure, where the three main elements are Deliverables, Criteria and Output. The deliverables are presented and held up to a number of criteria, both financial and qualitative. Finally the output includes the decision of whether to continue or kill the project and agreed plan and deliverables for next gate.

2.2.2 Integrated product development

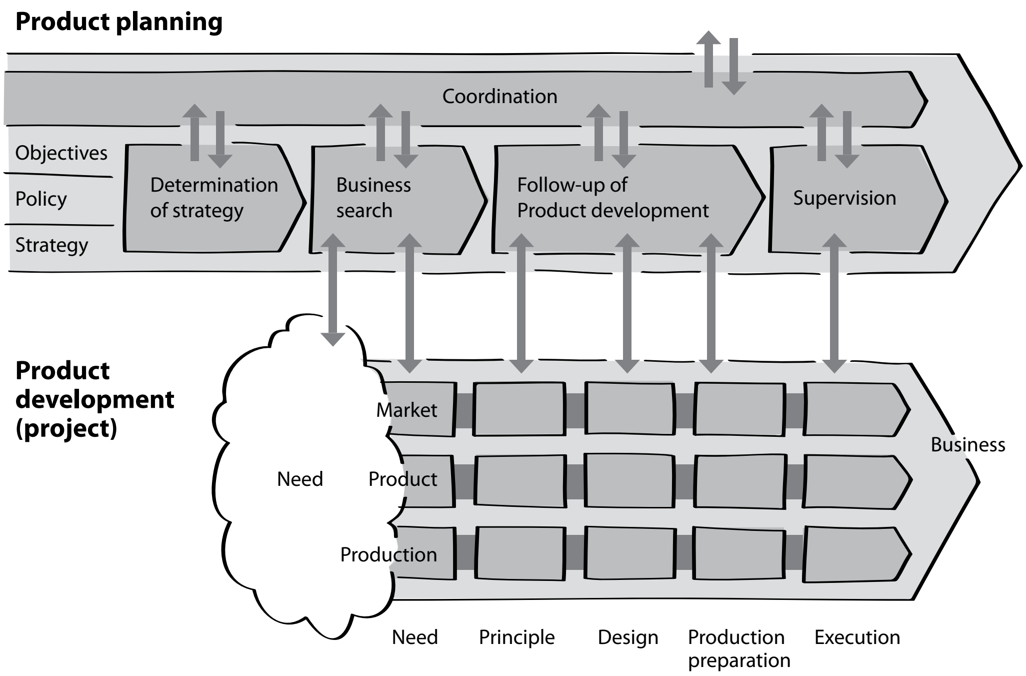


Figure 2.6: The framework of Integrated Product Development, which is a part of the overall strategic process of product planning.

The framework of Integrated Product Development [Andreasen & Hein, 1985], describes the process as parallel and coordinated activities in the areas of market, product and production. It is a general model (depicted in Figure 2.6) that address the development process on project level and relates to the company level, where it is part of the overall strategic process of product planning.

The model of integrated development includes the product synthesis model that describes the design process, and also prescribes documents to hold requirements, criteria and the goals of the development project and product, called the respectively the project and product specification. Both the synthesis model and the specification documents are shortly described below.

Product synthesis

The product synthesis by Tjalve [1979] is a design model that is a part of Integrated Product Development (see Figure 2.6). It describes the general steps in the process of product design in Figure 2.7 It takes its starting point in a problem analysis and then determines the main function, which is then split into sub-functions and means that can fulfill these functions. With these means as elements that must be integrated, the structure of the product is considered. The structure can be approached in two ways: The basic structure and the quantified structure. The basic structure defines the principle structure of how the different means interact, ant the quantitative structure defines how they should physically be structured. Finally the form, material, dimension, surface quality and the overall shape are defined in parallel with co-ordinated steps.

As Figure 2.7 shows, the steps in the product synthesis can be described with the model of general problem solving [Andreasen & Hein, 1985]. This activity can be considered to be the smallest building block in the ongoing activities of a development project and projects in general.

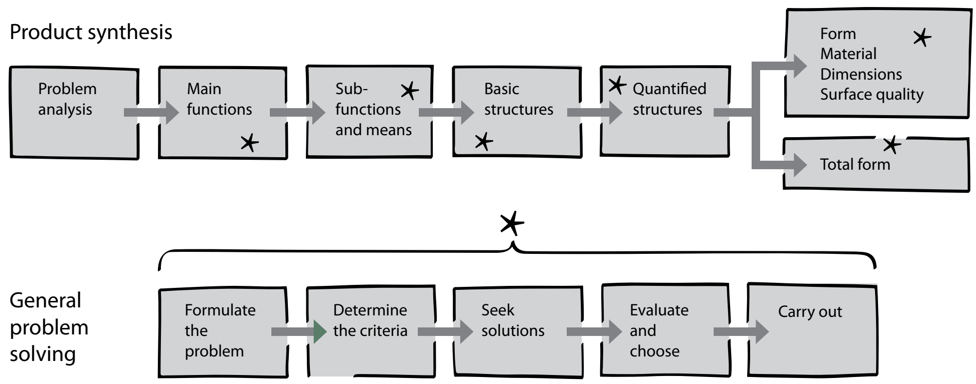


Figure 2.7: The product synthesis with different steps in the process of designing a product, related to the model of general problem solving.

Goal, requirements and criteria in Integrated Product Development

Integrated Product Development also describes the importance of management and supervision according to both company and product goals in the product development. A goal-setting document is suggested, namely the project specification to describe requirement and criteria and specify the goals. This project specification covers goals within the following areas:

- Business goals constituted by:
  - Market
  - Product
  - Production results
- Economical goals and conditions; i.e. core economical results and financial solutions:
  - Revenue
  - Sales cost
  - Production costs
  - Rentability
  - Liquidity

- Project conditions regarding:
  - Staffing
  - Resources
  - Responsibility
  - Management
  - Stakeholders
  - Organization
  - Etc.

The economical goals are very dependent of the business goal, which again are dependent of the "goodness" of the product, which is being developed. Hence the goals are interrelated and must be adjusted according to the changes which may occur.

In product development the economical goals must from time to another be approached with instruments from the financial world, making analysis of discounted cash flow (basing the net present value on discounted value of future in-coming and outgoing cash flows). in bigger projects with uncertainty aspects, real options theory, a financial approach, is also applied, describing the actual options and the consequences of choosing them, when uncertainty is present [Balck and Scholes, 1973, Gonzales-Zugasti et al., 2000]. This method has advantages compared to cash flow analysis methods, which is a traditional way of assessing value of development projects, because it considers that investments are made multiple times in the development process, and not just once, meaning that projects that start to look badly can be aborted before more investments are made.

2.2.3 The V-model

The V-model is a graphical representation of the systems development lifecycle. It summarizes the main steps to be taken in conjunction with the corresponding deliverables. The model originates from the field of Systems Engineering. The Systems Engineering discipline has evolved from the development of military system, where many different technical fields with different requirements and criteria have to cooperate.

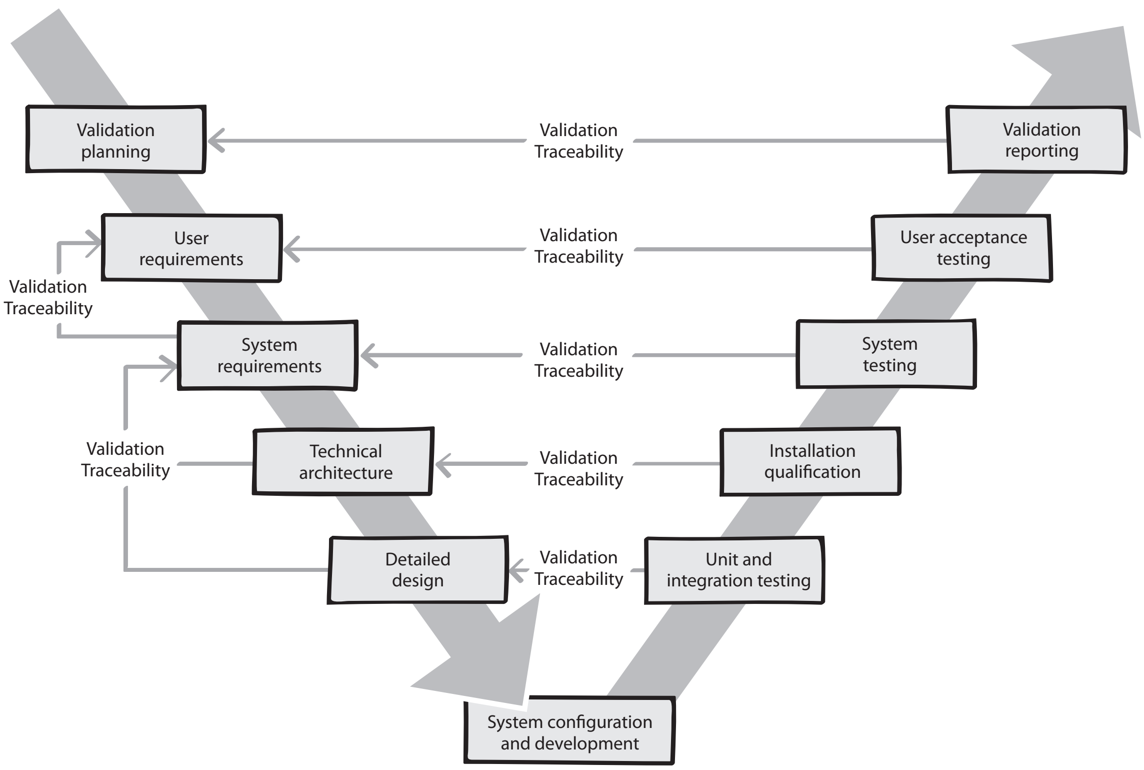


Figure 2.8: The V-model of a conventional large system development process [Turner, R: Toward Agile Systems Engineering Processes,Journal of Defense Software Engineering, April 2007],

The process represents the sequence of steps in a project life cycle development. It describes the activities and results that have to be produced during product development. The left side of the V represents the decomposition of requirements, and creation of system specifications. The right side of the V represents integration of parts and their verification.[International Council On Systems Engineering (INCOSE), Systems Engineering Handbook Version 3.1, August 2007, pages 3.3 to 3.8]

The model has focus on systems, their dependent but not integrated interaction and the validation of their performance, and the model has little focus on business, customers and process of synthesis of the system.

2.2.4 Relevance of product development models

The product development models serve as the basis for understanding the platform development process, which occurs in projects which are similar to the ones described in the above models. The stage-gate describes to context of which a project process often takes place in modern companies. The aspects of market, product and production and their interaction as integrated product development suggest are equally relevant in platform development, where not only one, but many products are developed. The V-model from Systems Engineering covers the more system-oriented aspects of a product platform, being a system, satisfying requirements from many technical areas.

Finally the aspects of the project specification, criteria and goal setting are relevant in the discussion of platform performance and achievement of goals and expected effects: The examples from Integrated Product Development serve as starting point of the discussion of the types of platform goals and their nature.

2.3 Organizational management theories

To understand the process of platform-based product development and the use of platforms, it is also necessary to understand the context of which these processes take place, namely in companies (organizations) consisting of a number of individuals. These aspects are described in organizational management theories, e.g. change management, motivation and goal setting theories.

2.3.1 Change management theory

Companies are running multiple different projects simultaneously, which necessarily have to be adapted to the changing surroundings. Some of these involve some sort of a change that according to Robbins [2001] may influence

- Structure
- Technology
- Physical setting
- People

One of the most well documented findings in studies of organizational and individual behavior is the resistance to change. There exist both individual and organizational reasons for this. The individual reasons may be due to habit, fear of the unknown, security, selective information processing or economic factors. The organizational reasons are structural or group inertia, threats to established resources, power relationships or expertise, or limited focus of change[Robbins, 2001]. There are different approaches to overcome this resistance, and one example is the change process of eight steps prescribed by Kotter [2007] described in Figure 2.9:

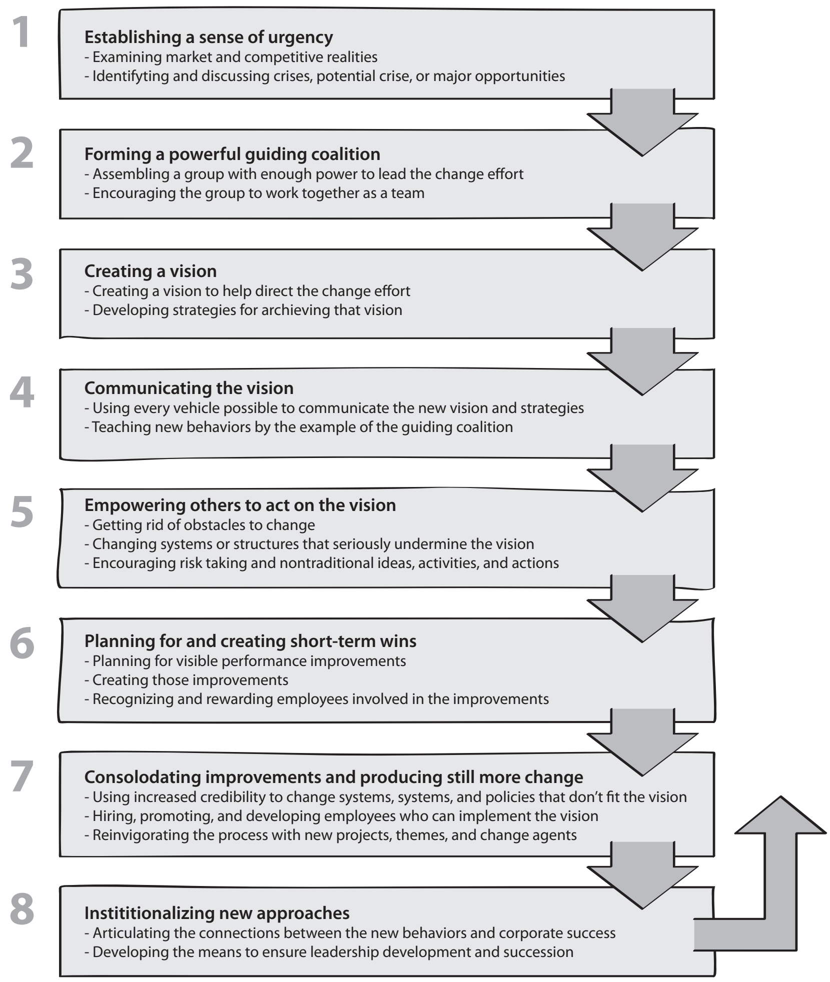


Figure 2.9: Kotter's [2007] prescriptive model for successful change processes involving eight steps.

The process involves both content oriented requirements such as recognition or establishment of a sense of urgency, creation of a vision and planning for short term wins (though without explanation of how this is done) and requirements to the organizational context such as a powerful guiding coalition and empowerment of other employees.

A way to deal with the ongoing change is to strive for a "learning organization". This is defined as an organization that has developed the capacity to continuously adapt and change by redesigning the organizations structure and reshape its' culture [Robbins, 2001]. The learning organization is characterized by the following according to Senge [1990]:

1. There exist a shared vision on which everyone agrees
2. People discard their old ways of thinking and the standard routines they use for solving problems or doing their jobs
3. People think of all organizational processes, activities, functions, and interaction with the environment as part of the system of interrelationships
4. People openly communicate with each other (across vertical and horizontal boundaries) without fear of criticism and punishment
5. People sublimate their personal sub interests and fragmented departmental interests to work together to achieve the organizations shared vision

2.3.2 Motivation theory

Looking at people as individuals is an approach in organizational management that draws on research from psychology and sociology. Motivated employees perform their work better and hence the motivational factors are paid much attention in modern management practice. According to Robbins [2001] there are different factors that increase motivation:

- Education and communication
- Participation
- Facillitaion and support
- Negotiation and reward
- Manipulation and co-optation
- Coercion

Motivation theory builds among others on the goal-setting theory by Locke [1968] and expectancy theory by Vroom [1964]: Locke's theory describes how goal-specificity, challenge and feedback improve performance, whereas Vroom describes, how individual effort is related to personal goals by the a series of relations, as described in Figure 2.10:

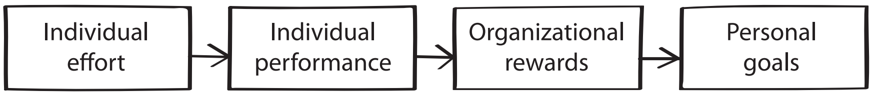


Figure 2.10: By having organizational goals it is possible to achieve personal goals, which serves as a motivation factor, with an individual effort.

- Effort- performance relationship: The probability perceived by the individual that exerting a given amount of effort will lead to higher performance
- Performance-reward relationship: The degree to which the individual believes that performing at a particular level will lead to the attainment of a desired outcome
- Rewards-personal goals relationship. The degree to which organizational reward satisfy an individual's personal goals or needs and the attractiveness of those potential rewards for the individual

These theories are also the foundation for more operational management methods, such as SMART goals suggested by Doran [1981]. The SMART notation is abbreviations for the following beneficial characteristics of a goal being Specific, Measureable, Attainable, Relevant and Time bound. The goals besides working as a motivational factor also enable evaluation, learning, improvement and promotion of good results. The aspects of goal setting was also discussed in the previous section about product development models, as part of the model of Integrated Product Development as a tool for guidance and control, whereas it in the above also serves a motivation purpose.

Motivation must however be understood in context opportunity and ability as described by Blumberg and Pringle [1982], who explain how opportunity, ability alongside with motivation influence the performance of an individual and each other.

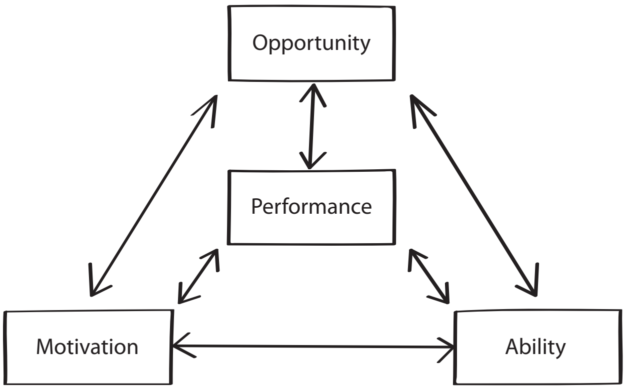


Figure 2.11: The interrelations between motivation, opportunity, ability, and performance.

2.3.3 Relevance of organizational management theory

Product platforms are in a way systems that are integrated in larger organisational systems. The organizational management theories do to some extend describe critical mechanisms in this dimension of platform-based product development.

Changing into platform based product development is change from the traditional product development process and hence it is relevant to study change management. The change management theories show some of the other aspects that must be present to ensure a successful introduction and continuous application of platform-based product development.

Finally this part of the theories describes motivation aspects and goal-setting theory, which is a relevant fundamental understanding in relation to study of the performance of the product platforms and achievement of their goals and expected effects.

2.4 Concluding on the theoretical background

A number of fundamental theories and models have been described within the areas of

- *System theories:*
  Theory of Technical Systems and Theory of Dispositions
- *Product development and Engineering Design theories:*
  The Stage-gate model and the model of Integrated Product development
- *Organizational Management theories:*
  Change management theory and Motivation theory

This theoretical background provides a fundamental understanding and mindset of the core concepts which are the starting point of this research, both relevant when studying and understanding platform-based product development and to assess existing methods. These theories and models (or comparable ones) are the theoretical foundation of which the findings and research results of platform-based product development build upon.

Part 3
Introduction to platform-based product development

Platform-based product development is described this part, based on the existing literature on the subject. Platform definitions and central concepts are reviewed, followed by the potential effects: Product platforms' benefits and risks. A number of platform design and development models are also described to create a basic understanding of these aspects of platform-based product development.

3.1 Setting the stage

The ongoing competition in the global marketplace has changed the market dynamics, which makes it necessary for companies to search for new opportunities to improve the business. To meet the market needs, companies strive to deliver increased customer variety and reduce development times [Sanderson & Uzumeri, 1995], without sacrificing efficiency, effectiveness and low cost [Pine, 1993]. Findings from the automotive industry [Womack et al, 1990] and empirical surveys of manufacturing firms [Duray et al, 2000] confirm this. To meet these demands, companies design and develop multiple products at the same time [Meyer & Lehnerd, 1997]. This development of multiple products often lack coordination and results in a diversity of products and parts that are very similar and only add little or none value. This causes great and costly complexity in the companies [Simpson, 2004].

The opportunities of creating variety on one hand and the necessities of cleaning up in the summed up consequences of past decision on the other are interrelated problems and tasks [Andreasen et al., 2004]. To handle these companies turn to approaches of applying reuse and partitioning strategies. Platform-based product development is one of these.

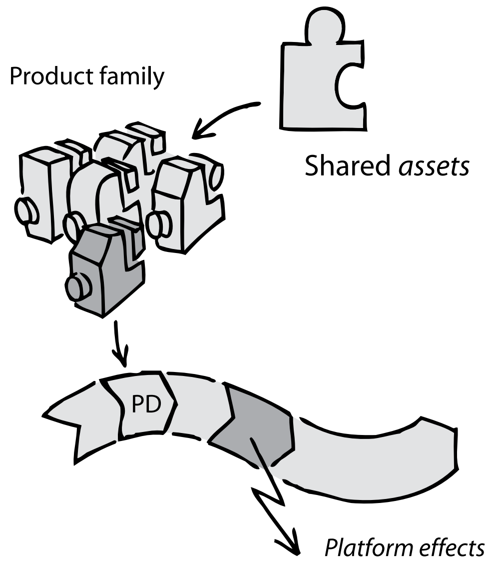


Figure 3.1: The key idea in product platform is to reuse assets in multiple products, which creates the desired effects in the different phases of the products life cycle (after [Nielsen, 2010])

Platform-based product development is a way of gaining effects by reusing assets across products. The assets that are reused may vary from physical elements like parts, components or modules, production processes and equipment to specifications, planning schemes and production layout. This reuse creates a competitive advantage, a desired benefit like a variety of products, reduced development time, lower costs or improved quality. The important principle is about reusing subjects across products, where it creates a desired effect, and concentrating on delivering distinctiveness, where it is valued by the customer.

Studies indicate that indeed there is potential to be more effective applying reuse: It is estimated that 90% of industrial design activities is based on variant design [Gao et al, 1998] and in redesign cases an estimated 70% of the information is reused from previous solutions [Khadilkar & Stauffer, 1996]. The use of previous concepts and application of the experience and knowledge connected to that is a natural part of the design process, and the above figures show that there is great potential to exploit the reuse.

Duffy and Ferns[1999] conclude, that applying an overall systematic reuse approach instead of an ad hoc approach has dramatic potential benefits: Gains should be 130% on time benefits, 367% of cost benefits, 175% of quality benefits and 90% of performance benefits. According to Duffy and Ferns the limiting factor of the current ad hoc reuse approach is the inadequate means used for documenting past designs, in the form of drawings, specifications etc.

3.2 The basic concepts of platform-based product development

This section introduces the basic concepts supporting the understanding or platform-based product development. To give an understanding of the fundamentals, four areas are described:

- Product platform definitions and concepts related to product platforms
- Commonality and variety
- Alignment with life phase systems

Different product platform definitions are described to understand the phenomena of platform-based product development, as it is the central concept. Other concepts closely related to product platforms are also described to enable the reader to navigate between them.

The two later bullet points of commonality and variety and life phase alignment can be described as what a product platform and it products (both contemporary and across generations) should be designed for.

Commonality and variety are central concepts in this research, because that is what platform-based product strives to combine, satisfying the customer desire for diversity with a product scheme, sharing various assets. The understanding of how these opposite concepts can be combined is elaborated in the following.

Alignment with life phase systems is the final central concept. Platform-based product development situates the reuse in products different life phases, e.g. in the development and manufacturing of products, by aligning the products and life phase systems characteristics and properties.

3.2.1 Product platform definitions

I stated that platform-based product development is a way of gaining effects by reusing assets across products. This description is rather broad, and platforms have many instantiations in industry and academic literature, hence there are many perceptions of platforms. In the following relevant definitions in literature will be described. There are many different descriptions, but in my perception product platforms, product families' modularity and architectural concepts, they are closely related, overlapping and different representations of the same aspects. Hence e.g. modularization is relevant for and describes the partition of some product platforms, and no exclusion is used between the two terms. It may be suggested that platform-based product development is macro description, focusing on both products and processes, whereas e.g. modularization and concepts like architectures has a product-oriented focus.

Definitions of product platforms span from being general and abstract to being industry and product specific, and some focus mainly on the product and artifact itself, while others explore the platform concept in terms of a firms value chain [Jiao et al., 2007].

A classical definition, which is often quoted, is from Meyer and Lehnerd. They state:

"A product platform is a set of common components, modules or parts from which a stream of derivative products can be efficiently developed and launched" [Meyer & Lehnerd, 1997]

Similar with this perception, though adding technology is the following definition:

"A product platform is a collection of the common elements , especially the underlying core technology, implemented across a range of products" [McGrath, 1995]

The element of technology concerning designs, materials and processes can be emphasized:

"A product platform in a firm has a twofold meaning, i.e., to represent the entire product portfolio, including both existing products and proactively anticipated ones, by characterizing various perceived customer needs, and to incorporate proven designs, materials and process technologies" [Tseng, et al., 2003].

Muffato (2002) adds the element of intentional planning to his definition, which underlines that a product platform is carefully planned and designed for specific effects, and not necessarily just something happening ad hoc:

"A product platform is a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced."

Muffato also states that *"A platform can be seen from a strategic, an organizational, and a technical perspective"*, [Muffatto, 1999]. This is in line with other definitions that underline other dimensions than the merely product and technically oriented, namely the business element:

"A product platform is not a product but a planning construct"..."platforms must be a business concept and not solely an engineering concept", [Yang & Jiang, 2006]

A general and abstract, but also common definition is the one by Robertson and Ulrich:

"A product platform is the collection of assets that are shared by a set of products" [Robertson & Ulrich, 1998].

The assets represent:

- Artefacts; element and modules
- Processes and equipment used for creating the products and the supply
- Knowledge related to design, technology and production
- People and relationships; teams, networks, suppliers

This definition is further developed by Kristjansson et al, [2004], based on the use of the term platform and its applicability in industry and reviews of previous definitions. They see a platform as *"a collection of core assets that are reused to achieve a competitive advantage".* They adopt assets from Robertson & Ulrich [1998], and in their adoption they elaborate on the core assets:

- Components, including functions, CAD tools, circuit designs, and software.
- Processes include the equipment used to make components into products, assembly system, and the design of the associated supply chain, and material
- Knowledge includes and the design know-how, material know-how, technology applications and limitations, production techniques, mathematical models, and testing methods.
- People & relationships include teams, relationships within and across teams in the organization, alliances in- and outside of the company and relations to suppliers.

They include the business dimension by adding the purpose of the platform, namely to create competitive advantage. Similar definitions regarding what a platform consists of are proposed by Miller [2001] and Andreasen et al. [2004], in a perception of the foundation for a product family, consisting of activities, products, and knowledge. In this case the products represent the components, and the activities may include both the processes and the people supporting them, hereby encapsulating both. A case from Phillips Consumer Electronics, [Niewland, 1999], supports this understanding and reports the use of a platform definition comprising three aligned architectural constructs within hardware, knowledge and activities. In the table below a number of industrial product platform cases are listed, which can be studied to see the breadth of the definition and application area. In this thesis the latter descriptions found the understanding of the product platform concept, using the definition by Kristjansson et al, [2004]: A product platform is *"a collection of core assets that are reused to achieve a competitive advantage".*

The above mentioned definitions of platform-based product development and modularization has been applied in a number of cases, ranging from aircrafts, cars, consumer electronics, househould appliances, personal computers, software, test instruments, power tools [Sanchez & Mahoney, 1997]. Selected examples are listed below and can be studied for inspiration:

• HP computers and Canon Copiers, [Meyer and Utterback, 1993]
• Kodak's cameras, [Robertson & Ulrich, 1998]
• Black & Deckers Power Tools, [Meyer & Leherd, 1997]
• Motorola's bravo pager, [Pine, 1993]
• Information technology and the software industry, [Meyer and Zack, 1996]
• Re-insurance business, [Meyer and DeTore, 1999]
• Non-assembled products: Chemicals, Materials and Film, [Meyer and Dalal, 2002]
• Sony's Walkman, [Sanderzon & Uzumeri, 1997]
• Hewlet Packard's ink and laser jet printers, [Feitzinger & Lee, 1997].
• Honda's "stretchable" automobile platform, [Naughton et al., 1997]
• Boings "stretchable" aircraft, [Sabbagh, 1996]

Table 3.1: List of industrial product platform examples from literature

Related definitions

A number of concepts are related to platform-based product development. In the following the product families, modularization and modular product architectures are described.

Product Families

A product family is a set of products which are related in some way, and this relation between the products is what differentiates a product family from traditional product portfolio [Sawhney 1998]. The relation is often based on a shared product platform [Sahin et al, 2006], being e.g. common structures or product technologies [Erens & Verhulst, 1997], but the interpretation of product families depends on different perspectives.

From the marketing and sales perspective, the functional structure of product families exhibits a firm's product line or product portfolio and thus is characterized by various sets of functional features for different customer groups [Agard & Kusiak, 2004].

The engineering view of product families embodies different product technologies and the associated manufacturability and thereby is characterized by various design parameters, components, and assembly structures (Simpson, 2004). Both perspectives must be taken into account when deciding upon product families and product platforms.

Modularization

Modularization is often mentioned in the same context and is describing some of the same phenomena as platform-based product development (e.g. Pahl & Beitz, 1996, Ulrich & Eppinger, 2000, Otto and Wood, 2001 and Ericsson & Erixon, 1999, O'Grady,1999 and Baldwin & Clark, 2000). It is also aiming at creating a partition of product(s), that create benefits and is in this thesis understood and used a describing the same core phenomena as platforms. A detailed review of the literature on modularity definitions, which also highlights some of the differences can be found in material by Gershenson et al.[2003].

Modular product architectures

The concept of product architectures is often discussed in close relation to platform-based product development. Establishing a platform often necessitates a product architecture [Baldwin & Clark, 2000], and there are various perceptions of product architectures:

The concept of product architecture is synonymous with the layout, configuration, or topology of functions and their embodiment (Van Wie et al., 2003). Ulrich [2007,1995] specifies it as

- the arrangement of functional elements,
- the mapping from functional elements to physical components, and
- the specification of interfaces among interacting components.

Others define it as the combination of subsystems (that does not necessarily rely on the functional structure) and interfaces and relate it to the product platform by describing the goal of making it common across the products, and use it as basis to create several more derivative products [Meyer et al.,1997].

In some cases the word architecture refers to the structural description of units and their interfaces in product assortment, a product family or a product [Harlou, 2006]. In that case the term also refers to a communication document that may work as a specification.

Product architectures are often described as either integral or modular [Muffatto & Roveda, 2002]. Having a modular architecture, a product is divided into independent modules, chunks or units, which are connected to each other by well-defined interfaces. On the other hand in if all components are integrated into each other and have no clear boundaries, the product has an integrated architecture. Changes in a component in a modular architecture can often be contained within one module, leaving the rest of the product unchanged, whereas changes in any component in an integrated architecture are likely to affect the whole product [Ulrich et al. 2000]. Ehrens, [1996], describes how essential it is to separate the stable and variable parts of design.

Studies shows that integral architectures are often driven by product performance or cost, while modular architectures are driven by variety, product change, engineering standards, and service requirements [Cutherell,1996]. This shows that the flexibility of a modular architecture often is more costly and therefore needs to serve specific purpose.

Finally it must be noted that modularity is a relational or relative property [Ulrich et al. 1991], and it is the effects it creates and not modularity that is a goal in itself as such [Andreasen et al, 2003].

3.2.2 Commonality and variety

The core concept of a product platform is to to provide commonality from the production viewpoint and variety from the customer viewpoint.

There are several perceptions of commonality. Many authors see commonality as a quantitative measure calculated on the basis of part commonality, that is, attributes that are common across parts [Jiao & Tseng, 2000b], [Martin & Ishii, 2002], [Thevenot & Simpson, 2007]. These measures are however dependant on the definition of the indices or metrics and the assignment of values. They are in general applied in hypothetical cases or on historical data.

In this thesis definition both commonality and variety are like modularization relational properties and depend on what you compare it to, from which viewpoint so to speak. This means that the same platform elements can have a high level of both commonality and variety if you focus on different characteristics.

To challenge is to obtain reuse benefits in a product platform by having commonality from a life phase system point of view and variety from a market point of view [Andreasen, 1998]. The below figure illustrates the concept;

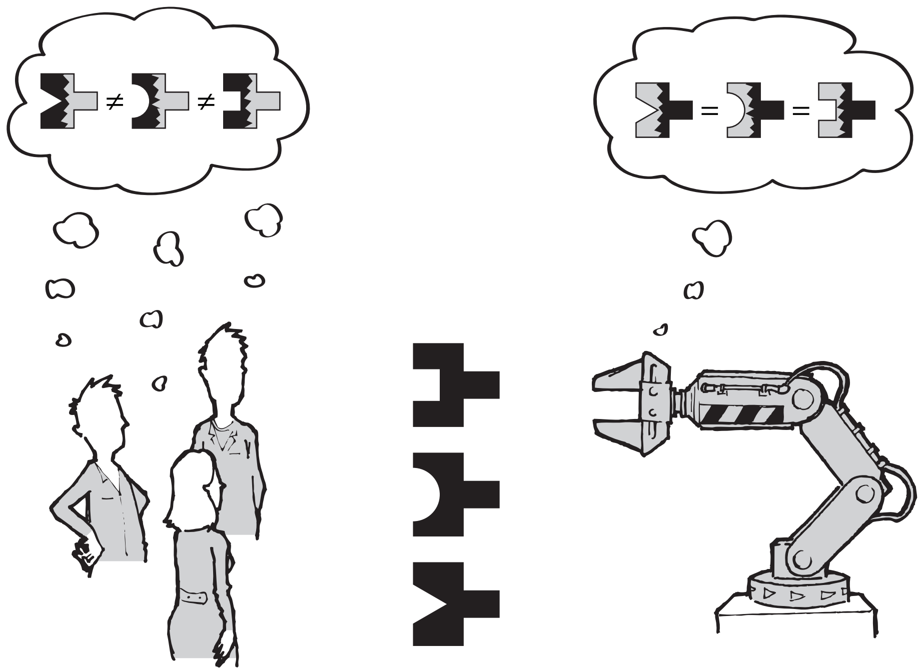


Figure 3.2: The same products can contain both commonality and variety: The customers perceive the products as different, whereas they from a production viewpoint are similar (after Pedersen, [2010].

The life phase systems, i.e. the fabrication system, assembly system, distribution system etc. can be designed in interplay with the platform in order to obtain commonality from an operations viewpoint. There is no simple way to perceive commonality. It has to do with 'smart' designing, as in the platform perception of Andreasen [1998]; "A platform is a means for rationalization of the product development and product realization seen in relation to the business process, based upon a smart, fitted interrelation between products, knowledge and activities".

3.2.3 Alignment with life phase systems

The above section described how it was central to obtain commonality in the different life phases. Rationalizing product development and product realization be done by creating a "fit" between the structures of the different life phase systems and the product. This concept is referred to as alignment, [Andreasen, et al. 2001], see Figure 3.3;

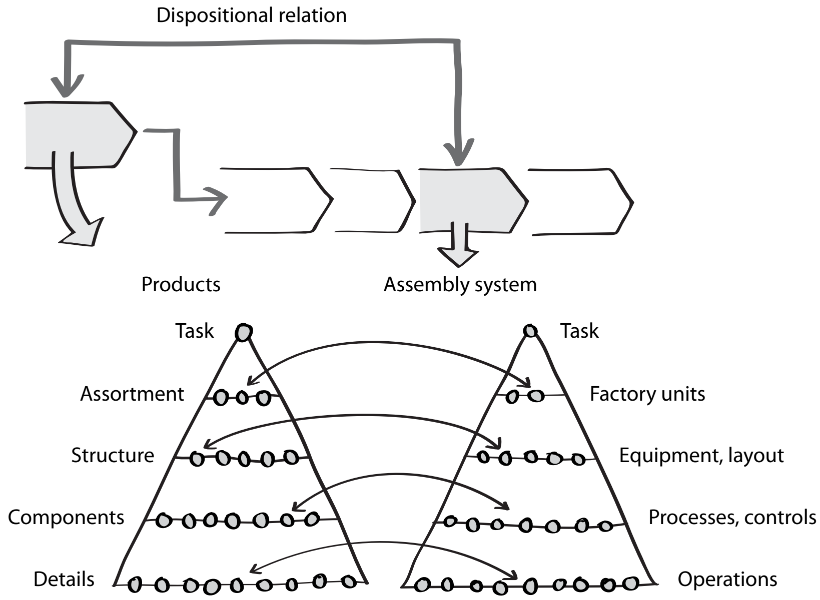


Figure 3.3: Illustrating the concept of alignment: The products characteristics' and the characteristics of the various life phase systems are defined (illustrated by the assembly phase), creating a "fit" between them on different levels of detail. This "fit" from components to the overall product structure and product assortment on the product side and from specific operations to the production layout of the assembly system is regarded as alignment.

A dispositional relation leads to rule-based alignment [Andreasen , 2004], which is also relevant concerning product platforms and the life phase systems to identify potential benefits, as described in Theory of Dispositions.

Other authors describe similar viewpoints of alignment or coordination, such as in the work of Erens & Verhulst [1997]. They describe how product families are based on coordinated product architectures in the three domains: The functional domain, the technology domain and the physical domain, respectively dealt with in product management, development and manufacturing.

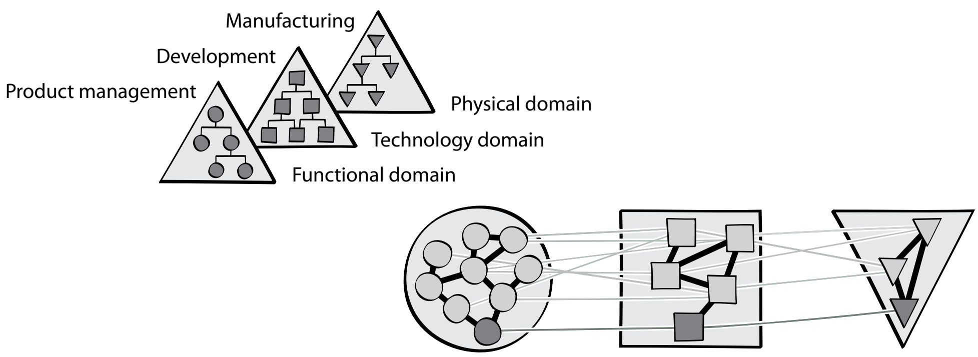


Figure 3.4: An alternative representations of alignment between domains instead of life phases [Ehrens & Verhulst, 1997]

3.3 Platform effects: Potential benefits and risks

The reasons for engaging in platform-based product development are of course the potential benefits. In the following the most commonly reported are reviewed.

3.3.1 Benefits

Since platform-based product development is a means [Andreasen et al., 2003], it can potentially deliver a number of various benefits, and numerous are described in literature. The typical benefits and risks are reported in single successful case studies, like e. g. Sanchez [2000] where the introduction of a platform produces great results: Up to 70 % reduction of costs, 30% reduction of development or production time, 50% improved quality etc. (Sanchez, 2000). The sizes of these benefits are probably not representative and may vary depending on context, which make them difficult to compare and directly transfer to other projects, but they indicate the potential. Others benefits are more dubious and based on hypothetical speculations with little scientific proof or anecdotal evidence, and in general achievement of the benefits often lack validation [Gershenson et al., 2003]. The typical benefits can be grouped within the following categories that are elaborated below:

- Increased revenue by enabling variety (Halman et al, 2003, Simpson 2004, Robertson & Ulrich, 1998)
- Time efficiencies: Reducing development time for derivative products (Muffato, 1999)
- Cost efficiencies: Reduce costs due economies of scale and less redundancy (Gershenson et al., 1999, Muffatto & Roveda, 2000)
- Product reliability and quality (Muffatto & Roveda, 2000, Andreasen, 2003)

A comprehensive review describing the benefits have been made Gershenson et al.[2003], but does however not come up with a total list. Also Ulrich and Tung's (1991) work is explicit in listing the overall costs and benefits of modular products. It must however be noted this thesis focus on internal effects which are relevant for the cases in this research, being mainly the benefits of time and cost efficiencies.

Increased revenue due to variety

One of the core thoughts behind platform-based product development is to be able to satisfy individual customer needs by introducing a variety of products while taking advantage of mass production efficiency (Pine, 1993). Product platforms enable the development and production of an increased number of products, reusing core assets. This helps controlling the complexity and its costs, that else would accompany these variants, and makes it possible to sell more products, when the customer get the exactly the variant they desire [Halman et al, 2003, Simpson 2004, Robertson & Ulrich, 1998)]

Time efficiencies

Reduced development time for the derivative products is another core benefit [Mufatto & Roveda, 2000]. Because of the reuse, the platform enables, only a smaller part of platform-based product needs to be developed, compared to a single product. However the development time for the first platform-based product may be prolonged due to the time it takes to develop the platform, and this risk must be considered, when designing a platform [Muffato, 1999). Lead-time in production may also be reduced; because modules can be produced to stock with less risk and lower inventory cost, and hence reduce the production lead-time compared single products [Ulrich & Tung, 1991].

Time efficiencies in the downstream phases, are mentioned, e.g. in testing and service, due to fewer modules [Ulrich & Tung, 1991], or reduced assembly, process or production time, due to optimized equipment utilization [Sosale et al., 1997].

Cost efficiencies

Cost reductions arising from platform-based product development are often due to higher volumes and bigger batch sizes, i.e. economy of scale, due to reuse of platform elements, lower inventory cost, less obsolete components and optimized equipment utilization [Sosale et al., 1997, Mufatto & Roveda, 2000, Ulrich & Tung, 1991, Ramdas, 2003]. Other also mention learning effects and indirect benefits in the production, arising from less complexity and operation of fewer item numbers and operations [Park & Simpson, 2008]. Reduced cost can also be achieved through reducing the product development costs with a lower development load, attained by reusing the platform elements. This may be specifically relevant in companies where the development investments make up a significant part of the product costs [Ulrich & Tung, 1991].

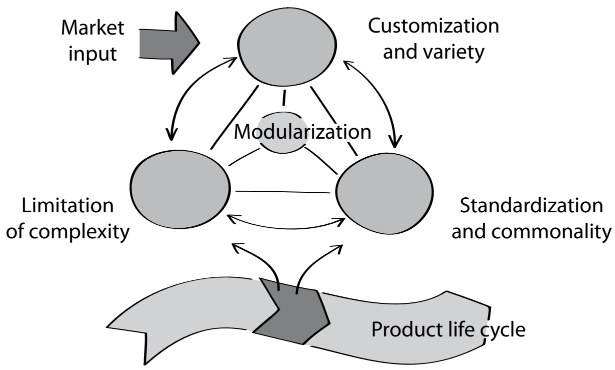
Though platform-based product development may introduce cost efficiencies, the development of a product platform and common modules is often a major investment compared to single product development (Ulrich & Eppinger, 2001). It must also be noted that it still is difficult to predict the total cost of a platform and the economic consequences of changes in the product architecture [Thyssen et al. 2006], even though PDM systems and calculation methods like total manufacturing costs, and activity-based costs [Kaplan et al. 1998, Miller 1996] has improved the transparency and tracking of costs.

Product reliability and quality

Platform-based product development may also result in improved product quality and reliability (Muffatto & Roveda, 2000, Andreasen, 2003, Fixon, 2007, Sosale et al., 1997). The reason is that development of fewer core modules enables aligned focus on core competencies (Meyer and DeTore, 2001, Sawhney, 1998) and a concentrated effort with the best available resources, and this result in few superior solutions (quality-wise) instead of multiple less optimized solutions.

Other views on benefits

The very tangible and measurable benefits described in the above section are sometimes described as derivatives of primary benefits. An example of this is Miller's[2000] work, where he describes the fundamental effects of modularization within the categories of resource leverage, limitation of complexity and variety, which may provide a more holistic understanding of modularization and platform-based product development.



Resource leverage	**Limitation of complexity**	**Variety**
Reuse resources gain rationalization benefits	*Decouple tasks and increase overview*	*Provide customers a well-fitted product*
• 'Avoid work' – not inventing the wheel over again • Working faster and better by learning effects and supporting tools • Reduce risks by using well-known solutions • Reducing internal variety, as it generates costs, but adds no value to the customer	• Break down in independent units • Work in parallel • Distribute tasks • Better planning • Better and easier perceived by humans • By encapsulation and creation of structures, humans can more easily grasp, understand and manipulate	• Provide useful external variety – the customer wanted variety created by combination of modules The following types are not wanted: • Useless external variety – choices the customer is not interested in • Internal variety – variation in processes, materials and solutions, which generate costs, but adds no value to the customer

Figure 3.5: Fundamental effects of modularization

3.3.2 Risks

While many focus on the benefits there are fewer examples of literature describes the risk of platform-based product development. Newer literature however report of cases where platform-based development has been less beneficial (Kristjansson & Hildre, 2004, Krishnan & Gupta, 2001, Hauser, 2001), and meets challenges in the actual operation or use of the platform (Juuti et al 2004), or the resulting properties (like cost and time) are less advantageous than expected (Holmqvist & Persson, 2004) and that product platforms may be a major investment compared to single product development (Ulrich & Eppinger, 2001).

Newer research focus on platform utilization or the execution phase [Juuti et al, 2004, Fiil-Nielsen, 2008] and underline that no effects are achieved, if the platform isn't utilized, which cannot be taken for granted.

Potential risks are:

- Increased cost and time development time for the first product (Halman et al., 2003, Ulrich & Eppinger, 2001)
- Reduced revenue due to commonality and cannibalism (de Weck, 2006, Krishnan and Gupta, 2001)
- Sub-optimal Product Design [Meyer et al.1997, Ulrich 2007, Robertson and Ulrich, 1998].

It must again be noted that this thesis focus on internal effects which are relevant for the cases in this research, being all the above but to lesser degree the risk of reduced revenue.

Increased cost and time development time for the first product

As already mentioned the development of a product platform and common modules is major investment and task compared to single product development (Ulrich & Eppinger, 2001). Hence it is natural that it takes longer time before the first product based on a product platform can be launched [Halman et al, 2003], and depending on the success of the following products (and how the company allocate the costs to the different products) it may have to account for entire platform investment. The challenge is to estimate if the value of an early launch exceeds the value of the platform, and maybe in that case introduce a single product, just to harvest the value from an early launch.

Reduced revenue due to commonality and cannibalism

To base products on the platform, it may involve compromises achieve the necessary commonality, and this compromise may danger the distinctiveness of the individual products. If the customers perceive the products as too similar, the different variants will only compete of each other's market shares and cannibalize each other and lead to reduced revenue [de Weck, 2006, Krishnan and Gupta, 2001]

Sub-optimal Product Design

Another risk of the compromise, the platform may impose on the products, is upscaling a module in low-end products, meaning that they actually can perform better than required, resulting in a cost increase, or down-scaling high-end products with a poorer module [Meyer et al.1997, Ulrich 2007, Robertson and Ulrich, 1998].

3.4 Platform design and development models

This section describes some of the model of how to conduct platform-based product development, namely models for design of a platform and models that describe the development process of platform and products. The task of designing and developing a platform has resemblance to product design and development, but differ in a number of ways as the object is not one, but a family of products, and hence the task is often more complex.

More attention is paid to the design than the development aspects in literature. Numerous methods concentrating on the product platform design task. The platform development process address the issues around the platform design itself and also deals with the more business-oriented and coordinating aspects, and has received far less attention in literature. In the following the methods and processes described in literature are reviewed and their approach to the process of effects and approach to effects estimation.

3.4.1 Platform design models

When designing a product platform, multiple aspects must be considered and there are many more parameters to design or optimize compared to single product design as described in Tjalve [1979], because the platform must leverage satisfying solutions for not only one, but multiple products.

To address this challenge, multiple design processes and methods have been developed [Andreasen et al, 2003, Jiao et al, 2007] and some of the different types will shortly be described below. The methods deal with the problem of creating the design and grouping/ decomposition of the different product elements and apply different strategies (and often a combination).

- *Commonality – Differentiation thinking*
  This approach is overall and pragmatically looking at what are common and differentiating elements and market demands across the products and sometimes in time, as done by Robertson & Ulrich

[1998] and to some extend Meyer & Lehnerd, [1997]. This approach relates to the basic concept of commonality and variety introduced earlier.

- *Functional thinking*
  This strategy is based on the products functionalities and aims at strict functional modules. The functionalities are mapped on-to-one or one-to-many with modules and emphasis is on interfaces and performance. Examples are Stone et al. [2000a+b] and Zamarowski & Otto [1999]. A subgroup of methods is concerned with identifying the optimal parameter values (usually in terms of cost and performance) for a certain functional element (e.g. motors and their power range) to cover a number of products[Farrel & Simpson, 2003].
- *Dispositional thinking*
  This approach relies on the dispositional thinking [Olesen, 1992], looking at what effects can be achieved downstream in production, in the supply chain or other life phases by a partition of the different product elements, similar to DfX, only for several products. [Erixon,1996, Ulrich & Eppinger, 2000]. This approach relates to the basic concept of alignment with life phase systems introduced earlier.

Similar to the potential benefits, often the processes and methods that have only been applied in few cases, and many are speculative and have only (if at all) been applied to historical data [Suh et al, 2007, Stone et al. 2000 a+b]. This lack of verification with actual application is a major weakness in the area of processes and methods in platform-based product development.

Most methods and models points out the need for iterations and creation of alternative solutions (just like in single product development), both in terms of modeling the alternative product or platform elements and of their effects: Only by establishing a solution and evaluate if its effects are satisfying, it is possible learn, gain knowledge and improve the solution [Kolb, 1984]

A few design processes and methods for designing platforms will be described below to provide insight in the variety of methods:

Robertson and Ulrich [1998] introduce a simple approach in the commonality-differentiation stream, focusing on product attributes and apply three plans:

- Establish a product plan (Roadmaps showing which products should be launched at what time)
- Specify differentiating attributes in a differentiation plan
- Quantify commonality across products in the commonality plan
- Iteratively refine plans

They note that the product plan is linked to availability of resources, lifecycles of current products and competitors product, major production system changes and availability of product technologies. They also suggest the costs and benefits are expressed in terms of profit and to focus on a few critical chunks.

Stone et al [2000a + 2000b] does not suggest a method for platform development, but propose a method based on so-called function heuristics where different functional flows are analyzed to generate different modular concepts containing the different functions.

The fundamental concept is to derive a future state functional layout of the product based on customer input, and from that basis design the physical products. The flow of decisions and activities are shown in the figure below.

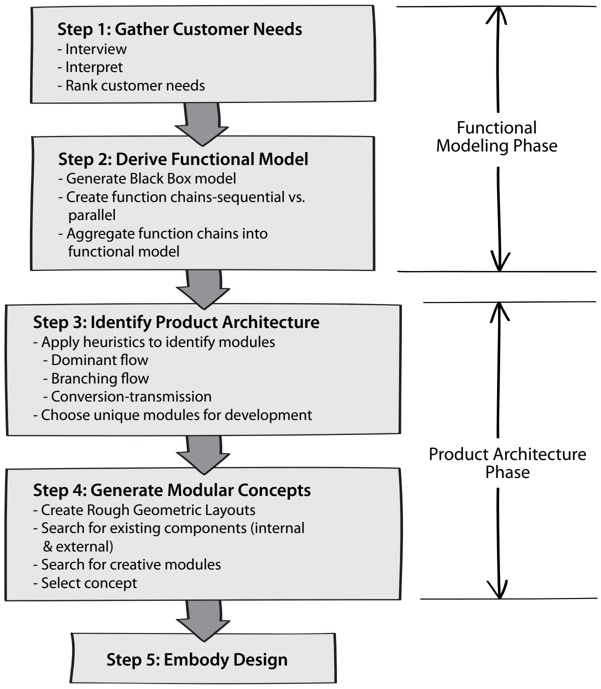


Figure 3.6: Illustration of Stone et al [a+b]'s platform design method based on function heuristics.

Ulrich and Eppinger,[2000] propose a method for establishing an architecture for one or many products, having elements of the dispositional thinking, that involves the following steps :

6. Define secondary systems, which must be detailed after the system-level design has evolved.
7. Establish the architecture of the remaining chunks
   - *Create a schematic of the elements*
   - *Cluster elements*
     (depending on a number of factors regarding product change, product variety, standardization, product performance, manufacturability and product development management)
   - Create rough geometric layout
   - Identify fundamental and incidental Interactions
8. Create detailed interface specifications

The different factors that influence the clustering of elements (or modularization) considers a variety of important aspects and are not only based on functional layout and expected flow and interactions within the product, but also on relational properties concerning various life phases, that the architecture (and platform) can be aligned with.

The factors are comparable to the module drives in Modular Function Deployment (MFD) framework proposed by Gunnar Erixon [Erixon, 1998]. The module drivers are shown in Figure 3.7;

Module driver type	Module driver	Description
Development and design	Carryover	A carryover module is a module used across product generations - i.e. reused in time
	Technology evolution	Technology evolution reflects the preparation for future changes caused by technological changes
	Planned design changes	Planned design changes reflects the preparation for future changes caused by planned design changes
Variance	Different specification	A different specification modularisation approach is used to allow key parameters to be changed in order to change the specifications of a product
	Styling	The overall product function is the same and the modularisation efforts have styling and aesthetics changes as its primary purpose
Manufacturing	Common unit	A common unit module is a module used across product variants - i.e. reused in the product "space"
	Process/organisation	The product is split due to organisational or process related reasons such as a specific production layout or competence driving a natural product split
Quality	Separate testability	Testing each module before the final assembly may lead to improvements in the overall product quality
Purchase	Supplier availability	Some parts of a product may be suitable for outsourcing or readily available, thus forming a natural module
After-sales	Service/maintenance	A service module is a clustering of functions that are prone for wear and tear
	Upgrading	Those functions that are often upgraded can clustered in a module to form a simple way of upgrading without a large part of the product being redesigned
	Recycling	Replacement is also useful for recycling purposes and a subsystem containing expensive materials or potentially dangerous parts may be isolated in a module

Figure 3.7: Erixons' framework builds upon the concept of module drivers that represent some of the benefits that can be achieved when products are modularized.

The module drivers in Figure 3.7 are used as module ideas in the Modular Function Deployment framework: First an overview of customer needs inspired by the Quality Function Deployment (QFD) [Hauser & Clausing, 1988] methodology is established. The QFD gives an indication of customer needs and the weighting of these needs. They are then mapped to desired functions, which link to technical solutions. The solutions are then mapped to the module drivers in a Modular Indication Matrix (MIM), in which the solutions are assessed and weighed based on the various module drivers. The result of that analysis is a list of possible modules. Figure 3.8 shows the iterative sequence suggested in the MFD framework;

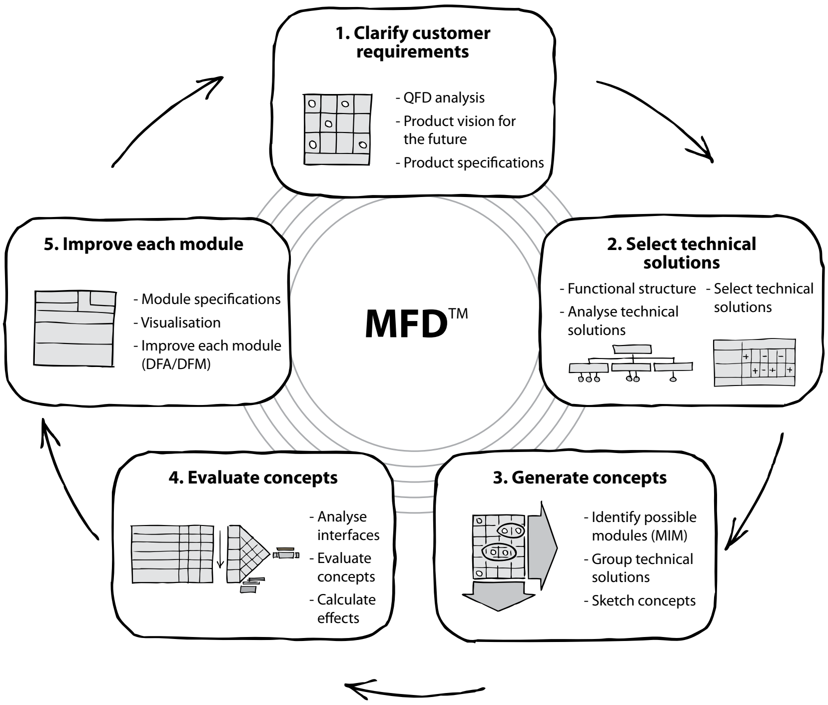


Figure 3.8: The Modular Function Deployment framework: First the customer requirements are classisfied (step 1), then they are translated into functional requirements and technical solutions that can deliver them are selected (step 2). Combinations of the technical solutions are used to generate different module concepts are generated (step 3), and based on analysis of the interfaces and the potential effects the concepts are evaluated (step 4). Finally the modules are improved and their design detailed (step 5)

Multiple other methods can be found in literature and continuously new methods are introduced. They range from being aiming at very specific problems to trying to tie together experiences from existing methods or development processes. E.g. have Suh et al, [2007] proposed 7 steps in platform design methodology (shown in Figure 3.9) and mapped to which extend their own and other methodologies include these steps. Further studies of these methods can be made in Simpson & Mistree [2001], Martin & Ishii [2002], Li and Azarm[2002] and Gonzales-Zugasti et al. [2000, 2001].

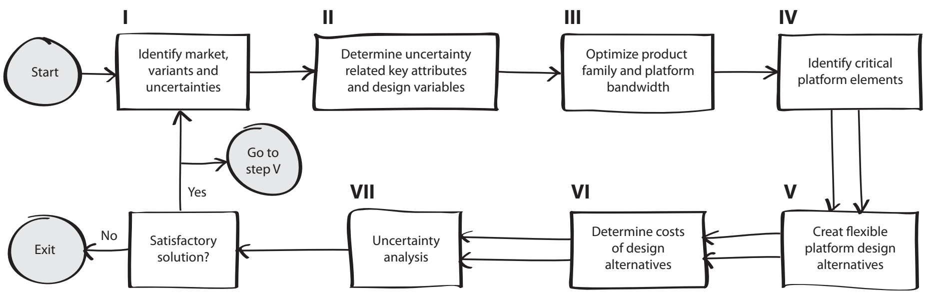


Figure 3.9: Suh et al's 7 steps in platform design methodology

3.4.2 Platform development models

Development of a single product may be a challenge as described in Integrated Product development [Andreasen & Hein, 1985], defining and the optimal characteristics of both product, market and production aspects. Developing multiple products at that same time requires handling of multiple challenges and at the same time compromising to achieve commonality and ensuring sufficient distinctiveness and variety.

Platform-based product development differs from single product development not only in the number of aspects that needs and the consequences in terms of the size of benefits and risks, but also on in the development process. Whereas single product development only deals with one product and only the technical specification and business case of it, platform-based product development deals with not only many products, but also changes the development process. This means that a company changing towards platform-based product development is changing in both the product and process dimensions. Changing both what you do (the products) and how you do it (the development process) is a substantial and complex task, which can be further studied and described.

The subject of platform development compared to the more specific task of product platform design has recieved less attention, and hence there are few methods and models, and more descriptions of characteristics, which are gone through below.

One of the rather few models that describe platform based is the one from Elgård, which shows how the platform-based product development differs from single product development by consisting of a preparation phase, where the platform is designed, and an execution phase, where the platform is exploited [Elgård, 1998, De Wit, 2000].

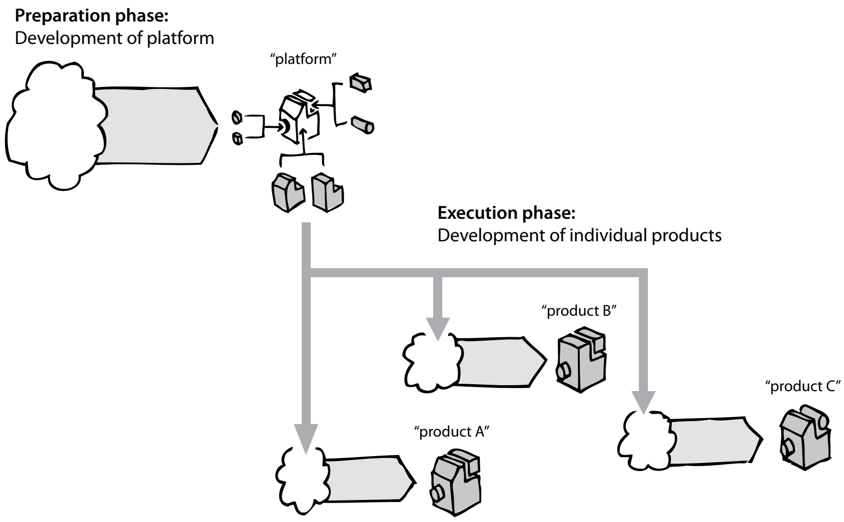


Figure 3.10: The preparation and execution phase in platform-based product development. In the preparation phase the platform and common assets are specified and in the execution phase the platform is utilized in the different products. Inspired by Elgård [1998]

In the preparation phase the platform development team develops, designs and implements the platform and its reuse elements. This phases will be referred to as the platform development phase . In the execution phase the platform is utilized by platform users, being product developers or similar, designing the platform-based products. (In some cases the execution phase can also imply the manufacturing phases, if platform parameters are defined here, e.g. in planning bigger batches). This phase will be referred to as the platform use phase.

The product platform assets are used in several products, possibly shortening their time to market and production costs. This requires that the development activities must be organized differently and there are a number of aspects to considering activities and tasks. It is mentioned by many that platform-based product development result in a different development organization [Muffato & Roveda, 2000, Holmqvist & Persson, 2004].

The differences from are among others [Nielsen, 2010]

- Update need of solution
- Coordination of activities
- Risk and benefits
- Communication/documentation

Nielsen has also described the activities in the early stages of platform-based product development, built upon Elgårds' model and with similarities to the Stage Gate model [Cooper, 2010]. It is in my opinion central to remember these separate phases and in the design activities also consider the later more operational phases and tasks of the execution in the platforms lifecycle, such as in information, support and maintenance and supervision. These new tasks require changes in performance measures for both products and people and also in the design of incentive structures, because the aim is not just performance of a single product, but of a product platform [Sanchez, 2000].

The different way of developing requires a changing process for the organization and may be a difficult task [Kotter, 1995], which may be a barrier [Simpson, 2004], not to speak of the implementation of the platform, an aspect that has been considered by Riitahuhta et al, [1998].

3.5 Concluding on the basic concepts of platform-based product development

In this part a number of different definitions on product platforms were presented and they represent a somewhat common understanding, with some differences. In this research the following definition by Kristjansson et al, [2004] will be applied: A product platform is "a collection of core assets that are reused to achieve a competitive advantage". Related concepts like e.g. modularization, were also found to represent parts of the same phenomena, but there is a also a tendency of a lacking common framework to relate the findings to each other.

The concepts of commonality and variety and the concept of alignment with life phase systems were explained. These concepts support the understanding of what a platform should be designed for in order to achieve the benefits of variety, time and cost efficiencies, product reliability and quality. The actual achievement of these benefits however lacks general and systematic validation in literature, which will be elaborated in the following chapter.

The risks in platform-based product development are increased cost and development time, reduce revenue and suboptimal product design. They are less frequently described than the benefits.

Finally multiple design models for product platforms exist representing three different approaches:

- Commonality – Differentiation thinking
- Functional thinking
- Dispositional thinking

Many of the models are theoretically founded and have often only been verified by few empirical studies.

The process of platform-based in product development is not as frequently described, but sometimes addressed via description of organisational aspects. Platform-based product development can be described in two phases, namely a preparation phase, where the platform is designed, and an execution phase, where the platform is utilized and the products are realized.

Part 4

State of the art and challenges: Product platform performance

This chapter takes its' starting point in the lack of validated achievement of product platform effects. Looking at product platform performance (achieved compared to estimated effects), I review the different factors mentioned in literature influencing this performance and describe the existing approaches for estimating the effects. Finally assessment criteria for product platforms are reviewed. These reviews lead to research questions concerning product platform performance, effects estimation and assessment criteria, presented in the later part.

4.1 Introduction to product platform performance

There are many specific examples of how platforms leverage great effects as noted in the previous part. Literature report of individual successful stories from industry, where the introduction of a platform produces great results and internal effects with reduction of costs, reduction of development or production time, improved quality etc., but in general achievement of the benefits often lack validation [Gershenson et al., 2003]. Fewer examples of literature describes the risk of platform-based product development with cases where platform-based development is less beneficial (Kristjansson & Hildre, 2004, Krishnan & Gupta, 2001, Hauser, 2001), and meets challenges in the actual operation or use of the platform (Juuti et al 2004), or the resulting properties (like cost and time) are less advantageous than expected (Holmqvist & Persson, 2004) and that product platforms may be a major investment compared to single product development (two to ten times the cost) (Ulrich & Eppinger, 2001).

These individual studies show great potential, but do only provide little empirical evidence or understanding of how well the product platforms generally perform, i.e. if they actually achieve the expected effects, which is not evident. There are single case studies where the results are sparsely verified, reporting of both significant benefits but also failures. There are studies that compare performance of respectively and product and platform development, but no comprehensive and comparable studies that documents and verifies platform performance and shows a more general picture.

It is relevant for both academic and industrial reasons to gain knowledge of product platform performance and what influences it: It increases the understanding of platform-based product development (academic success criterion) and this increased understanding will improve the performance of platforms and the competitive advantage for companies (industrial success criterion). Companies are hesitant to embrace product platforms, because they fear compromising the quality of their products [Simpson , 2004]. This risk must be outweighed by realistic expectations benefits and supported by methods that are empirically verified, developed in academia. Therefore it is relevant to address the lacking knowledge of whether product platforms achieve their expected effects, and the potential reasons for deviations in the performance.

4.2 Platform performance research framework

To study platform performance a frame of reference is established to describe the influencing factors. Figure 4.1 shows the reference model of this research, a network of influencing factors, based on the model by Blessing & Chakrabarti [2002]. The model illustrates that platform performance is influenced by multiple factors; many are known and are described in existing literature. Naturally the factors depend on the specific platform and its effects. If the list of factors were complete, strictly speaking it should be possible to predict the platforms performance (not taking into account the uncertainty of the individual factors).

The model also links the knowledge of platform performance to the overall aim of improving understanding of platform- based product development and the competitive advantage for companies. To achieve this, companies need to know what to expect from product platforms, i.e. how they perform and if they meet the expected effects.

If the expected effects are not achieved, it is interesting to understand what causes the deviations and if they relate to the influencing factors described in literature and addressed in platform assessment criteria in platform development and design methods.

Relevant assessment criteria can clarify if make the platform is robust and potentially improve the platform performance, because the platform can be prepared for the challenges, addressed by the criteria. Therefore it is relevant to study the reasons for platforms' performance deviations and if the existing platform assessment criteria are relevant and sufficient.

Platform performance can also be bad due to unrealistic expectations of the effects estimates made in the platform development and design process. Hence it is relevant study the process of effects estimates of platform effects and how they are made viable.

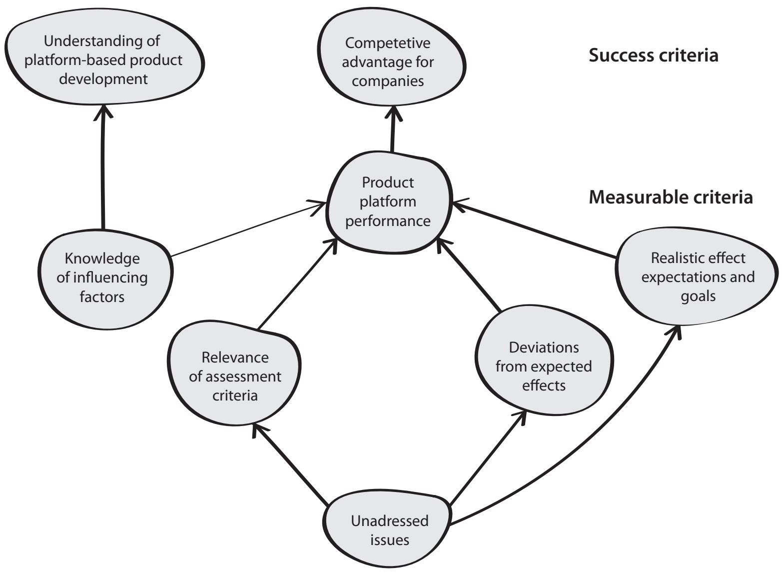


Figure 4.1: The reference model of this research, showing the different influencing factors, their interrelations, the success criteria and the measurable criteria.

In order understand the influencing factors and state-of-the of the different topics, I review existing literature in following sections:

- Research results concerning platform performance and what influences it is studied to get a comprehensive understanding of the mechanisms and to get a frame of reference to understand the reasons for deviations.
- Research results describing the process of making effects estimation for product platform and which elements the estimates are based on to understand how such estimations can be made and be viable.
- Research results that describe criteria used to asses product platforms to understand, what criteria that exist and have a frame of reference when evaluating if they are relevant and sufficient.

4.3 Product platform performance

Different definitions of platform performance will be described and existing studies in literature will be reviewed. Then studies of different influencing factors are revised and are grouped to provide an overview.

4.3.1 Performance definition

In design science performance is often described as attributes that are measurements of fulfillment of a function [Hubka and Eder, 1998]. However considering a system like a platform, the overall function of the system can be consider to deliver a variety of products and to reuse elements across those, achieving a number of benefits. Platform performance as studied in this thesis is the internal performance as expected by the companies, who developed the platform (derived from the definition of internal effect by Kristjansson & Hildre [2004]. This may involve that the performance is not the direct performance of the function, but derived properties from the reuse, such as revenue, cost, time spending etc.

In this thesis platform performance is defined as follows:

"Product platform performance is defined as the achieved effects compared to the expected effects"

The expected effects may both be specifically expected in terms of quantifiable goals, but also in terms of more vague, intangible or abstract expressions, sometimes not even clarified in the platform development process. It may be discussed if this is an appropriate definition, because one can argue that the companies may have wrong expectations or set their goal too high or low, and this affects their perception of a platforms performance.

It is however a concrete definition, which is beneficial in discussions with representatives from industry, and maybe a necessity, because it is still a challenge to measure a meaningful representation of performance of the still rather abstract and complex phenomena of platform-based product development.

It must be noted that the performance in this definition reflects the efficiency of the product platforms, i.e. how the expected effects are achieved, (how right the things are done), and not the effectiveness, i.e. if a product platform is the right solution in the given compared to other potential strategies.

4.3.2 Platform performance studies

There are as mentioned many specific examples of how platforms leverage great effects and as described in section "3.3 Platform effects: Potential benefits and risks". The cases in literature report of successful stories where the introduction of a platform produces great results and internal effects: Up to 70 % reduction of costs, 30%-80 % reduction of development or production time, 50% improved quality etc. (Sanchez, 2000, Robert & Ulrich 2000).

Fewer examples of literature describes the risk of platform-based product development with cases where platform-based development is less beneficial (Kristjansson & Hildre, 2004, Krishnan & Gupta, 2001, Hauser, 2001), and meets challenges in the actual operation or use of the platform (Juuti et al 2004), or the resulting properties (like cost and time) are less advantageous than expected (Holmqvist & Persson, 2004) and that product platforms may be a major investment compared to single product development (two to ten times the cost) (Ulrich & Eppinger, 2001).

It is though difficult to generalize on performance based on achieved benefits or drawbacks in individual cases. Even when such results are presented, it is not clear if they are the actually achieved or if it is the potential benefits of a platform project (actually the goals), set or calculated when the platform design had been finished. Few touches on the subject of how well platforms perform compared to the actual expectations of the company; Tanikonda, [1999], however describes how platform development projects do not differ in terms of success (defined as achievement of project objectives, level of company satisfaction and perceived customer satisfaction) compared to product development projects. This is the most relevant study to compare this study to, with is focus on internal effects, despite that Tanikondas' study does not elaborate on what the platform development projects objectives are.

It is not described what the success rate of product development projects is in Tanikondas' study, but a study of launched products and services estimates that no more than 60 % are successful (Adams, 2004) and an older study of ordinary product development projects only one of eleven considered products is successful and launched products have a success rate of 58 % (Page, 1993). This is mainly considers external effects, and is less appropriate to use as comparison for this platform performance study as it focuses on internal effects.

Even though there is little data on how well platforms perform compared to the expected goals, it is however clear from literature that product platforms may not meet the expectations cf. section "3.3.2 Risks" on platform risks, but no indications or estimates on how often this happens and why they fail. With so little research on the actual performance, it is an area with need of new knowledge.

4.3.3 Understanding influencing factors

To understand and diagnose why platforms meet or do not meet the expected effects it is necessary to know which factors that influence the performance and may caused deviations. In opposition to the lack of research on general performance success of platform- based product development, there are multiple studies describing characteristics, properties and parameters to model. In this study I have allowed myself to make an artifice and juxtapose all these different concepts. The reasoning behind this is that characteristics, properties or parameters may all be influencing factors in the context of platform-based product development. Also different challenges described in literature have been included, in the sense that when a challenge is mentioned, it is analyzed to find the relevant factors.

The term characteristic is used as in Tjalve (1979) and is a derivative of the physical design or object or system, such as structure, form material, etc..These characteristics may be influencing factors, when it comes to the platform performance. Some of them are design parameters, which are possible to specify in the platform design, while others are inherent in the system, and just must be included in the modelling or even determining for other characteristics.

The literature describing product platform performance is multifaceted and has many different viewpoints. In some cases it will be one set of factors and their interplay that is critical, and they may be irrelevant in other cases. Hence the following is not a complete overview, but tries to first to give an impression of the different studies that exists and then establish an understanding of the complex picture that describes platform-based product development. First different contributors are listed and then the factors are described in an overall model. The factors can both be critical (meaning that a platform is not established, if they are not satisfying, while others are enabling, meaning that the existence of a platform is a prerequisite for their importance, which however may be crucial in that case. As also stated by Ragin [1992] the relation between the different influencing factors and the effects can be understood as conjunctures of circumstances more than results of strictly independent factors: Looking on the variables and the effects as conjunctures means that variables are typically not really independent, but instead that causes are effective when the variables operate in concert.

I attempt to categorise the influencing factors into either one of four groups, respectively focusing on characteristics and properties of the platform solution, the existing context and the platform life phases of platform development and platform exploitation (respectively the preparation and execution phase [Elgård, 1998]:

- *The product platform solution*
  These describe the platform solution itself like the product scope, the market (size, customer type, and growth tendencies), the applied technologies (type and stability), and its properties like the clarity of the platform concept.
- *The existing context*
  These are the contextual prerequisites in the company (like size, culture, maturity, financial state, platform understanding) and industrial (competitor) tendencies
- *The platform development process and approach*
  This describes the conditions during the development process, like organization, team characteristics (cross functionality, ownership), management role, stakeholder involvement, modeling techniques (like platform concepts, scenarios and having alternatives), planning strategies and assessment criteria. Also the quality and clarity of the resulting work has influence, since this is where the platform characteristics are determined.
- *The platform execution phase*
  These factors cover the downstream and continuous use activities, where the platform benefits are realized, such as users, platform information, documentation, tools and platform responsibility.

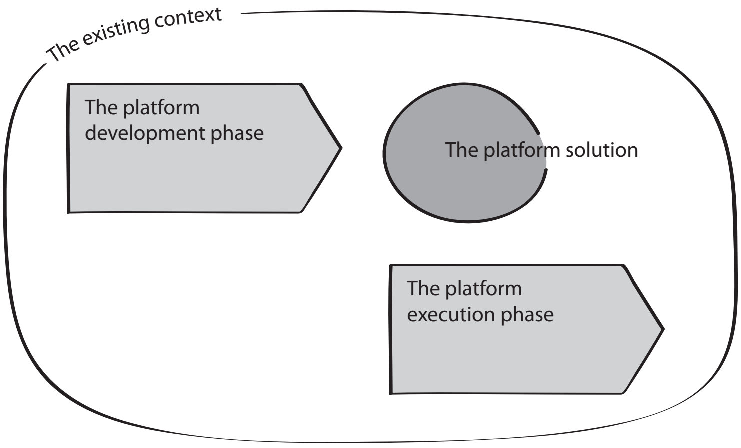


Figure 4.2: The framework of which the influencing factors are grouped: Existing context, Platform solution, the preparation phase and the execution phase

In the above figure the different groups of factors are depicted in the relation the platform development process, inspired by Elgård [1998] .

Concluding on the review of influencing factor, I see the following tendencies:

In general the success-related factors studied in previous studies are process-oriented (the platform development and exploitation phase) and context oriented. Many of the factors are also relevant in successful single product development and change management factors.

There are only few that describe influences of the actual design of the platform itself. This may indicate that in industry the specific design of the platform and the estimate of the effects it creates are too specific to make conclusions on general factors or that it is difficult to identify any meaningful relations.

It is likely that the process and context oriented factors are easier to generalize and describe sensible, and hence they are described to a larger extend. Though they are "enablers" more than a prerequisite to success, they still can be critical to a platforms performance.

4.3.4 Concluding on platform performance

Having revised literature on platform performance and the factors that influence it, I conclude the following:

- There is little literature on how well the product platforms generally perform, i.e. if they achieve the expected effects. There are single case studies where the results are sparsely verified, reporting of both significant benefits but also failures. There are studies that compare performance of respectively and product and platform development, but no comprehensive and comparable studies that documents and verifies platform performance and shows a more general picture.
- There are numerous factors influencing the platform performance, which can be placed within four groups:
  - The platform solution itself
  - The existing context
  - The platform development process
  - The platform exploitation process

The above represent a frame of reference and a framework supporting the understanding of platform performance.

These conclusions will be used to compare the findings from the LEGO platform cases regarding platform performance and analyze the possible reasons for deviations between expected and achieved effects.

4.4 Platform effects estimation

The previous chapter presented platform design and development models of platform-based product development. According to Simpson et al. [2006] there is a lack of cost-benefit analysis in the models, and the detailed quantitative modeling is elusive. There are however a few contributors to the topic of effects estimation in the reviewed models in the previous section on platform development and design models, whereas how the platform effects are identified is seemingly unaddressed:

Suh et al.[2007] consider the estimation of platform effects in their overall framework by valuing flexible elements. They mainly focus on market oriented parameters and discuss market share and variant price as mathematical functions based on past data and different studies of sensitivity analysis of values of different attributes and uncertainty analysis. Different values are selected to form different relevant scenarios. The approach is applied in a fictive theoretical case study and hence the approach needs to be empirically verified. Also the approach requires presence of the significant of data and analytically derived functions, which may be difficult to realize for most companies.

Gonzales-Zugasti et al. [2000] also make estimates in their method for assessment of platform value. They are inspired by the financial approach of real options, describing the actual options and the consequences of choosing them, when uncertainty is present [Balck and Scholes, 1973, Gonzales-Zugasti et al., 2000]. This method has advantages compared to cash flow analysis and net present value methods, which is a traditional way of assessing value of development projects. This method provides the mathematical framework for calculating value and it forces decision makers to be explicit about the assumptions underlying the estimates. The method does however not describe how relevant estimates for the different parameters are made and has only been applied on theoretical examples with arbitrary values.

Quite a few studies evaluate via metrics like Erixon [1998], but Kvist[2010] presents estimates of cost and market share of different product variants in his PFMP2 method, but does not describe in details how the estimates have been made and the process of how viable effects are estimated. Robertson & Ulrich [1998] gives describes a beneficial approach for estimating the effects as being focused on facts –based quick approximate results. Simpson et al. [2006] also emphasize the need of data.

In relation to the discussion of platform effects, it is also relevant to discuss platform goals. There is little in literature about how goals should be specified for a product platform, but Nieuwland [1999] stress that clear target and measures must be set. It is however more risky to make the estimates because the platform affects not only one but a group of product, which means that both failures and success have much bigger impact.

The general goal-setting theory [Doran, 1981] is applicable to some point and the goals must be defined within the areas presented in Integrated Product Development [Andreasen & Hein, 1985], namely business goals constituted by results from market, product and production and economical goals and conditions; i.e. revenue, sales and production cost and ratability. Integrated Product Development focuses on the subjects of goals, but not on the process of how they are estimated.

4.4.1 Concluding on the estimation of platform effects

The aspect of estimation of platform effects is not described extensively in literature, but there are some contributions. Many base themselves on estimated metrics, which are not necessarily transformed into more quantitative effects, and there is little focus on how these estimates are made, what or whom the sources are. Furthermore many of the studies are theoretical and their usefulness has not been validated by empirical data.

The estimation is generally based on different sources of data:

- External sources: Sales figures, Customer needs and segments studies etc.
- Internal sources: Investments, material costs & operations costs (both variable and fixed), ratability etc.

Also the financial aspects and how the business cases have importance for how and what is being estimated. The recommendation towards data approach spans from being theoretical and based on mathematical functions to being quick and approximate, but facts-based. The effects are suggested to be presented in scenarios with a relevant combination of values of different parameters.

In general the descriptions of the process of how the effects are estimated, not to mention identified, are rather limited. Since the expected effects are the reasons to engage in platform-based development, this area may serve more attention and be thoroughly described.

4.5 Platform assessment criteria

To establish a frame of reference, state-of-the-art literature on product platform assessment is reviewed. Aspects concerning platform assessment in the platform design and development models in the previous chapter on design and development methods are reviewed. Besides the basic platform development methods mentioned in the previous section, there are numerous platform development methods that optimize for a few (and sometimes constructed criteria) [Simpson 2003], but in this overview only more comprehensive contributions are considered.

Erixon [1998] evaluate concepts and have a more comprehensive list of evaluation parameters regarding the development task and parameters like quality and lifecycle aspects, service/upgrading. The parameters have a constructed values or rules linked to them. A concept is the given points based on the rules or values. Suh et al.[2007] mentions that it should be evaluated if the platform is a satisfying solution, but does not specify in what dimensions.

Pahl and Beitz [1996] state that a platform solution should be assessed with economical and technical criteria. It is however important that the economic analysis is based on data about market expectations of particular variants. Meyer and Lehnerd [1997] base their platform on market segmentation and have a list of economical and development oriented parameters, which are in agreement with Pahl and Beitz. They use data on cost and time to calculate the effectiveness of the platform, which is the net sales of all platform products divided by the development cost of both platform and platform products. The criteria are used to assess solutions that are credible in terms of platform market strategy, manufacturing technologies and organisation capabilities (the company infrastructure). Jiao et al, [2007] also focus on the economical and technical criteria and conclude that multiple criteria requires to leverage on three pillars; cost, revenue and performance, and typical approach to estimate these figures are done based on traditional principle of capital budgeting that is based on discounted cash flows (DCF) However this approach tends to underestimate upside potentials (Kogut & Kulatilaka, 1994, Fill, 2010)

Gonzalez-Zugasti et al (200] asses the value of a platform-based product family and consider the value of benefits vs. the value of investments. They describe how a number of various objectives can be weighed with a relative importance factor and together with constraints, requirements and uncertainty factors, they can assess the value, but the real challenge is to assign value to all the variables in a realistic way. They consider criteria as investments and uncertainty during platform development, variants development and variant outcome.

Khadke & Gershenson, 2008, also considers risk, specifically for technology change, and suggest a criterion for this. Otto and Wood (2001) also uses metrics and rules on appropriate performance metrics, and let the product designers be the one to decide whether a module should be common or not. Otto and Hölta-Otto(2007) have developed a tool to assess early platform projects. With the tool the platform receive a score, a percentage describing corporate focus and weighed contribution for each criteria, and the sum of all the criteria score shows how good the platform is.

Multiple others discuss the concept of optimal modularity, commonality and measures of it, like degree of modularity. Gershenson et al., 1999, base their number on subjective ratings of relationships between components, products and processes. Newcombe et al (1996) has a similar number based on multiplication of intermodular connections and average correspondence between the modules. Siddique and Rosen (1998) also introduce a measure based on the number of common and unique interface components. Tsai & Wang, 1999 describes how number of modules affect parts fabrication cost and assembly costs. The numbers are based on historical product data and use of theme in design of a new platform is rarely described. Thevenot & Simpson, 2009 establish a dissection-based methodology to benchmark product family alternatives, based on a commonality/variety metric and cost, and use it in historic data, but have no results for application in actual assessment in development of product family.

There are also different levels of detail in the assesment methods; some of the above are focusing on the modular partition in detail. Fixson, 2004,is also an example of this in his product architecture assessment considering functions (structure, side impact protection, aesthetic appearance, carry others parts) and interfaces (intensity, reversibility, standardization).

Another approach to platform assessment is taken by Kristjansson & Hildre, 2004, who suggest a platform evaluation framework considering

- Platform type: which core assets are reused
- Platform goal: Differentiation, Cost leadership or Focus
- Platform side effects (internal and external)
- Platform positioning (potential to maintain or improve its current value)
- Platform action plan - the need to change to the platform and the companys potential to change to it.

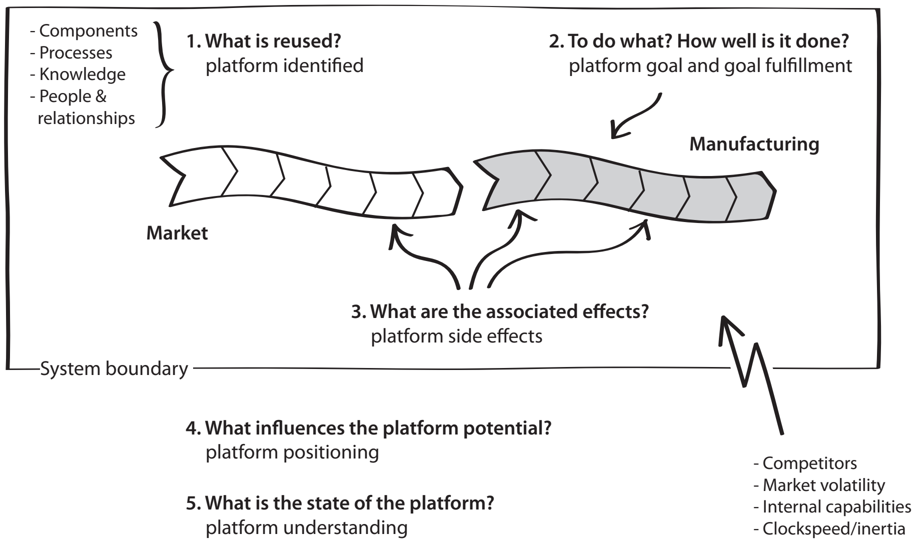


Figure 4.3: Illustration of the platform assessment framework by Kristjansson & Hildre [2004]

This more conceptual approach describes different platform elements and the issues that must be addressed in the criteria that are relevant to assess and understand the platform.

4.5.1 Concluding on platform assessment criteria

From the literature review we attempt to generalize and identify the following tendencies:

Assessment of platforms are done in multiple ways: Compared to single product development where products are assed in relations to goals, requirements and criteria, the goals and requirements is paid less attention, maybe because there is less experience and tradition of knowing what to expect and defining what is needed. It shows a tendency toward criteria that are not specified or measurable and seems to suggest that a platform is assessed from a general perception of is it is worth the effort more than specific quantifiable criteria.

There is consensus in the literature about the importance of criteria regarding the following aspects:

- Platform assets characteristics
- Market /customer aspects
- Technical aspects (performance and stability) and
- Economical aspects (revenue, cost).

Market / customer criteria must ensure that the different products satisfy the different customer segments in a satisfying way. The technical criteria are dependent on the specific products design and choice of technical solution, while input to the economical calculation is based on the design and manufacturing task includes cost, time of the development phase, cost of manufacturing and necessary investments.

Criteria regarding aspects below also often mentioned such as:

- Strategy
- Potential, uncertainty and risk
- Organisational capabilities

The first bullet address the assessment in a more general viewpoint, across the more subject oriented aspects of with there is concensus, i.e. looking at its overall potential to improve the overall the business or the uncertainty and risk of it, which can be broken into more specific criteria. The organisational capabilities in terms of the company's infrastructure and competencies are also considered in some methods.

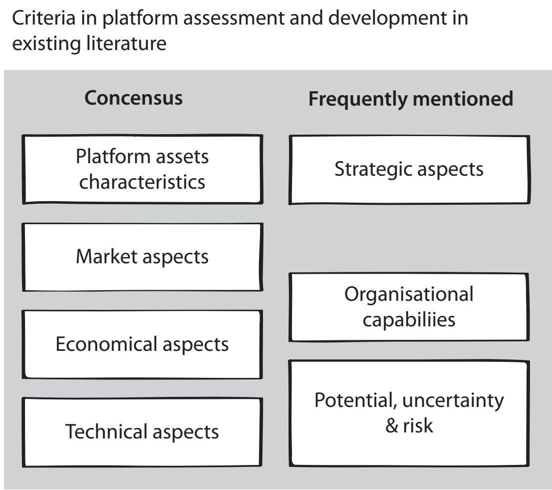


Figure 4.4: There is consensus of a number of aspects in platform assessment in literature and others which are frequently mentioned.

Some of the assessment methods has different viewpoints e.g. based on the lifecycle and include measures of the product quality and after sales criteria such as upgrading/service. Others again focus on what needs to be presented about the platform and suggest a framework, where the platform is more thoroughly describe in terms of reused objects, goals, side effects and potential.

Despite the general consensus about criteria, the literature has two generalised methods when it comes to the assessment result calculations:

1. *Metrics and constructed numbers*
   Metrics, constructed and product-dependent values and weighs are calculated for each of the criteria. The sum of the different values for each of the criteria is the assessment result.
2. *Estimates based on experience and historic data*
   Estimates (time and cost) based on experience and historic data are used in an economical calculation. The figures are derived from the platform concept, including product variants, technical solutions and manufacturing solutions. The convincingness of the platform concept is a prerequisite for the entire initiative and the result of the economical figures will show the size of the advantage.

4.6 Gaps in platform performance knowledge

In this part I have reviewed literature on platform performance, the process of effects estimation and platform assessment criteria:

There are multiple individual examples of rather extreme positive effects, but also reports of less successful projects: Empirical knowledge of general performance of product platforms and systematic documentation and verification of achieved effects, in a comparable and comprehensive way is lacking. This lack of knowledge makes companies hesitate when embarking with product platforms and hinder improvement of platform design and development methods.Therefore it is relevant to address the lacking knowledge of whether product platforms achieve their expected effects, what the reasons for possible deviations are and if they are addressed by existing platform assessment criteria. There are only few descriptions in literature of the process of how the expected effects are estimated in order to make the realistic and descriptions of how the platforms are actually assessed. The process and how the estimates are made viable are not described in detail, which should be addressed to achieve an improved understanding.

The literature review has pointed out unaddressed issues within the topic of product platform performance, and the following research questions seek to address these knowledge gaps:

4.6.1 Research questions

Platform-based product development is a complex phenomena and it is not trivial to evaluate platform performance, depending on the both the achievement of expected effects and the viability of the estimates of them. There is only little knowledge of how these platform performance estimates are made and to understand the context of how they are made, the first research question addresses this issue:

In order to understand if the expected effects are viable, the process of how they were estimated is studied to answer:

RQ1: How can a process of identifying and estimating internal effects of product platforms be described?

Having this established a frame of reference for this aspect, the key question of this thesis address the sparse knowledge on platform performance by asking:

RQ2: Do product platforms achieve the expected effects?

To understand why platforms do not always meet the expectations and if this is due to reasons already identified in literature or new ones, it is relevant to ask:

RQ3: What are reasons for deviations between achieved and expected platform effects and are they addressed by platform assessment criteria in literature?

The questions can also be related to the reference model, linking them to the overall aim of improving understanding of platform- based product development and the competitive advantage for companies. The questions are shown in the model next to the influencing factors they are related to.

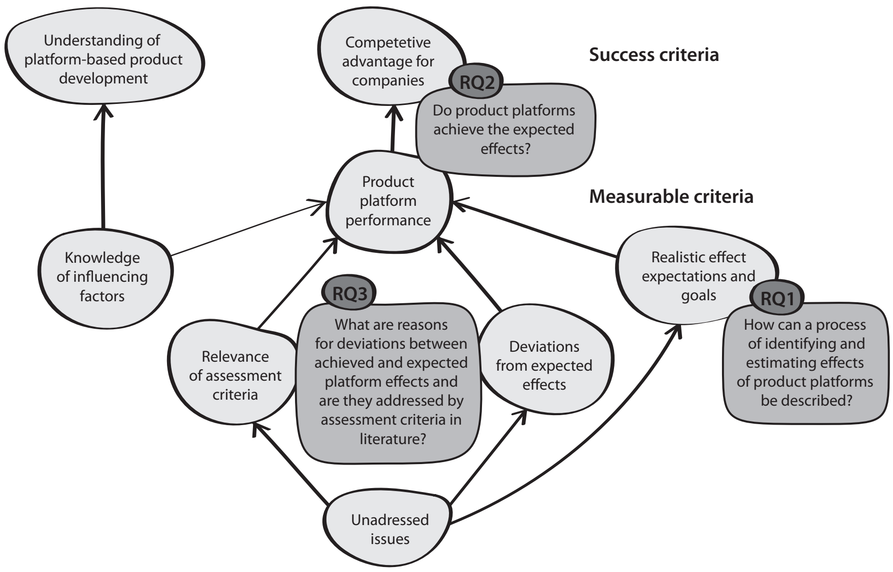


Figure 4.5: The reference model of the research and the research questions, related to the relevant topics

In the following parts I attempt to answer the above research questions answers by analysing and concluding on 8 platform cases from LEGO and interviews with representatives from Scandinavian industry.

Part 5
Research approach

This section describes the approach and the conduction of the research, aiming at answering the research questions. It first describes the overall methods and frameworks, laying the foundation for the research design. Then the different components are described; e.g. overall frameworks, case selection, data collection methods, case analysis and validity and limitations.

The main aim of this research is to investigate and gain knowledge about platform performance, and hereby answer the research questions. To ensure that this is done in an understandable, systematic, reproductable and comparable way (so it can be related to other research results), I use existing relevant methods, altogether pronounced the approach, which are described in the following

5.1 Overall research approach and framework

Two overall approaches have been used in this research.

- Engineering design research framework, describing the structure in the research design
- Case study research approaches, focusing on individual studies and their content

This research is within the subject of engineering design research. Because of this the structural framework in this research origin from engineering design research. The research objects, the product platform have been suitable to describe as cases and hence the research approach is based on case study approaches from traditional areas (such as economics and social sciences).

5.1.1 Engineering design research framework

The general research approach can be described in the framework suggested by Blessing et al (1998), shown in Figure 5.1. This approach is selected, because it provides a structure for different elements of the research and the process of moving from criteria and problem to prescription and it effect.

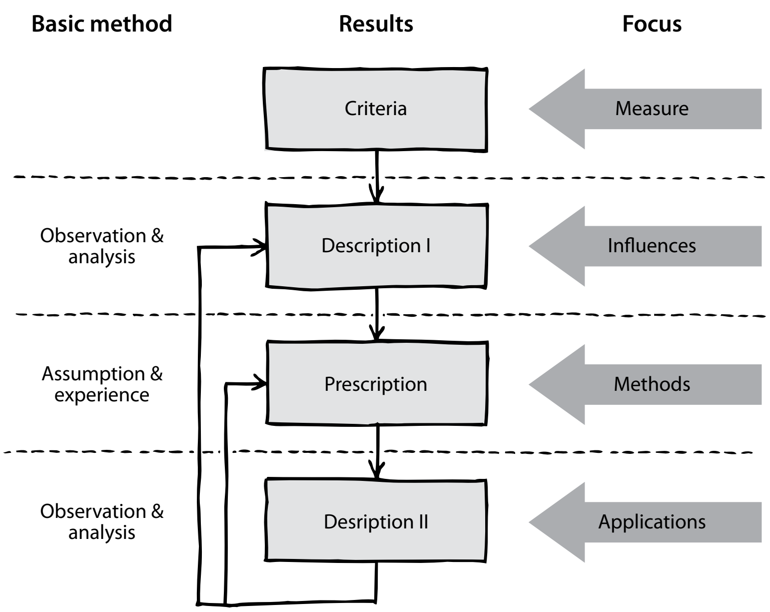


Figure 5.1: Engineering Design Framework [Blessing & Chakrabarti, 2002]

The engineering design research framework starts with a set of criteria that describe the success of the research. In the second step observation and analysis lead to a description of the research object and influences from the surrounding system. Based on assumptions and experience the next, third, step is to set up a prescription (method for improvement). Finally applying the prescription, its effects can be observed and analyzed leading to a description of the new situation in the fourth step. Feedback from the second description can help evaluate and validate or improve both the first prescription and the prescription.

The framework works on many levels, both on the overall research project and on lower level for the decomposed problems with many iterations and is not necessarily to be applied strictly as described above, but as a framework and inspiration. This is also how it has worked in this research.

In this study the focus is due to the research questions on the first descriptive study and makes a few prescriptions on how to improve platform-based product development. The second descriptive study is designed as focusing on validity of the findings; confirming the findings from the descriptive and prescriptive studies.

The framework is also linked to the reference model [Blessing & Chakrabarti, 2002], used to capture the different influencing factors and their relation to the measurable criteria and overall success criteria in the chapter on state-of-the-art literature. This framework supports the logical reasoning of the research.

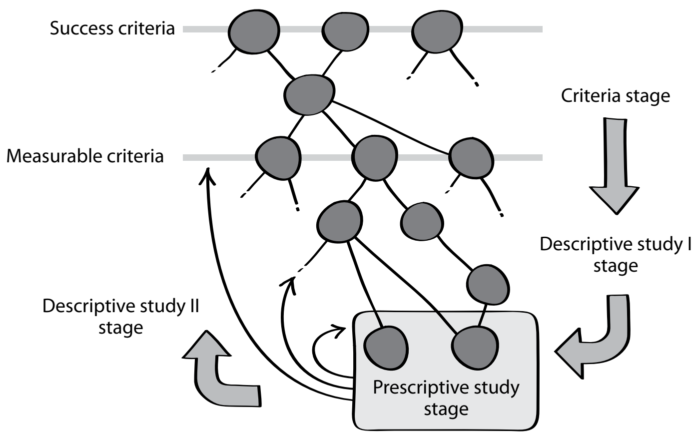


Figure 5.2: The reference model is a network of influencing factors, which have been used to concretize the research obejct and its success and measurable criteria and relate it to the prescriptive and descriptive study.

5.1.2 Case Study Research

Case study research is common within social sciences and is being more used increasingly in areas such as economy, organizational studies and also product development, like platform-based product development. In this study, the case study approach is selected because it is found useful to study the different product platforms as cases and describe them with a variety of different data types and sources. Yin's[1994] definition of a case is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context", which is a suitable description for the phenomena of platform-based product development.

In case studies, both qualitative and quantitative data can be used from a multitude of data sources; as long as it contributes to the description and understanding of the case and this is has been a pragmatic approach to describing product platforms. This approach with many types of data from different sources is a prerequisite for triangulation (minimum three independent sources showing converging results), which is important for the validity of the research findings [Yin, 1994].

Some critique has been raised towards case study research and generalization of the findings, but this critique is addressed by e.g. Flyvbjerg, who states: "One can generalize on basis of a simple case, and formal generalization is overvalued as source of scientific development, whereas "the force of example" is underestimated". Another critique he rejects is that case study should contain bias toward verification: "The study contains no greater bias than other methods of enquiry. On the contrary, experience indicates that the case study contains a greater bias towards falsification of preconceived notions than verification" [Flyvbjerg, 2006].

5.2 Research design

The research design consists of the following elements and is shown in the overview in figure:

The first descriptive studies consists of

- A literature study
- Multiple, in-depth product platform case studies in the toy manufacturing company LEGO Group

The prescriptive study consists of

- Recommendations based on the findings from the first prescriptive study

The second prescriptive study is a validation study consisting of

- Interviews with industrial representatives

The idea in this design has been first to gain an in depth understanding of the area from the literature study (providing the theoretical foundation) and from the participation in and study of a number of product platform projects and their performance (providing the practical understanding). Using the LEGO platforms as case it was important that the performance could be tracked over a longer period (in this case three years) to ensure that the results were representative for the more long term effects. The findings identified from the LEGO case was then validated by comparing them with similar findings across Scandinavian industry in an industrial validation study, ensuring a broadness of the research result.

The emphasis of this thesis is on the first descriptive study resulting in models and conclusions, translated into the recommendations in the prescriptive study and on validation of these findings.

The three steps are described in more detail below, referring to Figure 5.3:

1. In the descriptive part of the study, a study of literature study has been conducted both aiming at getting a solid understanding of the existing knowledge within the area of platform-based product development, the relevant influencing factors, process descriptions and state of the art of the core aspects, e.g. platform performance and assessment criteria. The central part of the descriptive study is the cases from LEGO company, which serve as base of observation and analysis to describe performance and why it may deviate from the expected effects and the process of identifying and estimating effects, answering the three research questions. Many different data collection methods and sources have been applied in this part of the study, as described in Figure 5.3.
2. Steps into the prescriptive study are made with recommendations based on the findings from the descriptive study. The recommendations are both counters against the responses to the reasons for deviations and more general conclusions on what leads to successful platform-based product development and improves its' performance
3. The validity study has also been conducted to respond to the validity and relevance of the research results. This study is based on interviews with 12 Scandinavian companies. The interviews both collect data about their experiences with platform-based product development and its' effects and get feedback on the findings and recommendations from the LEGO cases.

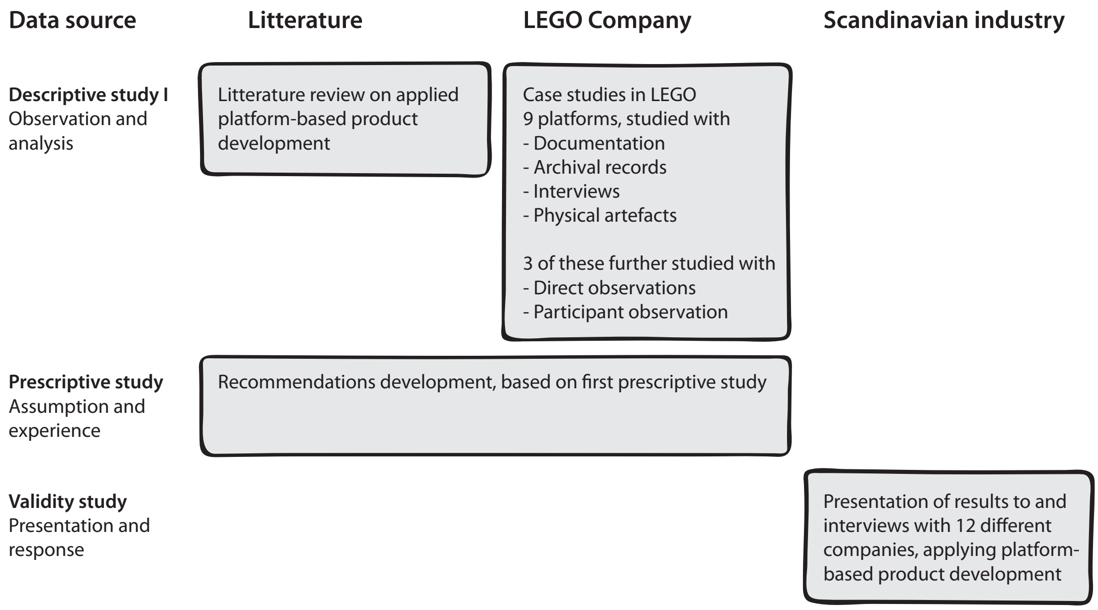


Figure 5.3: Overview of research design

5.2.1 Depth and broadness of the study

As mentioned is has been the intention to ensure both the depth and broadness of the findings in this study. The case studies in LEGO shows a more specific in depth picture (as being in one company only), but have been studied more thoroughly and in depth via different data collection methods and over a long period of time, which makes it possible to study and identify other factors and tendencies that may not be identified in the industry study. Also the platforms can be studied over time and with data from multiple sources.

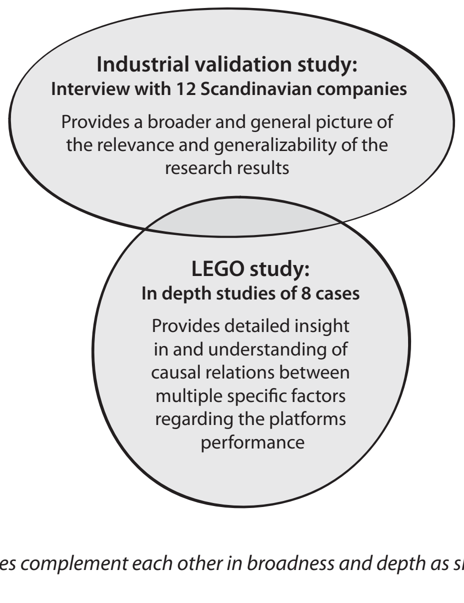


Figure 5.4: The two studies complement each other in broadness and depth as shown in figure Figure 5.3.

The experience and feedback from 12 different companies will show a general broad picture, which is based on statements from different individuals from the different companies across industry, size and other variables, and it indicates how relevant and valid the research results are across the companies.

5.3 Selection of the LEGO platform cases

The study is a multiple case study, where the main sources of cases are 8 product platform cases from LEGO's platform-based product development. It is though more correct to say that the cases have been found than selected, because they cannot be specified on beforehand as Ragin points out [Ragin 1992]. The Ph. D. study behind this thesis has been carried out in cooperation with the toy making LEGO Company, and this has made it possible to study the 8 different platforms in the company.

The selection of LEGO Company for the in depth study cases was based on the fact that they were interested in close cooperation with researchers, still letting the researchers work independently and that the company was initiating processes, focusing on developing and utilizing platforms and already had a number of platforms.

The individual platform cases from different parts of the organization were then identified based on the definition of a product platform (see section "3.2.1 Product platform definitions" for thorough discussion of the definition) as

"a collection of core assets that are reused to achieve a competitive advantage"

where the core assets may be:

- Components, including functions, CAD tools, circuit designs, and software.
- Processes, including the equipment used to make components into products, assembly system, and the design of the associated supply chain, and material
- Knowledge, including the design know-how, material know-how, technology applications and limitations, production techniques, mathematical models, and testing methods.
- People & relationships, including teams, relationships within and across teams in the organization, alliances in- and outside of the company and relations to suppliers.

The product platforms either existed when the research started or have been developed during the research. Due to the close and long co-operation they have been studied in detail onsite during development and use with multiple data sources. This enabled an independent and specific in depth understanding of the projects.

The multiple-case design makes the study more robust [Herriott & Firestone, 1983]. Having a multiple-case design enables the use of replication logic [Yin, 1984]. In general, it is recommended to have between 4 and 10 cases [Eisenhardt, 1989, Yin, 1994]: With less than 4 it is difficult to generate theory of higher complexity and with more than 10 the complexity makes it difficult to find patterns. This study is in the high end regarding the number of cases, which has been a challenge when conclusions should be made. However one of the aims of this study is to establish a comprehensive empirical study with comparable cases and show general conclusions across the diversity, which is possibly with this high number of cases.

5.4 Selection of companies for the industrial interview validation study

For validity reasons, in order to generalize and show the relevance of the research results, an industry study with 12 companies applying platform-based product development has been conducted. Having the industrial input from the companies provides a more general picture of platform-based product development. The data was collected via interviews with selected representatives and relevant documents they provided. These studies are more superficial and more vulnerable to be biased of the interviewee, him or her presenting the data of the case to the researcher.

The cases in the industry study were found making telephone contact to 15 of medium-large companies Scandinavian companies operating in Denmark. It was required that the selected companies should have platforms which as a minimum had been implemented for two years to ensure that there was proper experience and expertise within the field, after they have been developed. Of these 15 companies, 12 replied positively to having one or more platforms that had been implemented for minimum two years, and they were willing to participate in the interview session. The companies all have a variety of products and different product ranges, which is a prerequisite for a platform.

The companies are all developing and manufacturing products and were selected either because of one or more of the following reasons:

- Via contacts at the Technical University of Denmark it was known that the company was working with platforms
- The company was known to work with platforms from literature
- The company was known to be innovative business-wise (in opposition to conservative) and hence likely to have tried platform-based product development.

The cases were also selected to represent a broadness regarding different aspects to generalize from. The cases represent the different combinations of the following characteristics:

- Medium to big companies
- Business to Business or Business to Consumer
- Growing or declining market
- Different industries

The interviewees were identified by asking for the person responsible for the product platform development or platform project. They were required to have min. 4 years experience within the field, and min. 2 in the company, to ensure that they had proper experiences to talk about and had been present in the company a substantial period, where the platform was developed and /or applied. In some of the cases a platform user was also interviewed.

5.5 Data collection methods

In each of the two central studies, the LEGO platforms and the industrial validation study different data collection methods was applied. For the LEGO cases multiple methods were applied, whereas the industrial validation study was based on interviews. In the following the central elements of the data collection of the two studies are described, and then details about the different data collection methods are listed.

For the LEGO product platform cases, depending on the circumstances and possibilities regarding research resources and state of the individual platform, the platforms were studied using one or more of the following data collection methods [Yin, 1994] in each case

- Direct observation
- Participant observation
- Documentation (also presentations, models, ect.)
- Archival record (databases ect.)
- Interviews

Capturing the data from various sources ensures triangulation, which supports the validity of the research findings. The studied objects and the sources of data were chosen based on criteria of importance for and influence on platform and of course availability and varied from products and product models to different staff from marketing, sales, production and supply chain and on different management levels, dependent of their influence and role in the platform-based product development. Figure 5.5 below illustrates how the different methods were used in different phases of the product platform projects.

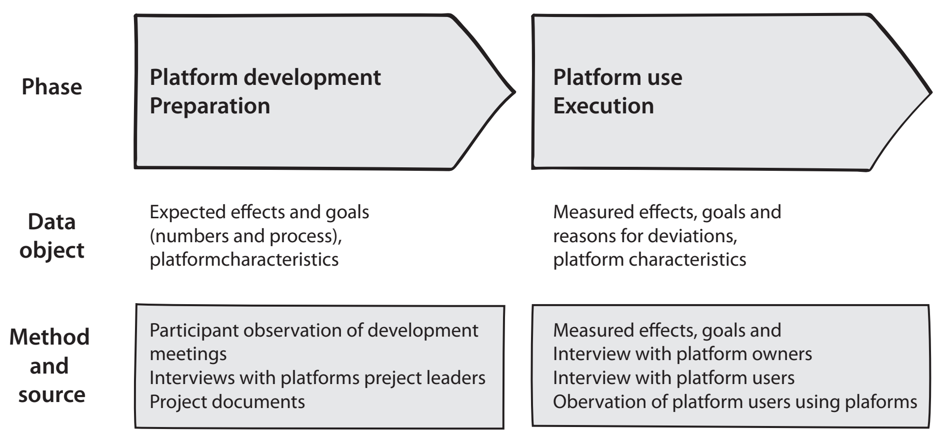


Figure 5.5: Different methods and sources were used to collect data from different phases in the platform-based product development

The industry interviews were conducted with one or more representatives for the company with knowledge of the platforms in the company, often responsible for the platform development and the platform. These people were identified via the product manager or the product development manager. The interviews were either conducted face to face in the companies or by phone, and lasted approx. two to three hours. In some of the interviews documents and artefacts were provided from the company to support.

In the following the different data collection methods are discussed. The different methods have each their strengths and weaknesses, which complement each other. Based on convergence of different studies' results, a consistent explanation or description can better be made. Both quantitative and qualitative data are extracted acquired from the data sources.

5.5.1 Interviews – LEGO cases and industrial validation study

Interviews is an essential and common way of capturing explicit knowledge [Ahmed, 2007] and very used in case study research [Yin, 1994]. Interviews are based on statements from different individuals from the companies and rely on their will and ability to give sensible answers. Personal experiences may show a biased picture of the actual facts.

In this study the interviews were semi -structured open response interview [King, 1994, Breakwell, 1995]. This type is most appropriate, when the objective is to gain a description of the topic and the interviewer is not formerly aware of the information participants will be able to provide. This is the case both in the LEGO cases, because the platform solutions vary in many dimensions, and in the industrial validation study. In the interviews the researcher has a number of topics, but the precise questions and their order are not fixed; they are allowed to develop as the result of the exchange with the respondent.

A general interview guide has been created. It has been used both in interviews with platform owners in LEGO and in the validity study interviews with the industrial representatives (an extended version). It can be seen in "Appendix 2: Material for industrial interviews". Its contents and topics are of course derived from the different factors this study seeks to describe. Inspiration from multiple sources has been applied, when it comes to the structure of the interview guide and formulating the questions. The interviews were started with descriptive questions [King, 1994] followed up by case-focused questions and examples, using drawings and sketches as an important tool of communication [Smith & Osborn, 2003].

In the industrial validation study the results from the LEGO were described in a presentation with questions about relevance of and support to the findings ("Appendix 2: Material for industrial interviews" and "Appendix 3: Data from industrial interview")

5.5.2 Direct and participant observation – LEGO cases

Direct observation can be used to capture implicit knowledge. The strength is that it is direct; there is no time delay or interpreter between the events and the researcher [Yin, 1994]. Being connected to LEGO through 4 year, I was present in everyday life in the company, following product and platform development teams in individual work and meetings, in management meetings with leaders and in production and production equipment development.

The most important source of data in this study is participant observation. Participant observation enables the researcher to perceive reality from an insiders' viewpoint and also to affect things in a way that would not have happened, if the researcher was not present [Yin, 1994]. Participatory action research involves a risk of the researcher pushing the project in a certain direction. Participant observation is similar to self-ethnography [Alvesson, 2003] and participatory action research [Wadsworth, 1998].

I participated in several of the platform development projects as full team member with responsibility for individual tasks. The tasks were e.g. identification of platform solutions, gathering data, making calculations and conducting meetings needed to develop the platform.

The collection of evidence from direct and participant observation is inspired by Alvessons work methodology [Alvesson, 2003]: Field notes are taken in the daily activities, and routinely scanned events for interesting elements related to selected areas, getting input from varying viewpoints.

Field notes focus on situations of interest and how the different factors of interest are affecting these situations with the aim of presenting sequences of actions and interactions and interpret aspects of the situations [Wilkinson, 1995]. In this research the situations of interest were the process of identifying platform effects in the platform development process and the use of the platforms. The field notes have iteratively been written, analyzed and challenged and are concentrated with input from other sources like documents (presentations and documents from the team work) in individual descriptions of the LEGO cases.

Both direct and participant observation have challenges of biases, regarding the role of the researcher as neutral observant vs. biased supporter and attention and time required to observe and question the events [Yin, 1994]. Knowing these challenges, the researcher has been focused on reducing the bias from them, which will be further elaborated in the section"5.7 Analyzing the case study data" about data analysis.

5.5.3 Documentation and archival records – LEGO cases

Documentation material from the different LEGO platforms and their development processes have been useful sources of evidence, mainly used in the first descriptive study. They have been used to understand the different concepts of platform solutions, to capture the expected platforms effects and follow certain people's perception of different issues. Different documents were analyzed, such as project proposals, specifications, working papers, presentations for different receivers and other communication documents.

Archival records (like data bases) have been used in the analysis of the LEGO cases performance and in the development of the LEGO platforms. Quantitative data have been retrieved from the organizations ERP and PDM system for various analyses, taking notice of the conditions of which it was produced and its accuracy and purpose [Yin, 1994].

5.6 Data presentation

The approach to the documentation and presentation of data in this thesis differ in main parts from research in other areas: Often researchers within other research areas will record interviews and videotape meetings and workshops and transcribe it in detail as basis for their analysis. The cases from LEGO however have many sources of raw data which is scattered throughout countless presentations, data extractions, discussions, interviews, posters, notes, and weekly project meetings through many years. Much of the case data that is presented in this thesis is therefore extracted from numerous sources, where each of these sources has only contributed very little to the whole. The strength of this approach is however that multiple sources have been involved, giving a more comprehensive description of the phenomena. It is however considered too extensive to present in any meaningful way in this thesis. Hence the presentation of the data for the cases haves been summarized as key findings in case descriptions presented in the thesis. These cases descriptions are results of iterative writing up of different data on the individual cases, analysis and presentation of the conclusions to the LEGO stakeholders such as platform developers, users, owners and managers as the study proceeded. The final versions of the case description are presented in this thesis.

The above does however mainly concern the LEGO platforms. The concrete statements from the more formal interviews from the industrial validity study are listed in appendixes in order to make them traceable to know which company they are from. This leaves the possibility of seeing if general characteristics outside the scope of this research may have been more influential on conclusions from the individual companies.

5.7 Analyzing the case study data

The approach to analyzing the data has not been a strictly followed procedure, but has been based on the theory of critical rationalism of Karl Popper in mind [Andersen, 1992]. It encourages a style of thinking that addresses real problems in a practical way, leading to real solutions and concerns all what can be observed (empirical phenomena).

In the critical rationalism there are no objective perceptions of phenomena; objectivity is only achieved when experts agree. Critical rationalism hence also claims that observations are loaded with value, depending on the theory they are observed to validate or falsify. The core point in critical rationalism is to be critical toward your own and others experiences. The theory also concern aspects about hypothesis and their falsification, which however are not transferable to this research.

Based on this approach the analysis has been an iterative process, constantly comparing evidence with research questions and models and discussing them with research fellows. The presented findings in this thesis are the result of this process. Analyzing the individual cases and comparing them with each other has been central in this study. Within-case analyses (as recommended by Eisenhardt [1989]) have been used on all the cases to achieve an understanding of the unique patterns in the individual cases and be familiar with the cases, before proceeding to generalization.

The understanding of conjunctures as suggested by Ragin [1992] has inspired the analysis: This means that the factors are typically not really independent, but instead that causes are effective when the factors operate in concert. This has inspired a more comprehensive picture of all the influences that matters in order to make platform-based product development succeed.

In general conflicting evidence have been analyzed until a satisfying explanation has been found, and care has also been taken to avoid the risks of qualitative analysis [Hockerts, 2006]:

- Risk to jump to conclusions based on limited data
- Overly attention to vivid stories
- Deference to elite respondents
- Inability to see statistical probabilities
- Inadvertent ignoring of unwelcome data

Also the fact that interviewees, authors of documents or other personnel sources may have various conscious or unconscious motives not to tell the truth has meant that the responses have been followed up on by other sources [Breakwell, 1995]. This may be the case when the a platform responsible or owner is interviewed, giving a more positive image than real life, exaggerating the positive result. That is why the analysis of the data always must be done with the source and possible motives in mind. As mentioned critical rationalism and triangulation have been the key approaches to minimize the above.

5.8 Research validity

To ensure that the conducted research has satisfying quality, it has to be valid. Alternative validation approaches from case study research and engineering design research, which are the dominant approaches in this research, are described below. The different types of validity has both been used as guidelines in the research design and conduction and will also serve as starting point and benchmark in the later discussion of the validity of the research results. Generally validity is understood as how relevant and reliable the results are and how well they respond to the defined problems, where verification is understood as how well a method fulfills a number of requirements, but there are different perceptions of these concepts. Since this research is more about answering the research questions and only gives a few recommendations and no method as such, it is mainly validity, we focus on.

5.8.1 Case study validity aspects

This research is solidly based on case studies and hence it is relevant to consider validity aspects in the case study tradition. Four different types of validity defined by Yin[1994] has been used to establish the quality of empirical research:

- *Construct validity*
  Establish correct operational measures for the concepts being studied.
- *Internal validity*
  Establish a causal relation relationship, whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships.
- *External validity*
  Establish the domain to which a study's findings can be generalized.
- *Reliability*
  Demonstrate that the operations of a study, such as the data collection procedures, can be repeated with the same results.

These guidelines are considered in the research design, in the executions of the operations of the studies and in the reasoning throughout the thesis in order to gain validity in the research. The first bullet describes the importance of scrutinizing the constructs and measures for the objects of the study. In this research the constructs and measures are based on substantial knowledge from academic literature and practical experience, using existing concept definitions. Internal validity has been sought achieved by challenging the reasoning in the thesis in discussions with research fellows and industry practitioners and in conference presentations.

The limit of the external validity in terms of generalization has been investigated by having a comprehensive study of companies with different characteristics. Finally reliability regarding the repeatability of the results of this thesis has been in focus when conducting the research and afterwards describing the relevant elements, like tools and data collection methods that have been applied, and circumstances of importance. In the end it is however up the readers to judge whether the thesis demonstrate rigor in the operations to ensure reliability.

5.8.2 Engineering design research validity

An approach to determining validity within the engineering design research field is given by Olesen [1992]. He states five characteristics that a research result may have in order to be valid;

- *Internal logic*
  A research result is internally logic when consistency between the research motivation, the hypothesis and the research results exists. In addition, the research has to comply with known theory that is accepted.
- *Truth*
  A research result can be claimed to be true when the theoretical and practical implications of the result can be used to explain phenomena that are founded in reality and not just theory.
- *Acceptance*
  A research result has to be accepted by a research community and industrial practitioners in order to be valid.
- *Applicability*
  The research result has to be applicable in practice in a real industrial setting.
- *Novelty value*
  The research result has to have newness, i.e. have to provide new approaches or new realisation.

The first three bullets are similar to the requirements made by Yin [1994] whereas the latter two contains new requirements of applicability and novelty value.

5.8.3 Validation approach

To make the research findings valid, three different actions have been taken:

- Triangulation of sources and data collection methods, including conduction of validation study
- Presentation of findings to key actors and stakeholders in LEGO
- Presentation of research to academic community

Triangulation is done by collecting general different types of data, representing the same aspect from different sources and study if they are converging. E.g. reasons for deviations from expected performance of a given platform was both identified via interviews with the platform owner/ developer and the platform users combined with observations of the actual activity of use of the platform. On a higher level triangulation is done in the industrial validation study by comparing the findings from the LEGO cases are compared to findings from the series of interviews with company representatives.

The research results have been presented to key actors and stakeholders in LEGO continuously throughout the study and hence it has been ongoing process to validate the findings according to their input. Input on correction of factual issues was integrated in the research results, whereas input about interpretation of the data was used as inspiration.

The research results have also been presented to and discussed with research fellows and peers, both at conferences and in journal papers with review feedback. This feedback serves as an evaluation of the research results from academia, and will indicate if the validity of the research is strong.

5.9 Concluding on research approach

The overall research approach is based on the research engineering design framework and the case study research. To answer the research questions, the research design contains the study of a number of platform cases in LEGO. An industrial validation study is performed to validate the answers to the research questions. The criteria for platform cases and the companies in the industrial validation study is described. A variety of data collection methods, including e.g. participant observation, document analysis and interviews, have been applied. Finally the approach to research validity is described, being based on case study and engineering design validity aspects. To ensure the validity of the research, following strategies have been applied: Triangulation of sources and data collection methods, including conduction of a validation study, presentation of findings to key actors and stakeholders in LEGO and presentation of research to academic community.

Part 6
LEGO ® Group and the platform cases

This chapter describes the eight platform cases that have been studied at LEGO Company from 2004-2009 and the context in which they were developed. LEGO is a unique case in the sense that so many different platforms has been developed and implemented within a relatively short period. It makes them more comparable than platform cases generally are, because they are situated in similar context, and makes it possible to conclude with a more constant factor of company context.

6.1 Introduction to the platform cases

I start out with a brief company description and how LEGOs approach to platforms has been. Important context factors or prerequisites that are present in LEGO are then presented. Then the individual cases are presented. Each case is described within a standard frame. The detail of description of each case depends on the depth, it has been studied, and how important it is as example.

6.2 LEGO Company

LEGO Group is a global company that develops and manufactures toys. In 2008 LEGO Group was the 6th largest toy manufacturer (in terms of sales) worldwide. The toys mainly consist of a variety of coloured plastic blocks which all can be connected and combined into various models, depending on the specific theme of the product.

- Main Markets: Europe and USA
- Employees: Approx. 7000
- Development: Billund, Denmark
- Production: Denmark, Eastern Europe, Mexico

	2009	2008	2007	2006
Income Statement (DKK million):				
Revenue	11,661	9,526	8,027	7,796
Expenses	(8,669)	(7,522)	(7,522)	(6,393)
Profit before specials items	3,002	2,004	1,471	1,405
Profit before income tax	2,887	1,852	1,414	1,281
Net profit for the year	2,304	1,362	1,028	1,200
Balance Sheet (DKK million):				
Total assets	7,788	6,496	6,009	6,907
Equity	3,291	2,066	1,679	1,191
Financial ratios (in %):				
Gross margin	70.3	66.8	65.0	64.9
Operating margin (ROS)	24.9	22.0	18.1	17.0
Return on equity (ROE)	82.3	72.2	71.6	147.1
Equity ratio	42.3	31.8	27.9	17.2

Table 6.1: Key data and figures for the LEGO Group in 2008 [LEGO Group, 2008]

Globalisation has lead to fierce competition on the toy market and combined with a decline in the market demand, this left LEGO Group in a financial crisis in 2004 that made them reconsider their entire business. The crisis resulted in a seven year strategy, Shared Vision that aimed to rebuild the company and revitalise the LEGO brand. Platform thinking was seen as one of the approaches to improve business, necessitated by too high costs and lack of business focus (also described by Mortensen and Nielsen [2010]

Many of the initiatives in Shared Vision were successful, and the company started to make money on their business again. In the following it is described how the platforms leveraged some of the solutions for this turnaround.

6.3 LEGOs platform approach

The starting point for many of the platforms was to reduce the complexity and they were developed coherent with standardization initiatives or as part of these. LEGO develops and launch more than 100 products (sets) pr. year, and the products have a lifetime of 2-4 years, meaning that more than 300 different item numbers are handled in the organisation [Fiil,2010]. I 2004 more than 12.000 different elements existed and new elements were continuously introduced, resulting in high handling cost. Figure 6.1 shows the complexity perspective on the different levels from the individual shape to the complete packed product and also illustrates how the standardization and platform initiatives were being applied on many levels.

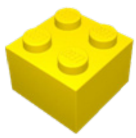
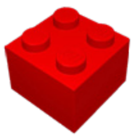
	Parameter	Complexity Perspective
	**Shape level** How many shapes are available? Total platform potential – active/inactive	Shapes are being standardized, Cleaned up (=K registered), new universal platforms are being developed. Existing and new shapes are Challenged from a Design for Manufacturing Perspective. **Today no frames pr. Novelty Project.**
	**Color level** How many colors are available? Internal (55) External (xx) frame	Colors have been standardized, Cleaned up (from 106 internal to 55). Color palette are being Challenged for 2008 portfolio – e.g. further Standardization, and shut down of external color palette. **Today no frames pr. Novelty Project.**
	**Components level** How many components are available? (shape combined with color & material)	From 12.000+ to below 8.000 end of 2005 From below 8.000 to below 7.000 end of 2006 (inclusive components who are moved to Flex). Unwanted components are A – registered. **Novelty Projects have frames.**
	**Packing level** How many components are used pr. model?	The tendency are that more components are being used pr. model. This can challenge the packing set up (pre-pack) – creating bottleneck capacity wise. **Today no frames pr. Novelty Project.**
	**Product level** How many products are available?	Portfolio has been standardized, Cleaned up. Standards put up for market exit date and last production date. **Novelty Projects have frames.**

Figure 6.1: The figure illustrates how the complexity problem was attacked from different levels from product to individual element shape

The company approach to platform-based product development was like a cascading initiative, slowly developing in the manufacturing department (apart from the earliest element and box platforms), gradually growing with the creation of successful pilot projects, finally consolidating different departments in specific processes oriented towards screening potential platform candidates, maintaining and possibly out phasing the existing ones.

There was a long introduction period, where people tried to get hold of the concept and terminology of platform-based product development. Many projects had several rolls, before the platform was defined, got approved and implemented. Often the first projects clarified the platform concept, then the scope and details, and the latter the quantified the benefits. And quite a few platform projects stopped in the early phases. Some platform ideas have ripened and new have appeared during the improved understanding of the benefits and solutions in platform-based product development. Many of the platforms did not have clear objectives in the beginning of the platform development process, but more an expectation of which kinds of benefits that could be achieved. When the platform has been developed there were often some objectives or expected effects, that the platform should deliver, based on the analysis in the platform development phase.

6.3.1 Characteristics of LEGO's platform approach

A number of different characteristic aspects are relevant to know when describing the platforms in LEGO. They describe the prerequisites and context of which the platforms are developed and used, and cover from the general focus of the platforms to the organizational organs, supporting the process, listed below:

- Focus on cost, rationalization and little risk
- Willingness to and necessity of change
- Forums looking across products
- Component management strategy and pricing strategy
- Large amounts of historic data
- Incremental product development

Focus on cost, rationalization and little risk

The overall financial crisis in LEGO was starting point for many of the platforms, and due to the fact that the cost of the products was too high, the focus of the platforms was to reduce the cost, rationalization and internal benefits, which is reflected in the platform solutions. The platforms were also generally relatively low risk solutions, because due to the crisis, there was no room for major investments, risking a lot of capital. On the contrary there was more or less a requirement of a viable payback time on less than two years, which was an important criterion in the evaluation of the platforms. Maybe this rather concrete cost focus has meant that the platforms have been optimized towards many life cycle systems to make e.g. the claimed cost reductions viable and realisable. In this process substantial benefits have been identified, when the platform is aligned with the different life phase systems.

The low risk focus manifest in two dimensions:

1. *Little market risk*
   The platforms mainly affect product characteristics that are not critical to the customer, i.e. the reuse does not affect value-creating variance in the products and are more or less invisible to the customer
2. *Little technology risk*
   In most cases known technical solutions (both in terms of products and production methods) have been applied and hence there was little technology risk

Willingness to change and making committing decisions

The fact that LEGO was facing serious financial trouble and risking bankruptcy, creates a general understanding in the organisation of the urgency and hence willingness to change and think differently. This is described in change management theory [Kotter, 1995], and I consider it an important factor in the introduction of the many platform solutions, because it made people more willing to make a committing decision, which often is necessary in platform-based development.

Forums looking across products

LEGO has a classical product development organisation, consisting of a number of different departments: A Product development and marketing department, in which product development teams with product design/ model builders, element designer and marketing workers. They come up with idea of the product and which elements should be used and set up the business case.

Other departments work in parallel and with the teams, eg manufacturing support, (which design new equipment), sourcing and supply chain department, investigating alternative production strategies and also the production preparation and planning departments, ensuring an optimal production of the products. All these activities are defined in LEGOs development plan, LDP, which is a stage gate model– modified to suit the LEGO context.

Alongside these activities, LEGO has three forums, considering products or production solutions from a system viewpoint, focusing on the entire portfolio, standards and the long lines instead of optimization of a single product. The existence of these forums show that there has been focus on ideas similar to platform based product development for a period, before many of the platforms were implemented.

The forums are:

- Element forum and Design Lab
- Packaging forum
- Manufacturing support forum

Element forum and Design Lab assist the product developers in the design of new elements and classifying new elements, as every element belongs to a group with elements with similar characteristics. With the introduction of element platform this classification influences the internal price. Packaging forum and Manufacturing support forum search for and develop new solutions and survey the existing respectively packaging and manufacturing solution and coordinate them according to the overall needs.

Component management strategy, pricing strategy and large amounts of historic data

LEGO had worked with the principles of having categories for the elements in a long period before these studies. This categorization has made the employees in the organisation understand that different elements have different purposes, e.g. Some elements enable building and can be used in many products, while others have the purpose to create a distinctive feature for a specific product.

The categorisation also goes for the economical characteristics of the elements: LEGO price all the elements internally reflecting the actual cost. This pricing strategy meant that the LEGO workers already had some notion of different reasons for different pricing, making them able to understand the principles of and arguments for platforms. Finally the pricing strategy means that the entire ERP and PDM system are based on these principles, where the value of each activity and component are specifically assigned. This enables quantification of different tasks and makes it possible to make detailed estimates.

Besides from being a development company, LEGO is also a production company. To optimise the production processes, multiple data is collected in the before mentioned PDM system. If sensibly applied, this data can provide basis for estimates and arguments in platform discussions, especially when analysing and getting facts about the existing solution.

The data together with the pricing strategy comprise a solid foundation for a more facts-based discussion about platform effects in LEGO. Such estimates have played a significant role in the platform projects, when it came to estimating the effects of a platform solution.

Incremental product development

The LEGO products are not undertaking revolutionizing development steps, they change slowly from the viewpoint of underlying principles, and are to different degrees more subject to more trends regarding product theme. This means that there are a number of parameters that only changes little across products and over years and hence have been rather stable over a the last years. It is however still a major task to handle the complexity of having so many different products, constituted by various different elements, changing frequently due to trends and the toy industry’s focus on newness.

6.4 The LEGO Platforms

LEGO has actually been working with platform-based product development since 1958, where the modular system of the LEGO brick was patented. From 2004 to 2009 where I studied platforms at LEGO, 8 different platforms were active (a ninth project solution was also named a platform, but it did not live up to the characteristic of reuse across products and was not considered in the following). Two of them originated decades back, but the other six were developed and used from 2003 to 2006. Many of them were updated or continuously developed during the time of the study. The platforms in LEGO were developed in different functions in the organisations and have been developed by different people, however with some overlap, because some projects members have participated in several of the platform development projects.

The LEGO platforms fall in two groups depending on what assets they reuse: Either they aim at reusing the elements in the products or they aim at creating production equipment that can be reused across many differentiated products. This was the case in some of the LEGO platforms, and it does implies a different approach to the requirements of the product platform because they origin from another department in the company and not a market. Similar concepts are however some places in literature referred to as process platforms as described in Halman et al [2003].

In the table below the eight platforms are shortly described with relevant characteristics to provide an understanding framework for the different platforms. The name and implementation date are listed for each platform. The actual elements that are to be reused and the rules that must be followed are described (the rules describes the how and when the platform should be used and can in some cases be the operative goals. The expected effects are described in terms of e.g. reduction of components, reduced investments, costs, lead time or more efficient exploitation of production equipment. The goals and expected effects are what the platforms performance will be held against. For some of the platforms there have not been any specific goals, only expectations. It must be noted that the expenses of the platform development process is not included in the platform performance evaluation.

To give an impression of the "size" or "influence" of the platform in the organisation, an estimate of the impact is made. It is a relative measure to describe the scale of the effects of the platforms. Due to confidentiality the actual figures on the effects cannot be revealed, hence this relative impact measure. Each platform have a measure from 1-5, where 1 is the smallest impact and 5 is the largest, described in Figure 6.2 below. The measure has been set in cooperation with platform owners and developers, and it is a subjective estimation based on platform and its effects.

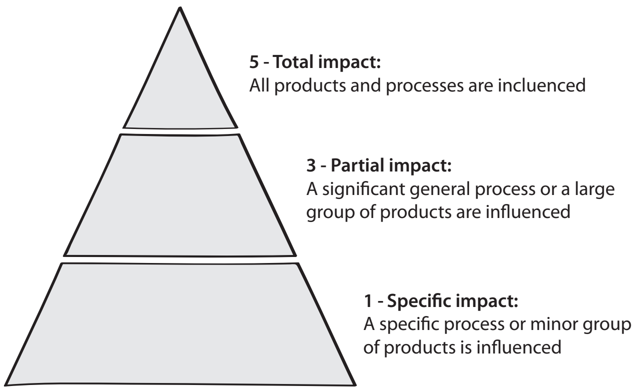


Figure 6.2: Relative platform impact levels from one to five. The impact of the platform usually corresponds to the efforts put in developing the solution.

Finally the data collection methods are listed to make an impression of how detailed the study of the particular platform has been (the abbreviation PO stands for Participatory Observation). The platforms have also been described by Munk & Mortensen [2010].

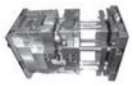
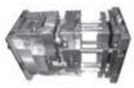
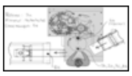
Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Relative impact level (1-5)	Data collection
Element platforms (system, technic, duplo, mind-storms, functions) (1958) 	Building elements and the standardised connections system. The elements are categorised as either universal, generic or special, which is used in the cost calculation.	Limit no. Of 7500 elements, providing the possibility of building endless variation and reuse multiple elements across products.	5	Interviews and document analysis
LBS (before 1990) 	Packing box system using standardised dimensions, optimised for shelves in shops, and transport logistics. Approx. 80 % of all LEGO products are in these boxes.	Reuse of production equipment, high transportation efficiency, short development time and few investments.	5	Interviews and document analysis.
Low Volume Mould platform (2001) 	Standard mould boxes with insert cores and mould gate solutions (for low volume elements). No specific goals	Reduced mould investments, shorter development and lead time, lower risk.	3	Interviews and document analysis.
Can platform (2004) 	Packing can platform with reusable elements and supported by fitted flexible production frame. No specific goals.	Improve sales with design freedom and reduce cost of rebuilding production equipment.	2	Interviews and document analysis.
Wheels (spring 2005) 	A collection of generic wheels based on a preset no. Of rims Caps used for variance. 90 % of the wheels volume in LEGO must be platform wheels.	50% reduction of wheel types and reduced investments in moulds that optimise reuse of production equipment.	3	Interviews, observations, PO,and document analysis.
Module mould platform (2005) 	Standard mould boxes with insert cores and mould gate solutions (for medium-high volume elements) used for 80% of all new moulds.	25% reduction in mould investments, 30 % shorter development and lead time, lower risk.	4	Interviews and document analysis. Economical analysis of historic data.
Pre-pack Platform (spring 2005) 	Pre-packed bags with common elements. 60% reused product content within product family.	50 % reduction of bag types within product line Reduced production costs and time saved for product development and production.	3	Interviews, observation, PO and document analysis.
Decoration Five star (2006) 	Decoration printing equipment with flexible function modules and interface to moulding equipment. Print has max size. No specific goals.	Reduced equipment investment and equipment flexibility for varying product volume.	2	Interviews, document analysis and PO.

Table 6.2: Overview of the eight platforms studied in LEGO group in this thesis

6.4.1 The different studies in LEGO

The case descriptions of the product platforms and the research are based on a number different studies made during the cooperation with LEGO during this Ph.D. a substantial number of studies different studies have been made. They all contribute to the finding described in this thesis and are shortly described below:

- Participant observation (PO) studies during in design or analysis/ update during development or update of platform
- Document analysis and interview with platform designers or owners describing the platform solution and the development process
- Interviews focusing on performance, challenges and reasons for deviations with platform responsible after minimum one year after implementation for all nine platforms.
- Data from the ERP and PDM system from 2006-2008, reflecting the key figures relevant for the goals
- Observations and interviews with platform users (product designer, production equipment developers and supply chain engineers)
- Historical Total Cost Analysis of performance of the Module Mould platform
- Interview and feedback on prescriptions for Information support system for the Wheels platform

The data has been collected in case study reports, which have been concentrated into the following case descriptions. The collection of data is of course time dependent and must be considered a snapshot in time, meaning that improvements can have been made or new challenges have appeared when the primary ones have been solved and hence the process that followed the final data collection is shortly described within each platform case, if relevant.

6.4.2 Case description framework

To ease the reading and make the platforms comparable and address the relevant aspects in relation to the research questions, the case descriptions follow the same structure, described below:

- Platform background – why was the platform needed?
- Platform description – elements and characteristics and level of impact
- Platform effects –what was it expected to change / optimise
- Platform goals, performance, challenges and reasons for deviations
- Platform development process
    - General description
    - Effects identification and estimation
    - Goals specification
    - Adjustments and follow up
- Other relevant aspects

Each platform case story is ended with a summarizing table with the facts about the platform, similar to the overview table. An example is shown in the Table 6.3 below.

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Element platforms (system, technic, duplo, mindstorms, functions) (1958) 	Building elements and the standardised connections system. The elements are categorised as either universal, generic or special, which is used in the cost calculation.	Limit no. of 7,500 elements, providing the possibility of building endless variation and reuse multiple elements across products.	★★★	Selecting reusable elements and finding the number of elements on sufficient level, balancing the building options and the complexity of many elements. Maintenance and platform erosion. Making the users understand the platform rules.

Table 6.3: Example of summary table

First box contains the name and implementation year, the second what reuse assets elements the platform consists of and if there are any operational rules or goals, hereby named the rules. The third box describes the expected effects, the fourth describes the platform performance (to which degree the goal or expected effects was achieved). The level of achievement is described within three categories:

Symbol	Category
★★★	The platform performs satisfying and meets its expected effects and goals.
★★	The platform performs somehow satisfying and does not meet all expected effects or goals.
★	The platform does not perform satisfying.

Table 6.4: Platform performance categories.

The final box described reasons for deviations and challenges as reported by platform developers, owners and users. The challenges describes historic reasons for deviation, before the period 06-08, which do not influence the measured performance, but still is relevant to know, in order to identify reasons for effects deviations. The historic deviations are written in italic.

6.5 The Element Platforms (LEGO building block system)

6.5.1 Platform background

In 2004 there were more than 12000 different elements, a number that had been growing since the early 80'ies. The number of bricks became so high because new items were continuously introduced on an individual and unsystematically basis and it caused many extra expenses to control all these variants. An internal complexity cost project in LEGO estimated that just introducing an element in the ERP system cost approx. 22000 DKK. Furthermore many of the moulds were designed to produce a much higher number of elements than necessary, just in case they could be used in another project. But many of the moulds were left unused and bound a significant amount of resources and were expensive in maintenance too.

Hence there was initiated a complexity reduction project, aiming to reduce the number elements from 12000 to approx. 7000 in two year, see the Figure 6.3 below. To avoid a similar situation in the future a new pricing politics for development of new element shapes, taking into account the savings achived by reusing the elements.

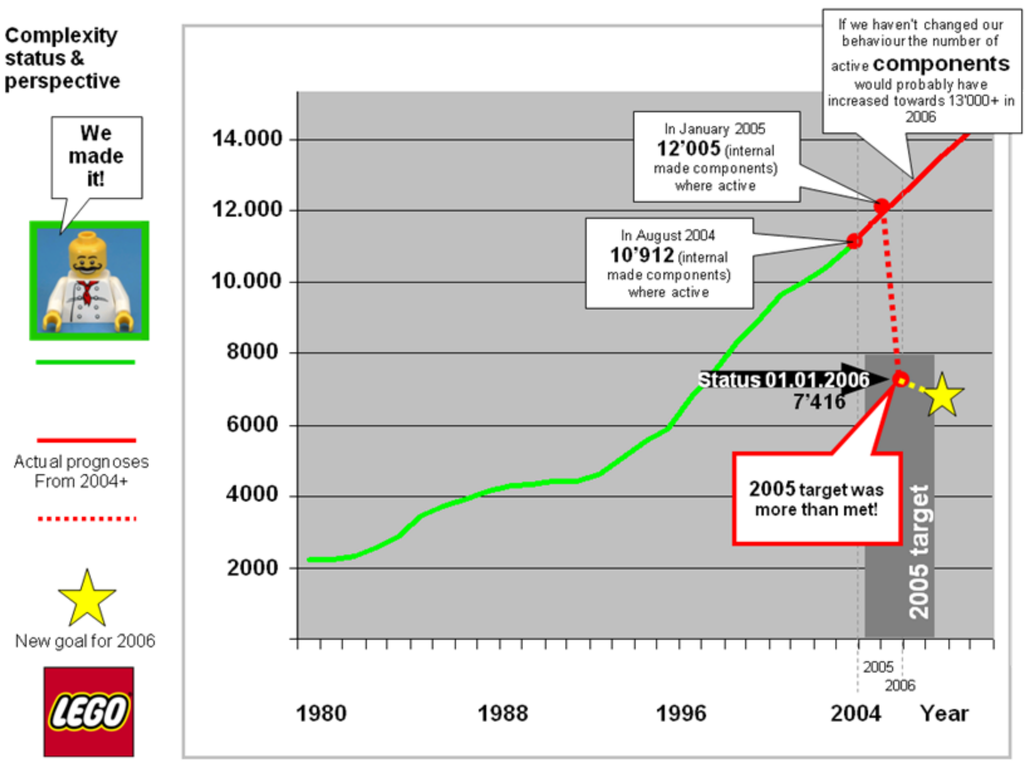


Figure 6.3: The number of components in LEGO was reduced from more than 12000 to less the 7500 (Slide from internal LEGO material).

6.5.2 Platform description

LEGO products consist of a number of building blocks, based on one of the different building systems, (SYSTEM, Technic, Duplo, Mindstorms, functions). The different elements are reused across products at the same time and over time.

Figure 6.4: Examples of the element platforms showing typical components and the description of the platform rules: System , Duplo and Technic

These building systems are platforms with a number of modules and rules for interfaces.

There are approximately 7500 different elements, all LEGOs elements are on display on big boards on the walls, placed in the belonging group and with codes showing relevant information, as well as they are represented in the PDM and ERP systems with the same information codes. All the platforms have definitions regarding allowed dimensions and possible interface connections. The element platform covers the very core of the LEGO products, meaning that it effects the entire organisation and in a fundamental way, because the entire business revolves around the elements.

There are three main aspects that characterise the element platform, namely:

- The classification system, depending on how universal or special an element is to the LEGO products
- The economic consequence of the classification on the internal element price
- New element development process, where the elements are designed based on need from many different products instead of in individual projects.

Platform element classification: Universal, Generic and Special

All element shapes are classified as one of the following:

- Universal
- Generic
- Special

This classification was also known as the UGS system. It sought to stimulate design of shapes that were useful for many products, instead of elements that only suited the product it was introduced in. The idea behind this classification is that many elements (universal elements) can be reused in multiple products, if they are designed aiming at this. The generic elements can be reused only within certain groups of products, and the special elements are aiming differentiating the products from each other, so their purpose is variance, the exact opposite of the universal elements. The characteristics of each class in carefully described, so it is general and not based on the judgement of individuals. The UGS system classifies only the shape; there are also classifications for material colors (depending on how much they are used) and volume (how many elements are produced in total).

Economic consequense of the classification

Each element has assigned an internal price that is used in the product development , when aiming for a price point of the total product. The price per element is calculated based on three cost factors, as see in Figure 6.5:

- A material cost
- A moulding process cost
- A mould investment

This cost is now dependent of the UGS-classification, reflecting that there are different costs of having few moulds and high production volume vs. Many moulds and low production volumes.

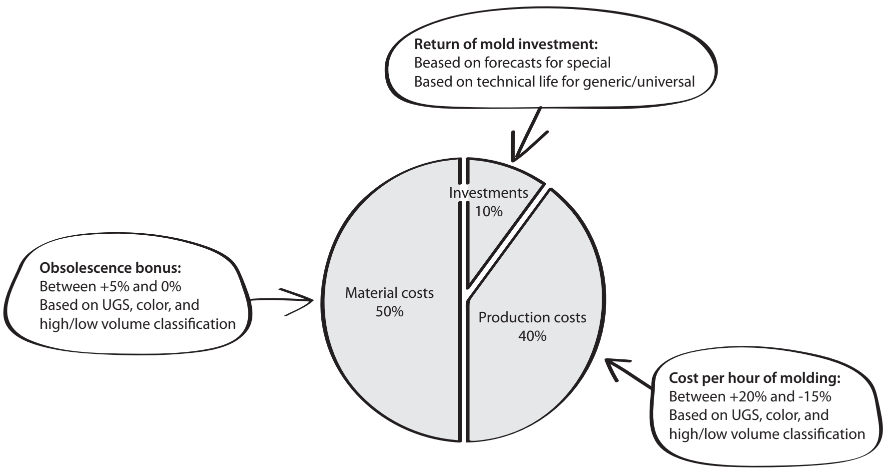
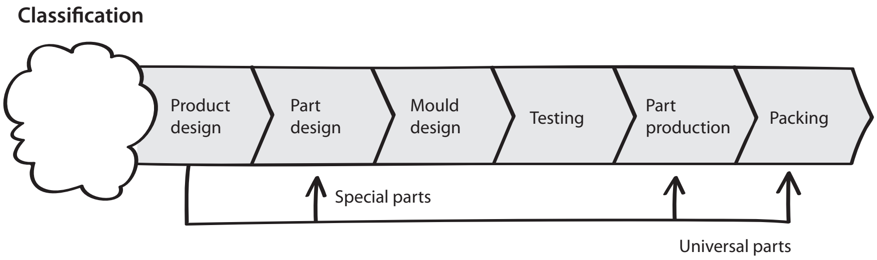


Figure 6.5: The classifications moderate the cost and makes up a total price for an element and based on historic data from the existing elements [Nielsen, 2010].

The mould investment is spread out on the total number of produced elements (the mould lifetime). The UGS classification influences this calculation by determining the lifetime. For generic and universal elements, it is expected that all shots in the moulds will be used, so the total number of produced elements depend on the technical lifetime for the mould. Universal elements are considered a long –term investments, but the use of them can vary much and hence the batch size and volumes, depending on the products they are used in. This may require flexible moulds. The total number is based on forecast for the special elements. Special elements are considered a short-term investment. They are not expected to be used in any other products, but they can still have a very high production volume and high batch sizes. Their mould solution lifetime is based on forecasts and is close to the forecast of the product they are launched with.

The moulding production cost depends on batch sizes, the bricks are produced in and the price is moderated by the UGS, the color, and the volume classification. Finally an obsolescence cost is added to the special shapes, because there is more risk of obsolete elements with the forecast estimates. The UGS classification also describes which mould solution that must be chosen and how the moulds are handled throughout their life cycle, as described in Figure 6.6.



Universal parts
These parts are considered evergreen – temporary lack of production quantities may occur
Parts and moulds are kept – regardless of production quantities
Costs are low and lead-time is rapid as parts are produced for stock.

Special parts
These parts are considered temporary and trend-driven – even though they may have large production quantities
Parts and moulds are destroyed or recycled – regardless of remaining shots (some generic elements may be kept)
Costs are high and lead-time is moderate

Figure 6.6: The process diagram shows how the special parts differ from the universal parts in terms of activities, because universal parts can skip a number of processes compared to special parts (Internal LEGO material).

The platform affects the product development in many ways, because the changed internal price of the elements have an impact on what elements are chosen.

The product development projects must carry the expenses of the new (special) elements they introduce, and they are only allowed to introduce a few. It is often very uncertain until the very last period of the development, how many new elements the budget allows. In that case the universal elements (that do not put a financial burden on the project and has no risk) are attractive alternatives.

The UGS classification and the element prices are integrated in LEGO 's 3D model building tool, which make it possible to inform the users (the product designers) about each element (price, specific design information and out-phasing) , in real time as they develop the model.

New element development process

In the product development process there is an intensive focus on hitting the price point and a great pride in making a good model, which often is opposition to each other, according to the model builders.

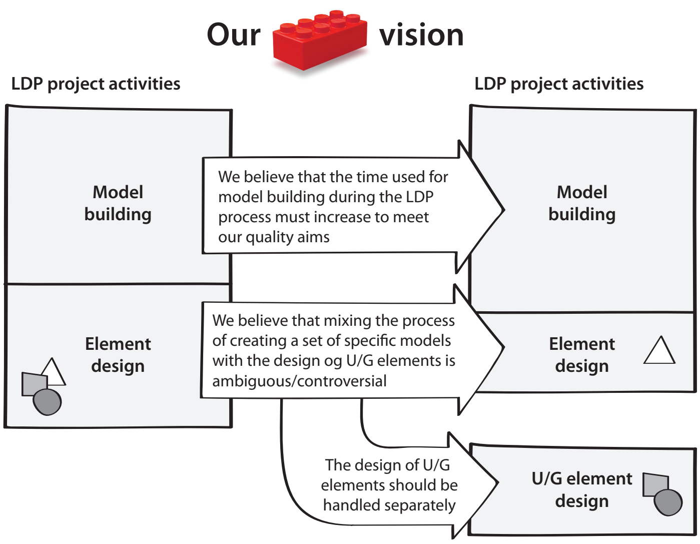


Figure 6.7: Development of the universal and generic elements are separated from the other project development activities in the LDP and to a higher degree become a platform project activities, where the need of many projects instead of single products are addressed (Internal LEGO Material) .

With the UGS system, reflecting the cost structure and lowering the prices of the universal elements, there is significant incentive in using and developing universal elements instead of generic or special elements. Furthermore a new process for development of universal and generic elements has been introduced: Previously all new elements were developed in the individual product development projects, prescribed in the LEGO Development Plan (LDP). Now the development of some of the universal and generic elements has been moved into platform projects, where the interests of multiple product development projects are handled, as described in the above Figure 6.7. A process for screening for and presenting alternative candidates has been implemented and is described in the work of Fiil-Nielsen [2010].

Platform maintenance and tracking

Design Lab is responsible for the element platforms, different groups assigned to specific employees, which also are contact persons and post information on the intranet about the platforms or convey it otherwise to the relevant stakeholders. There are yearly checks of the total number of elements, the information and use of the different platform elements.

6.5.3 Platform effects

The main expected effects from the element platforms that enable more reuse are

- Reduced development time in product development projects
- Reduced investments in moulds
- Reduce production cost due to production levelling

The platform element classification effect on the internal element pricing changes the tendency towards more use of universal elements. Using existing universal parts in the products reduces the development task in the product development projects, since they can concentrate on fewer new elements, and there is no risk of time delay due to mould design or testing,

The reduced number of elements also results in fewer moulds and fewer types of mould, reducing the investments. The changed composition of element towards more universal elements also determines the production planning, because universal elements are produced to stock and special elements are produced to order. This differentiation in production strategy has also made it possible to optimize the production set up, because the universal elements can be produced in the low season and frees production capacity in the peak season, limiting the need for extra workforce and extra wages, see Figure 6.8 below.

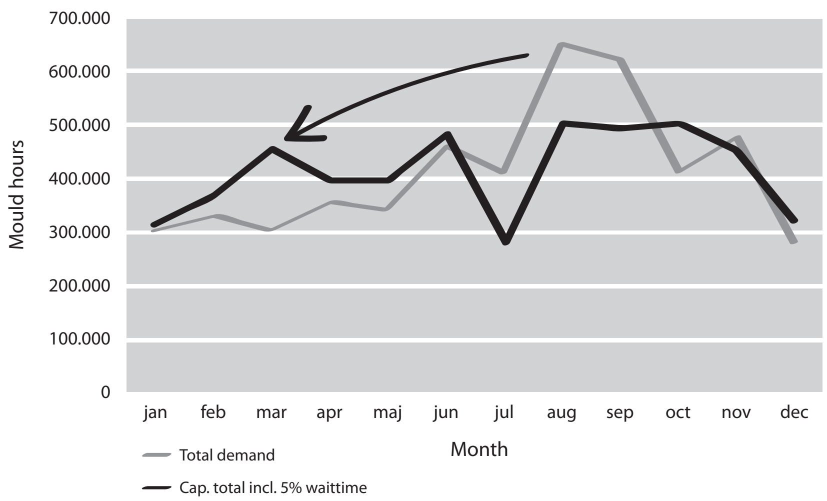


Figure 6.8: The high season production of uncertain special element can be replaced with production to stock of low risk universal elements.

6.5.4 Platform goals and performance

The element platforms have a common goal of a maximum total number of elements of 7000, and still provide the variety needed to build models that satisfy customers.

The goal of a limited number of 7000 elements was reached due to a cross-functional effort in the company, and the latest rise in sales figures (see Table 6.1 about LEGO) show that they still provide the necessary variety to design products that satisfy the customers.

The measurement of how well the goal was fulfilled and identification of challenges were made in 2008. The figures from 2006 to 2008 support the data, showing that the platform actually more than meets its goal. The platform had however been through a loop of optimization, where some issues were handled. This is addressed in the following section about the challenges and reasons for deviations.

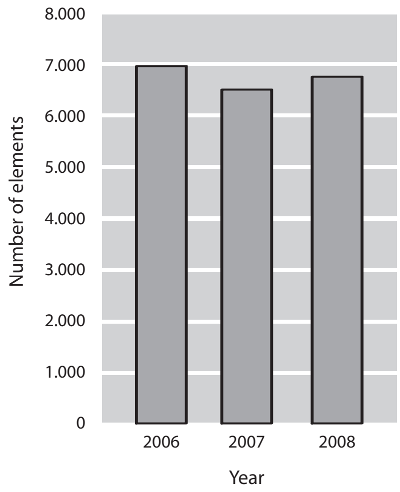


Figure 6.9: The number of elements in LEGO in 2006-2008. The figures show that there are actually less that elements than the 7000, which was the goal.

6.5.5 Challenges and reasons for deviations

A number of challenges had occurred during the development and use of platforms. They were however addressed, so that they did not influence meeting the goals. The reported challenges are

- Selecting the elements, balancing building options, complexity and cost and finding the appropriate level
- Maintenance and avoiding erosion
- Making the users understand the platform rules

Selecting the elements that should be part of the platform was a challenge to address, because the selection was questioned, and corrections in the elements were requested by designers. New wheels were added and some were removed. Keeping the number of elements at the same low level is an ongoing challenge.

Another challenging issue were that fact, that the product designers that were supposed to use the platforms were actually not able to understand the reasoning behind the platforms and the rules of which they should be applied. This necessitated a clearer description of the rules and what effects the platform had and a better integration of the platforms in the development process (called the LEGO Development Plan) and the development computer modelling tools and the supporting ERP(Enterprise Resource Planning) and PDM (Product Data Management) tools.

6.5.6 Platform development process: Cleaning up in the LEGO elements

The development process of the element platform was a rationalization and update of the existing element system, which has been around since 1958, meaning that a lot of processes of sharing element and tools for supported this existed. Design Lab was in charge of the process of reducing the number of elements, since they had the overview. The project was however cross-functional, since they involved people from both marketing, product development, manufacturing and supply chain departments.

Identifying and estimating effects and goal specification

Due to the financial situation in LEGO, a major cost assignment project had been carried out; using activity based costing (ABC) to describe the cost of individual activities related to different element. This was a major project, connecting multiple different sources of data from all departments of LEGO, resulting in detailed cost descriptions. These cost levels indicated that the reasonable expenses for the element platforms corresponding to 7 -8000 elements. This was the starting point of the rationalization of the element platforms. They had existed for a long time, so the ideas about what to share existed, but needed to be expanded to achieve a satisfying level of reuse. Hence the different groups of elements were individually considered to which elements were less valuable.

A rough sorting of the elements, leaving only those that significantly added value to the building system and a reduction of the number of colors from 106 to 55 made it possible to achieve the substantial reduction. In some cases it was obvious that elements could be taken out, e.g. there were three mini-figure chefs and three different airplane tailfins, see Figure 6.10, but in other cases it was a tough discussion with the development teams about whether an element could be taken out or not. Altogether 1180 moulds were scrapped in the clean up. Some of these moulds were still functioning perfectly well, but due the maintenance and complexity cost of having them in stock made it a better business case to scrap them.

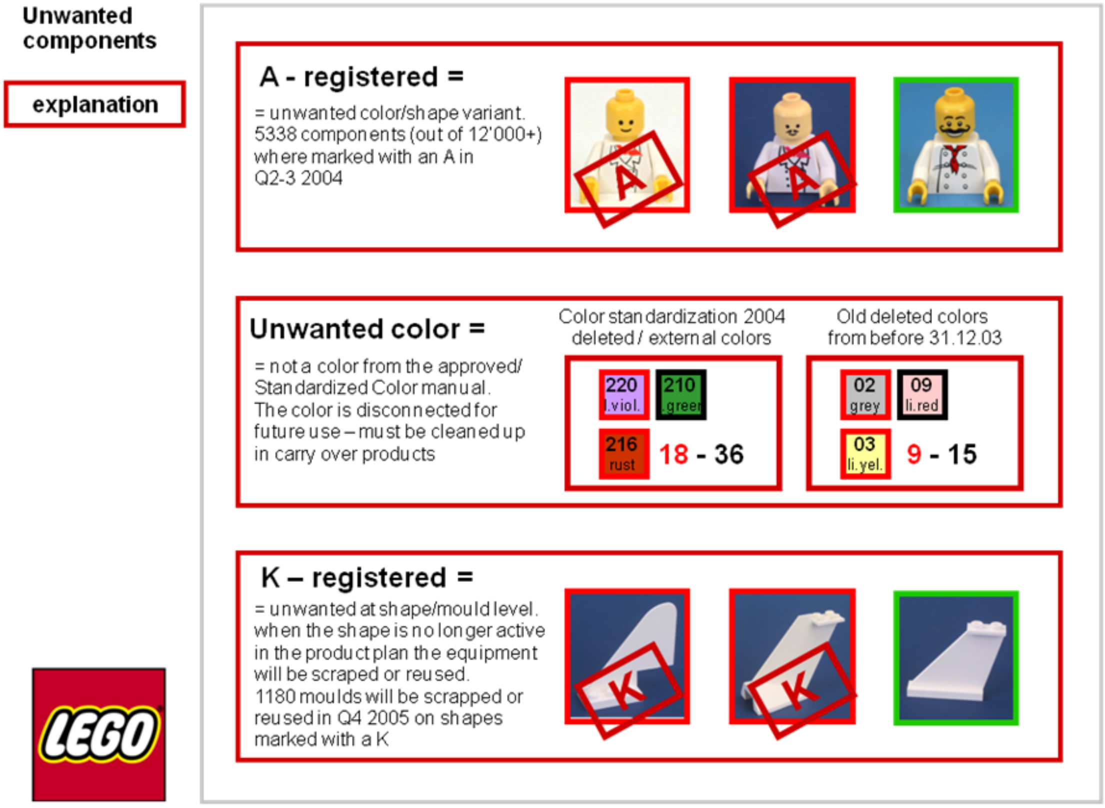


Figure 6.10: Examples of components and colours that were taken out of the assortment. They fell in different categories, explained above and were accordingly phased at different times (Internal LEGO material).

Adjustments and follow up

When the update of the product platforms was implemented, it appeared that some elements groups had been reduced to dramatically, making it difficult to make good models. This potential risk had been taken into account, by leaving room for introduction of some extra elements in the element frame. Another aspect that had to be dealt with after the platform project was the fact that it was necessary to provide a great deal of information and explanation about the platform and its rules, and also about the business case and the argumentation for the platform. This information, its form and the procedures for update was developed in several minor projects.

6.5.7 Introducing a platform screening and selection process for element families

After the reduction in elements it was necessary to take precautions to avoid a similar situation with too many elements after a few years. Hence it was chosen to try to use platform-based product development to develop some of the groups of elements. The idea was that it if a family of elements was developed all at once, the elements could be designed so that they supplemented each other and had more universal characteristics that made them cover a larger functional area, than if they were designed one by one by different product development projects. Based on the experience of earlier platform projects a standard process would ensure a more relevant and fair evaluation and also ease the steering committees understanding of the different platforms.

A platform screening and selection process was set up, and in the process senior management is presented to alternative platform opportunities, identified by Design Lab. Design Lab searches for the platform alternatives by asking experienced product developers. The process was set up with 8-10 different platform opportunities and a common presentation template, see the Figure 6.11 below. During the three years the element platform projects have been undertaken; usually two or three gets approved, and continues in the process of being fully developed and implemented.

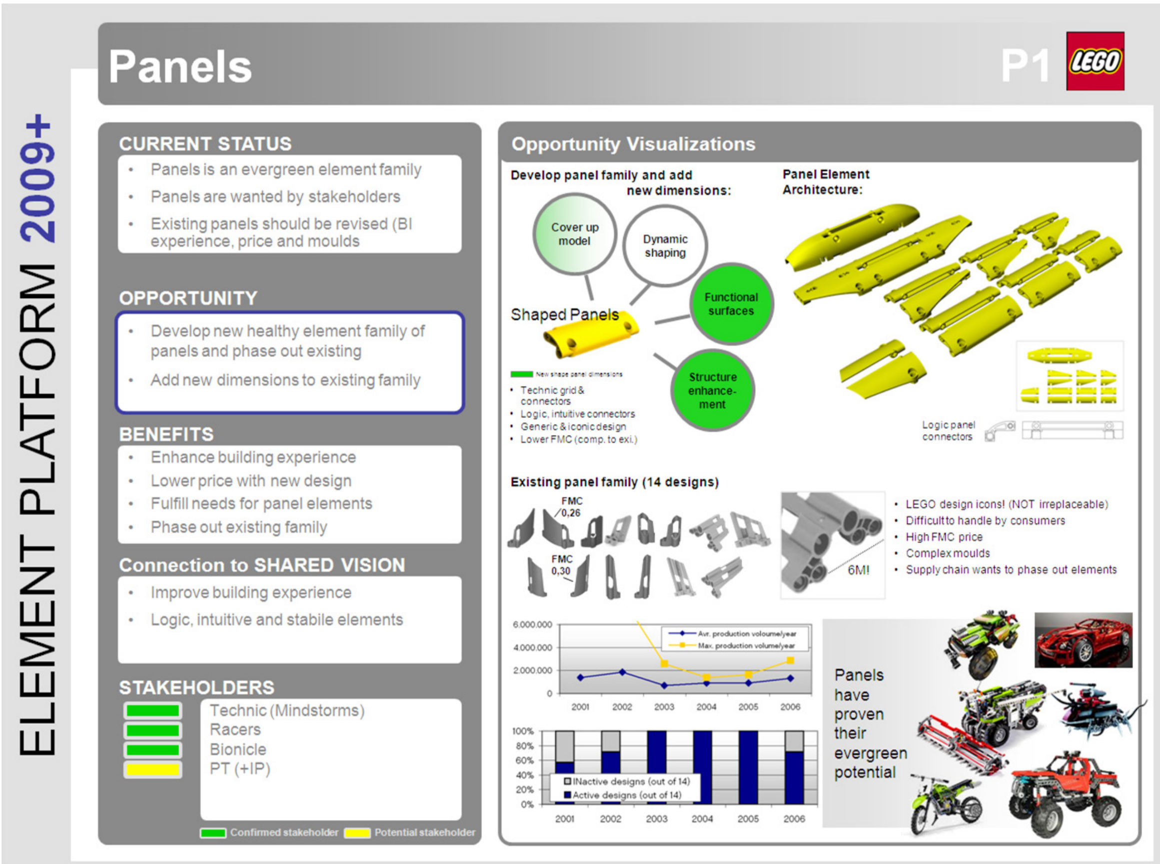


Figure 6.11: Example of slide used in the presentation of an element family, namely panels, describing the different aspects and visualizing the potential platform elements and the opportunities the offer in terms of products and economical consequences.

The platform presentations were based on the following aspects (see Figure 6.11)

- Current status
- Opportunity
- Benefits
- Strategic alignment
- Stakeholders commitment
- Opportunity visualisation

The process itself is coordinated with the product development process. To ensure commitment from the users (the model designers) in the product development teams, the platform solutions are developed in close contact with them, just slightly ahead of the product development, so that the stakeholders can feed input and verify their commitment. This ensures that the elements are designed and are ready to be used in products, when needed them. The process has been going for some years, and new platform ideas are discovered, though not in the same pace as the first year and slightly fewer year by year. It seems to be the case that ideas mature slowly, as the process is implemented, the organisational culture has changed and people see the effects and begin to think in platform solutions. Some of the platform candidates have been presented as opportunities multiple times, with an improved understanding of the opportunity, and some have been approved after several presentations.

Summarizing the element platform

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Element platforms (system, technic, duplo, mindstorms, functions) (1958) 	Building elements and the standardised connections system. The elements are categorised as either universal, generic or special, which is used in the cost calculation.	Limit no. of 7,500 elements, providing the possibility of building endless variation and reuse multiple elements across products.	★★★	Selecting reusable elements and finding the number of elements on sufficient level, balancing the building options and the complexity of many elements. Maintenance and platform erosion. Making the users understand the platform rules.

6.6 LEGO Box System

6.6.1 Platform background

The LEGO Box system goes back to the 1980'ies and hence nobody knows how and when it was developed. It has however been successful, so it continued and has been revised a few times, mainly because extra box sizes were introduced, and having too many box sizes eroded the benefits of the overall system. This means that there has been updates of the platform, either by introducing alternative sizes and take out the less optimal sizes.

6.6.2 Platform description

Figure 6.12: A few of the LEGO boxes

The Box platform covers all the different sizes of the LEGO cardboard boxes.

More than 90% of LEGOs products are sold in these boxes and it is the standard for all new products. The system is based is based on cardboard boxes with shared dimensions. These dimensions are aligned with parameters from other life phase systems:

- The dimensions enable use of the same production and packaging equipment

- The dimensions are aligned with container dimensions, which enable full utilization of the container, packing more boxes pr. Container.
- In the toy stores the aligned box sizes also make it possible to fit in a maximum number of boxes on the shelves.

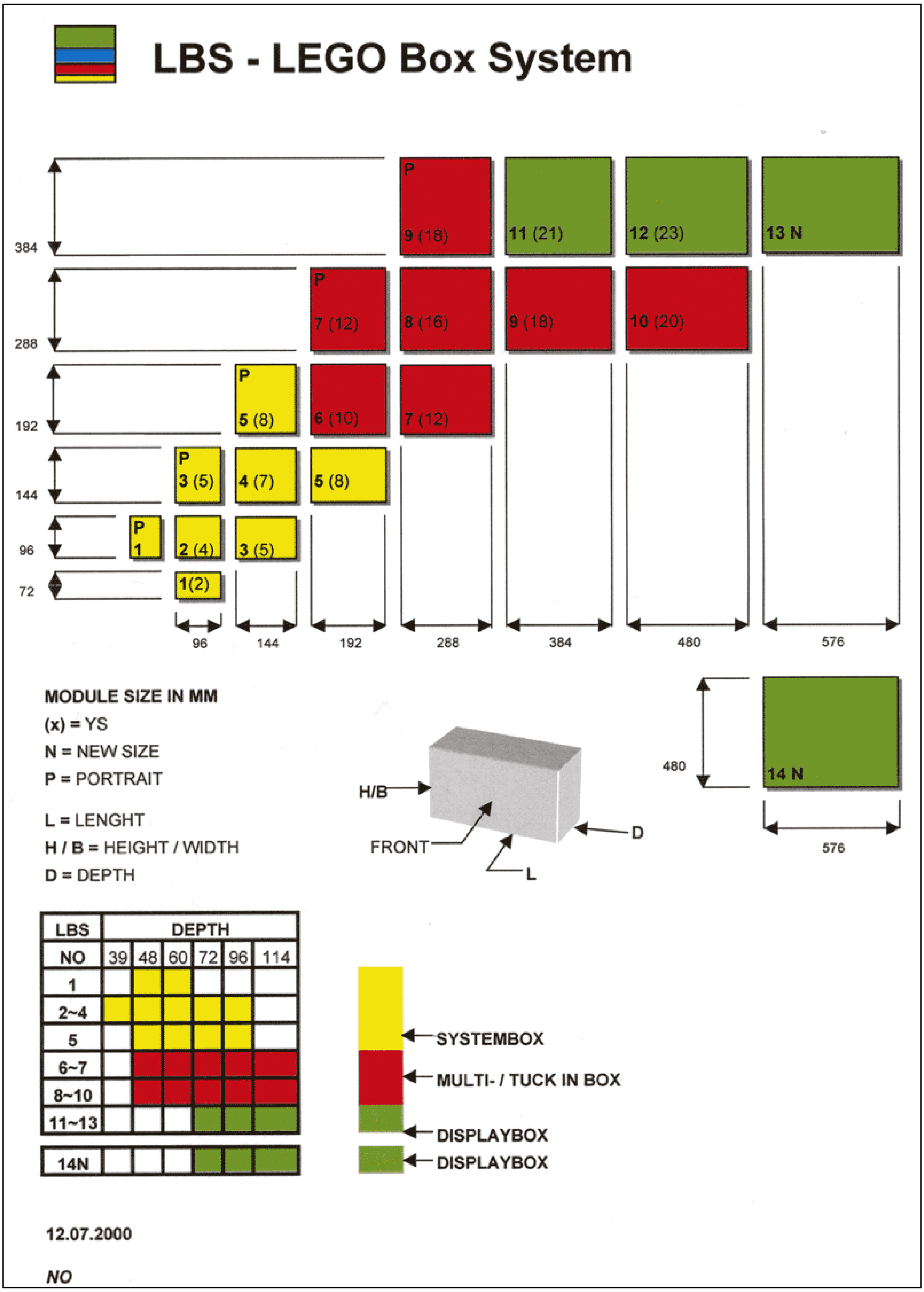


Figure 6.13: The visualization of the LEGO Box System and the 14 different boxes where the dimensions are the predefined and reused in multiple boxes.

Figure 6.13 shows the system design guidelines and how the dimensions of height, length and depth are reused. The guidelines also contain descriptions about the number and size of elements that can be fit into and certain box and which price point the box should be sold at, and in this way the platform influences the product development too. The box system is fully integrated in the LEGO development process and the graphic design of the boxes images is automatically designed in the dimensions the guidelines prescribe. The ERP and PDM systems support the individual solutions, but do not describe the platform attributes. The platform description (see Figure 6.13) is on the intranet, linked to the LDP plan. The platform owners in the packing forum check if the platform goal is met on a yearly basis, but are also indirectly aware of it throughout the year, because all products that is not packed in an LBS box, have to be approved individually.

The platform influences most of the products in LEGO, but is not at core part of the product, and has significant benefits; hence it has medium impact on the business.

6.6.3 Platform effects

Due to the age of the platform, there is no frame of reference to compare it to, but the effects of platform are also mentioned previously as being:

- Low investments in production equipment due to reuse in both
  - Production of boxes
  - Decoration of boxes
  - Packaging of element s in the boxes
- Low production cost due to optimised utilization of production equipment enabled by early planning of production
- Low logistics cost due to optimized utilization of container space.
- Shorter packing development time and guidelines for the product development

6.6.4 Platform goals and performance

The goal of this platform is to be used in approx. 80 % of LEGO products, and leveraged packing solutions that covers the size range with a suitable number of box sizes. These goals are met or close being met (based on data from 2006-2008, see Figure 6.14)) and the platform is successful, but also close to what some may call standardisation. This can be considered a rather mature platform, which has been updated a couple of times. The platform is an old and very integrated part of the LEGO products, which remains because it covers the need for packaging very well, leveraging the necessary variety at a low cost.

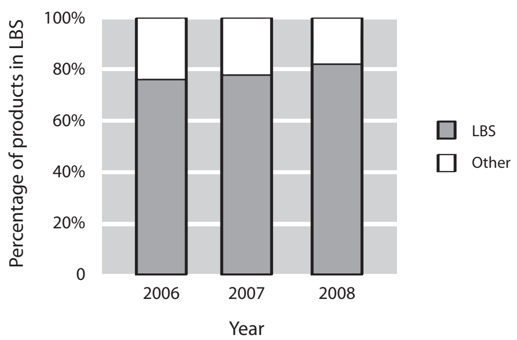


Figure 6.14: The LBS platform meets its goal of being used in approx. 80% of the LEGO products

6.6.5 Challenges and reasons for deviation

There is no evidence of the platform doesn't meet its goal, but the platform has been revised from time to time according to the platform owners, mainly because extra boxes had been introduced to the platform, and eventually too many boxes eroded the platform benefits. Other challenges are not reported.

6.6.6 Platform development process

Similar to the knowledge of platform challenges along the platform lifetime, it has not been possible to find any information on exactly how the platform was developed nor updated, but according to the platform owner the updates was requested either

- To expand the solution with an extra box from the product development teams via the packing development, saying that an extra size is needed due to different reasons
- To reduce the number of boxes from finance or production planners because the cost of having so many variants seem unreasonable to the benefits.

The implementation has been finished many years ago, and the updates of the platform seem to have caused few, if any problems.

Summarizing the Box platform (LBS)

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
LBS (before 1990) 	Packing box system using standardised dimensions, optimised for shelves in shops, and transport logistics. Approx. 80 % of all LEGO products are in these boxes.	Reuse of production equipment, high transportation efficiency, short development time and few investments.	★★★	Platform erosion: Addition of extra boxes undermines the benefits of the platform

6.7 Low Volume Mould and Module Mould Platforms

6.7.1 Platform background

LEGO produces not only millions of elements, but also the moulds for these elements. The moulds were historically designed for high volumes, but as the toy industry has become more trend- oriented, a substantial number of elements were not needed in high volumes (see Figure 6.15) and hence the moulds were over-dimensioned. Hence solutions for lower volumes were being developed, namely the Low Volume Mould and Module Mould platforms. The Low Volume Platform was developed first and then the Module Module was an optimized replacement, meaning that they are closely related and hence they are described at the same time.

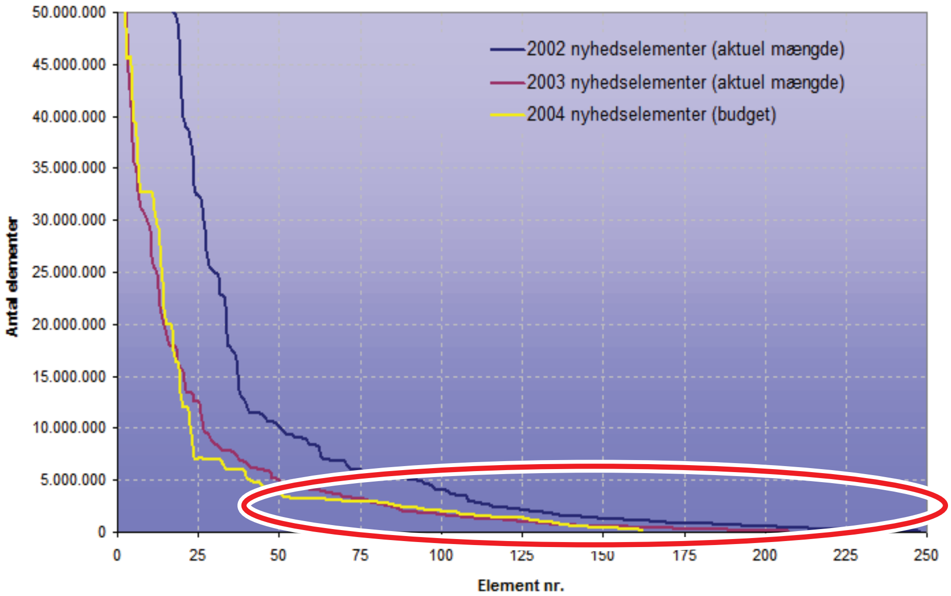


Figure 6.15: The graph shows the volume distribution for new LEGO elements. In 2004 less than 50 of the elements were produced in volumes higher than 5 millions. The red ellipse shows the target for Low Volume Moulds and Module Moulds.

The projects originated in the Mould Manufacturing department and were developed there too, involving technical element and mould designers from the product development department and were actually developed, before the Shared Vision initiatives were started. The first steps were made in 1997, when a new mould concept for elements that should be produced in low volumes was investigated.

6.7.2 Platform description

The Low Volume Mould Platform and the Module Mould Platform are modularized mould systems, where a few types of standardized mould boxes are common for the moulds and only the mould inserts (with different cavities according to the desired shape) has to be designed. The Low Volume Mould Platform was the first to build on this principle and the Module Mould Platform was an update and extension of the platform. Figure 6.16 shows a typical LEGO Mould, consisting of two moving parts.

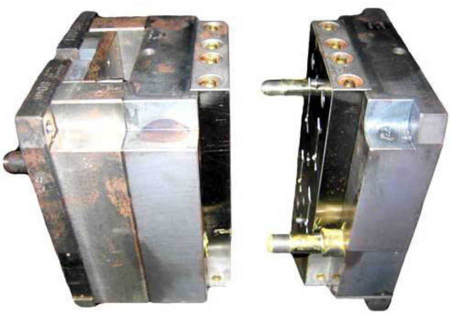


Figure 6.16: A simple LEGO mould, consisting of two moving parts. More complex moulds can have different types of exhaust, curtains etc.

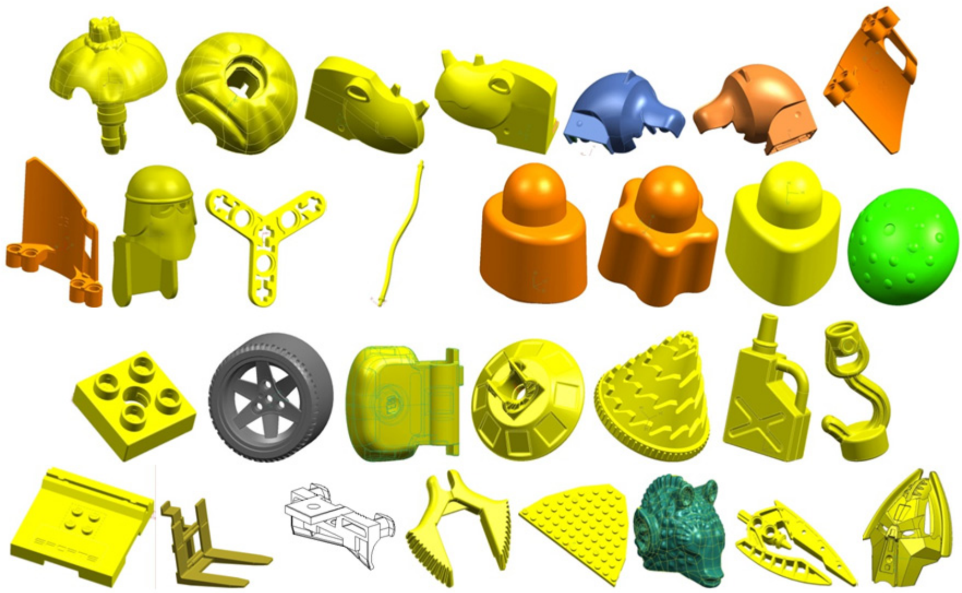


Figure 6.17: Examples of the variation and complexity of elements, that Low Volume Moulds and Module Moulds should cover.

Platform mould principles

The existing moulds were constructed with a shape insert with a number of systems to fit into shared mould boxes. In the modular moulds the cooling system, gate system, exhaust system etc. are integrated in the mould box that can be reused for many inserts with different cavities, which were made of "softer" material and hence used for production of lower volumes, as described in Figure 6.18.

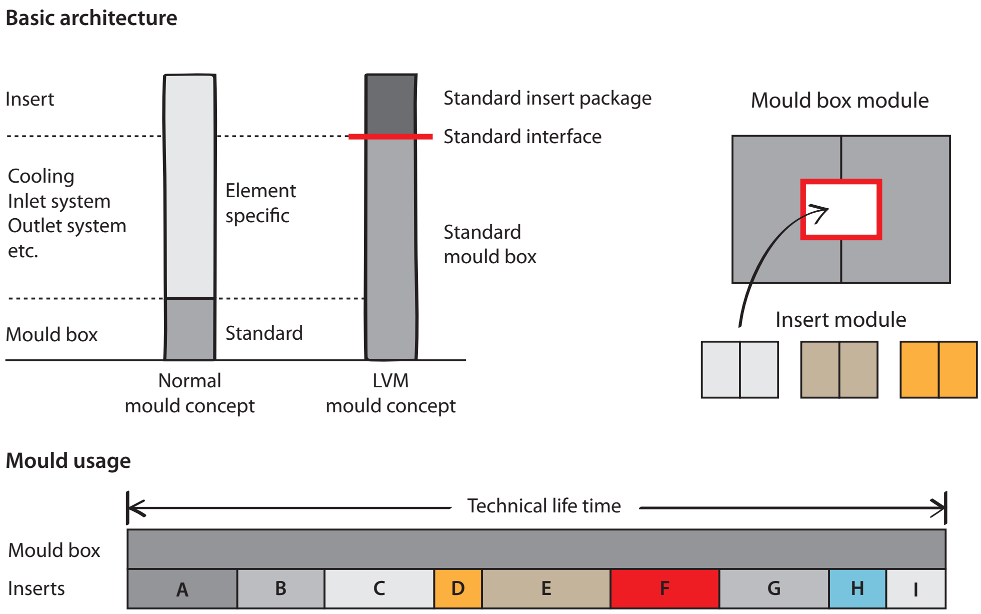


Figure 6.18: The basic principle of the modular moulds. The concept is to expand the mould box, so that it contains cooling system, inlet- and outlet system, so they can be reused with many different inserts. The new moulds reuse the mould box across the lifetime of many inserts (A, B, C etc.)

The four sizes of the new Low Volume Moulds, LVM 1, LVM2, LVM3 and LVM 4 were launched drip by drip, in respectively 1997, 2001, 2002 and 2003.They had different combinations of inserts, wings and inlets that made them capable of covering at large group of the elements.

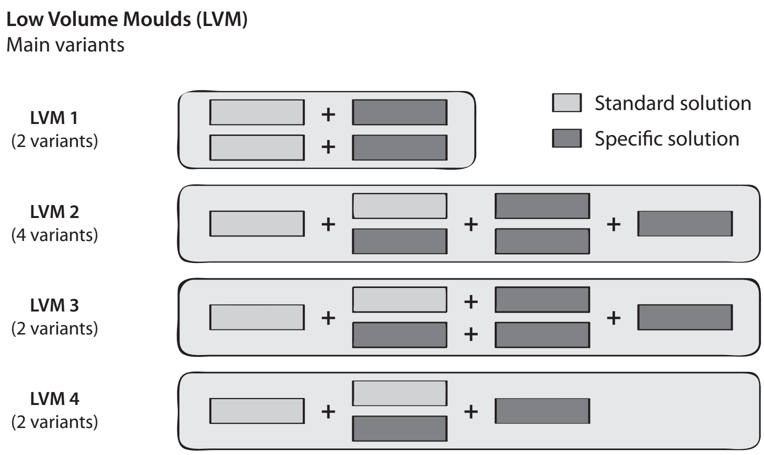


Figure 6.19: The main variants of each of the 4 LVM types. The blue color indicates that the solution is standard, whereas the yellow is dedicated to the element. The specifications of the solutions have been removed due to confidentiality issues.

In 2004 a new platform for modular moulds was introduced, based on the experiences from the Low Volume Moulds platform. The soft inserts of the LVM were causing problems in the production, and they were replaced by harder material which five doubled the life time from 1 to 5 million shoots, corresponding to 80% of the elements produced in LEGO. The Module Mould platform introduced four new mould types. MM2 and MM4 were updating LVM 2 and LVM4, and two bigger moulds, MM5 and MM6 were able to contain two of the standardized inserts instead of on only one, as the rest of the moulds. This made it possible to scale production from high volume in the peak season to low volume in the low season, using the same four inserts: With four inserts in a large MM6 the demand of the high season or the first launch were met, whereas two inserts in a MM4 in the low season or the following later launches (see Figure 6.20 below).

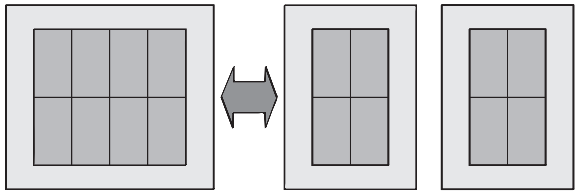


Figure 6.20: The new MM5 and MM6 were capable to contain two inserts that can be reused in respectively two MM2 and MM4, making it possible to scale the production volume and be flexible regarding equipment.

Platform calculation model

A part of the platform solution was also to integrate the new moulds in the existing calculation model, used when choosing between the alternative mould options in the development process of elements and mould. LEGO Group has developed a calculation model, which the selection of moulds are based on. This model is used by both mould and element designers and the model program is placed on the intranet as a part of the LDP. The model calculates the production cost of an element, based on the mould investment and production process cost. Optimal batch size is suggested by the program.

The platform moulds were all documented in this existing program, which also was capable of containing the platform guidelines for element and mould designers, but it does not present the background material of the platform. However the calculation model did not consider nor include the benefits of the modular moulds, which meant that the calculation model doesn't make a realistic calculation of the overall cost of them. Compared to the old moulds the modular moulds do not appear as a cheaper or better alternative, because quantified effects have not been included in the calculation.

Platform tracking and maintenance

The resources spent on the area of development and production of the moulds and the following production of elements is a significant expense, and to optimize the area, LEGO has substantial data on the moulds and their performance, which are regularly checked. Hence similar controls of the key goals are made by the platform owners as part of the regular performance evaluation.

6.7.3 Platform effects

The main expected effects of respectively the Low Volume Mould and Module Mould platforms were different, due to the changed and bigger scope of the Module Mould platform. Low Volume moulds were expected to

- Reduce investments due to cheaper material for the inserts and reuse of mould boxes
- Shorten lead time because the mould boxes did not have to be developed every time
- Reduce the amount (and risk of) of obsolete moulds that were newer exhausted

The focus on less investment was relevant due to the major investments that are made in moulds every year. Reducing the time it takes to manufacture the mould was made possible, when reusing a larger part of the mould box. The time it takes to develop and manufacture the moulds is very critical in LEGO Group. The very season dependent toy market and the feedback mechanisms in the product development process means that most of the new elements are defined at the same (late) time and has to be mould before Christmas. This creates a great peak in the mould need, and the shorter lead time there is on a mould, the longer time there is to mould the elements.

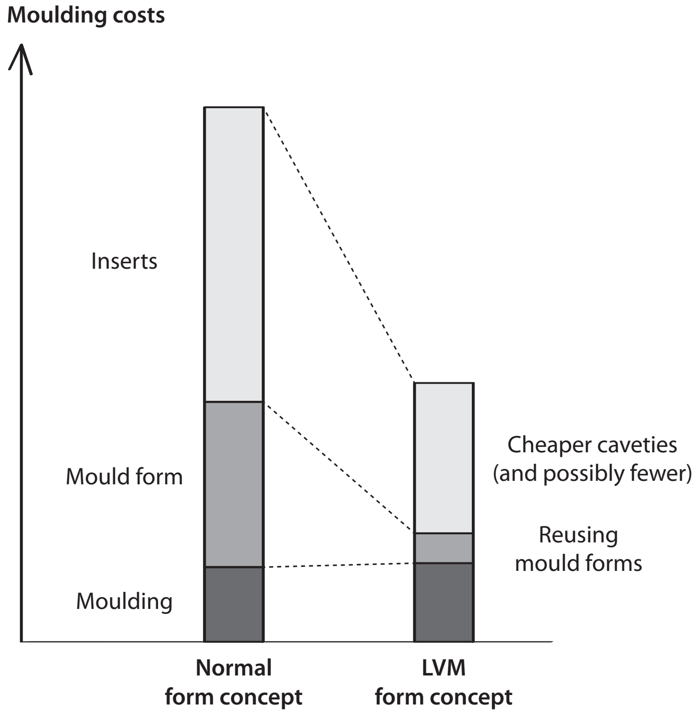


Figure 6.21: The illustration shows how the LVM concept will reduce cost/element of both insert and mould box.

The Module Mould Platform was subject of expectations regarding effects of reduced investments and lead time that were similar to the ones of LVM, but did also introduce new ones. It was expected to

- cover a much larger part of the element portfolio, due to the new harder insert
- reduce maintenance costs because of fewer moulds and more experience with the common mould boxes
- reduce the overall total cost of the molding solutions
- improve the level of quality due to more experience with the common mould boxes

6.7.4 Platform goals and performance

There were no specific goals for the LVM platform, and hence nothing to compare the achievements to. Two out of the four solutions, LVM2 and LVM4, became successful in terms of they were used in a high percentage of the moulds, due to the fact that they were capable of leveraging low volume elements at a lower investment and hence cost and offering a shortened lead time, but the rest of the moulds were not used as much as expected. There were some problems in the production due to the soft core, because it was deformed and had a shorter lifetime than expected, which meant that the production concept did not work as expected, and hence did not deliver the expected effects. This was also the partly the reason for the development of the Module Mould platform. The goal of the Module Mould platforms was to

- Be used in 80 % of the new element moulds
- Reduce the investments with minimum 25%
- Reduce the lead time with minimum 30%
- Raise the level of quality to 95%, meaning that 95% of the mould designs go through quality control first time.

It was also expected to reduce the total mould cost, mainly due to lowered maintenance costs and reuse of the mould boxes, even though it was not quantified.

Based on data from 2006 and 2007, the expected goals can be compared to the actual performance: The first goal, 80 % coverage of new elements was not completely fulfilled, since only 75% of the elements were actually made in the MM platform. The goals of reduced lead time and the rise in quality control were actually more than met.

The fulfillment of the second goal was uncertain, because it wasn't clearly defined exactly, how it should be measured, but it was considered to be achieved. It was however certain that the recycling of the mould boxes were not taking place, since only 8% of the boxes were returned, so that they could be reused.

The last goal of reduced total cost was not followed up, and there were different opinions about whether this goal was met or not. Actually this lack of knowledge and justification of overall consequences in term of cost and performance caused that the mould development and production were split in two: One half mainly use the Module Mould platform and the other half the original standard solution, because both parties thought that this was the best solution. To clarify this discussion, an economical analysis was made, based on the historic data from 2006-7, which is described in detail in section "6.7.7 Establishing insight: Performance analysis of module moulds". It was a complex analysis, where the prerequisites were discussed in detail both with people that thought the platform was the best economical solutions and those who did not.

The result of this analysis showed that the Module Mould platform on average did not deliver the economical benefits as expected, mainly because it was less suitable for a number of types of moulds. If the recycling of the mould boxes had worked, this result would have been better, but still not as good as for the standard moulds.

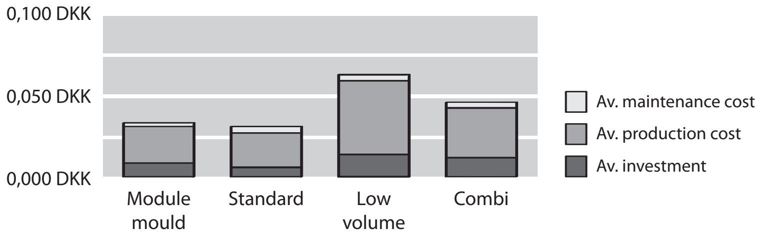


Figure 6.22: Average prices for elements, manufactured in different type of moulds. Elements from the Module Mould are significantly more expensive than the ones from Standard moulds.

The analysis also showed the importance of knowing and tracking the performance of individual subgroups, because there was great variation, which blurred the overall picture of the performance. This variation should be addressed with different strategies for when to use the Module Mould platform. The Module Mould platform did however still provide substantial benefits regarding reduced lead time, which is a critical parameter. Hence it is a strategic decision to determine whether the benefits in reduced investment, development time, lead time and lower risk are worth the extra total cost.

6.7.5 Challenges and reasons for deviations

As mentioned the LVM platform experienced technical problems due to the soft core, which was replaced in the MM platform. Also some of the alternative concepts were not used to the expected degree, and the platform owners and users (the element and mould designers) explain this with a combination of the following:

- The calculation models used to develop and decide upon a mould did not show the benefits of the platform solutions
- There were no clear goals describing to which degree the platform should be used
- Finally nearly half of the users did not consider it to be an attractive alternative, because they did not believe in the benefits, since they could not be calculated properly.

Some of these challenges and reasons were also present in the module mould platform.

The Module Mould platform met some of its goals, but not all and the reasons for this were partly described in the above description of LVM platform. Other reasons were described by the platform owners and users:

- The technical platform solution was more costly than expected in terms of productions hours, which increased the total cost
- The planned recycling of moulds was not realized due to lack of follow up and lack of incentive for the platform users in production, which also contributed to the total cost

The reason for the longer production time was that the platform moulds on average are less optimized for fast cooling than the standard moulds, and this had bigger consequences than expected.

The recycling process of the mould boxes was newer properly implemented or followed up upon, meaning that there were no prerequisites in the production enabling the reuse. The operational production personnel were not involved in the development of the solution and there is no incentive that makes them recycle the moulds. In the period 2007-8 390 moulds were ordered, and only 29 were returned. It is mainly due to the fact that the moulding workers find it easier to let the inserts stay in the mould box, because then they won't need to put them in again. They sub optimize their own work, and have no incentive or information that makes them do otherwise, and this undermines the platform solution.

6.7.6 Platform development process

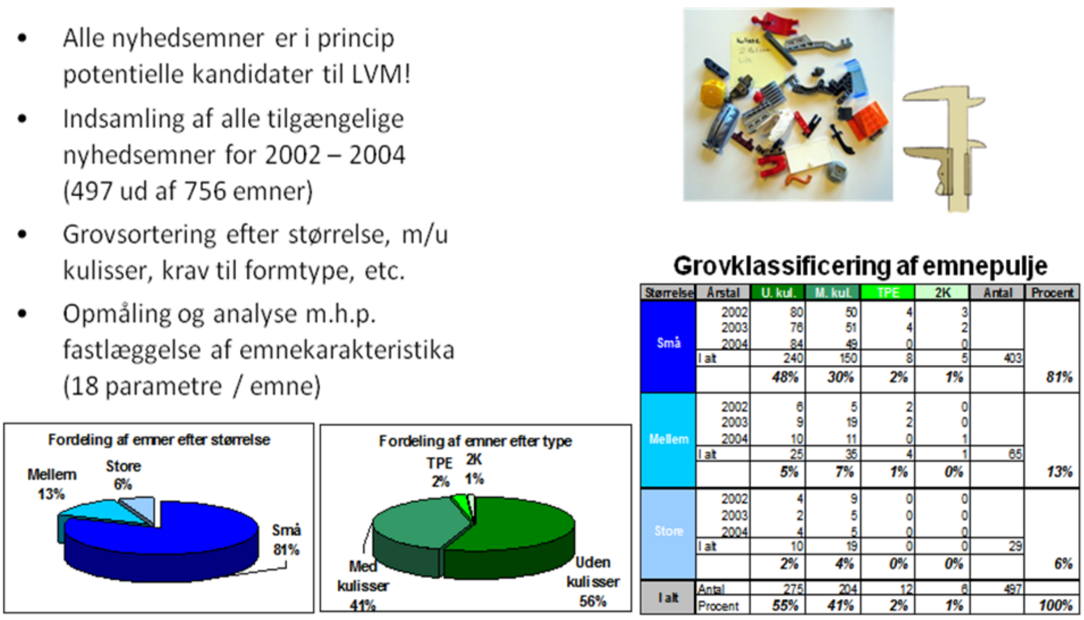
First the development processes for the Low Volume Mould Platform is described and then subsequently for the Module Mould Platform.

Development process for Low Volume Mould Platform

The development process of the LVM moulds started out with a need for cheaper low volume elements and ideas for the technical solution. According to interviewees and documents the process was based out with a thourough analysis of the existing elements and the different dimensions in which they varied e.g.

- Historic elements dimensions,
- Exhaust type
- No. of curtains
- Volume and demand curves

The below Figure 6.23 shows a slide from the presentation, showing the scope of the platform in terms of general dimensions for the elements.



Størrelse	Årstal	U. kul.	M. kul.	TPE	2K	Antal	Procent
Små	2002	80	50	4	3		
	2003	76	51	4	2		
	2004	84	49	0	0		
	I alt	240	150	8	5	403	
		48%	30%	2%	1%		81%
Mellem	2002	6	5	2	0		
	2003	9	19	2	0		
	2004	10	11	0	1		
	I alt	25	35	4	1	65	
		5%	7%	1%	0%		13%
Store	2002	4	9	0	0		
	2003	2	5	0	0		
	2004	4	5	0	0		
	I alt	10	19	0	0	29	
		2%	4%	0%	0%		6%
I alt	Antal	275	204	12	6	497	
	Procent	55%	41%	2%	1%		100%

Figure 6.23: Studying and describing the distribution of elements based on size and type was the starting point for the analysis in the development process of LVM (Slide from the LVM development process)

The results of the analysis were several figures and schemes describing the different characteristics, and they were presented on board, as shown in Figure 6.24below. The boards were used in discussions and when the platform was presented to e.g. stakeholders, giving their input.

Figure 6.24: Examples of the analysis result, on the top, the distribution of curtain span, below the distribution of demand and production, and the bottom shows the presentation of the results on boards.

Based on the analysis and the principal idea of the reuse of mould boxes, an number of alternative concepts with different coverage on the various parameters was developed. Different specialists and stakeholders were involved in the design process to contribute to the solutions and to identify potential effects. Different sub-solutions were discussed and modeled and compared to results from the analysis to know how well they covered the need. Below in Figure 6.25 an example of the potential solutions of standard insert cores were modeled.

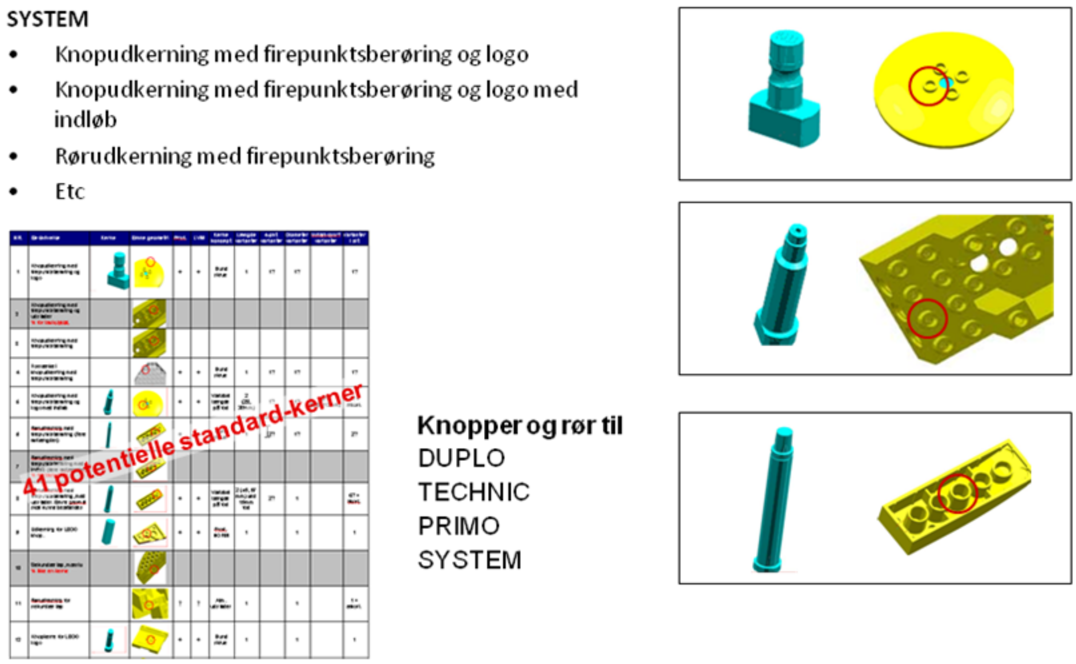


Figure 6.25: Example illustrating how alternative sub-solutions for the mould platforms were investigated: Her e some of 41 solutions for standard insert cores (Slide from the development of the LVM development process).

The effects of the individual sub-solutions were studied and estimated of experienced specialists based on exemplary problems. The estimated effects on these individual solutions were however not scaled up and used to predict overall effects of the platform. Figure 6.26 below shows an example of the potential reductions in lead time and cost by using standard insert cores.

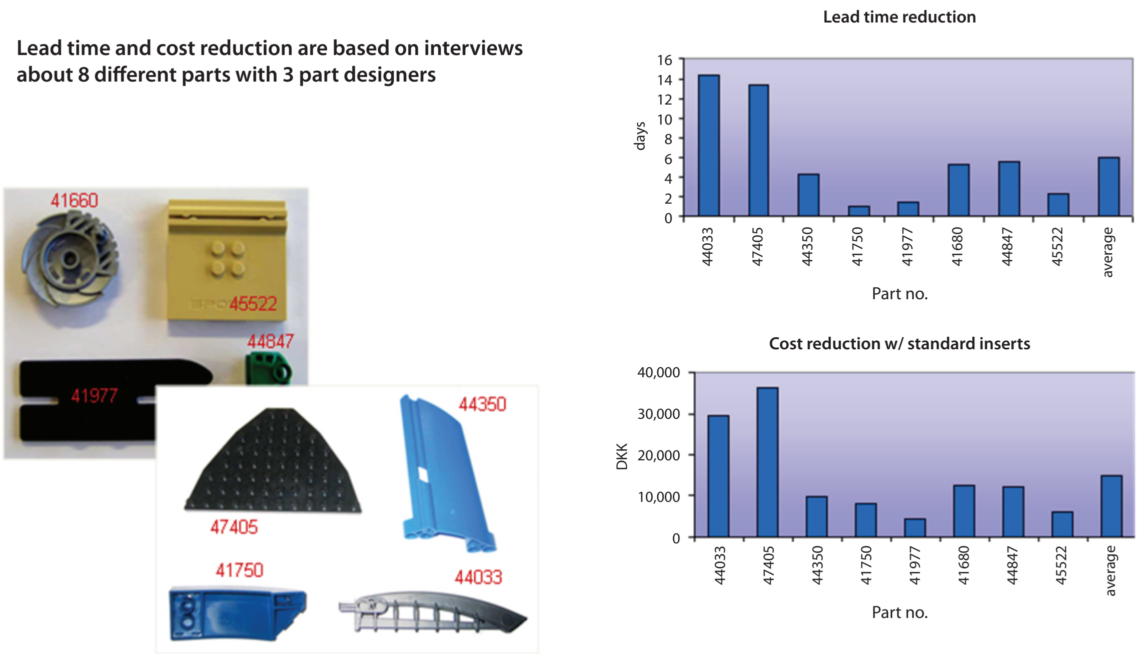


Figure 6.26: Based on interviews with experienced designers, effect estimates were made on reusable mould core solutions, showing 1-14 days of reduced lead time and between 5-37.000 DKK reduction in cost. (Slide from the development of the LVM development process)

The development process generated a number of different concepts for mould boxes. The different alternatives were each evaluated in terms of how well they covered the different parameters, identified from the analysis. Figure 6.27 below shows an example of a concept and how it covers the parameters.

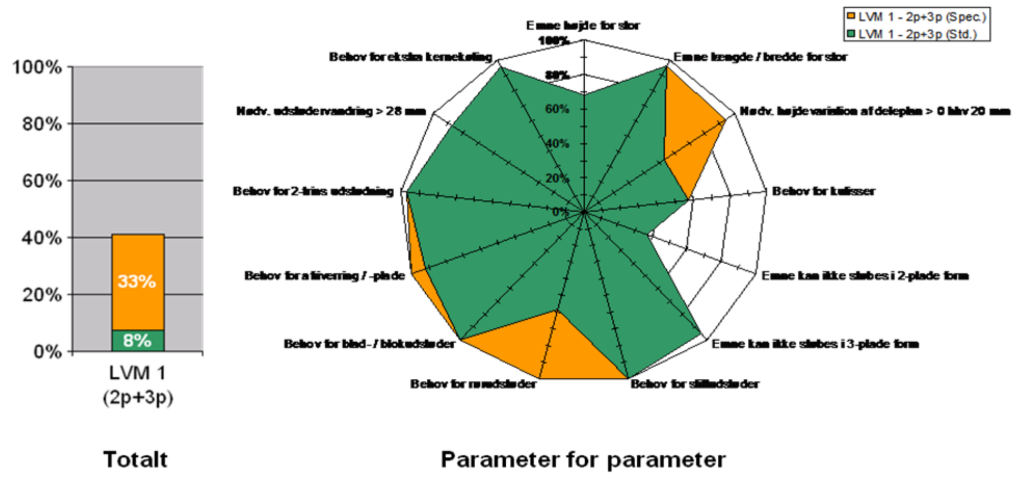


Figure 6.27: Example of how a mould concept covers the different parameters, resulting in a total coverage of 40+ % of the elements (Slide from the development of the LVM development process)

The platform solution consists of a combination of different mould sizes that covers all the elements, and hence alternative combinations of moulds in different sizes were investigated. The final platform solution was based on 4 sizes of moulds and it is depicted in Figure 6.28 how many percent of the LEGO element portfolio the different mould sizes covered.

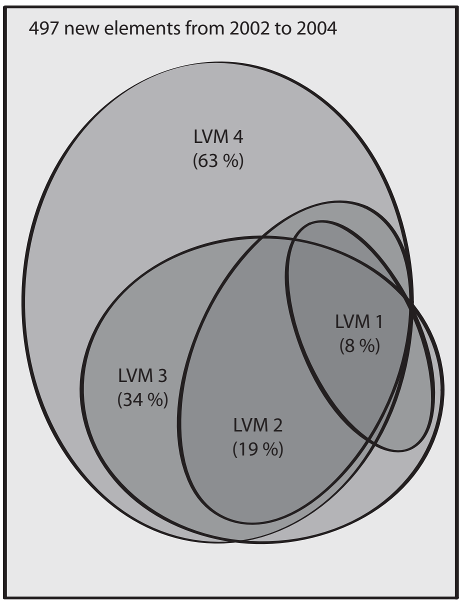


Figure 6.28: The four mould sizes of the LVM covered different parts of the LEGO element portfolio, shown with percentages (Slide from the development of the LVM development process)

In the LVM platform development process effects were modeled in terms of coverage of element portfolio, lead time and cost reduction. These effects were not scaled up to make an impression of the overall effects nor translated into operative goals for the platform.

Development process for Module Mould

The development process of the Module Moulds built upon both the element analysis from the LVM platform and the experiences from the realized moulds. The development process was a combination of updating some of the LVM moulds and introducing new ones. The optimization was mainly technical, concentrating on how the number of cavities could be increased and how the inserts to be used across different sizes of mould boxes, see Figure 6.29.

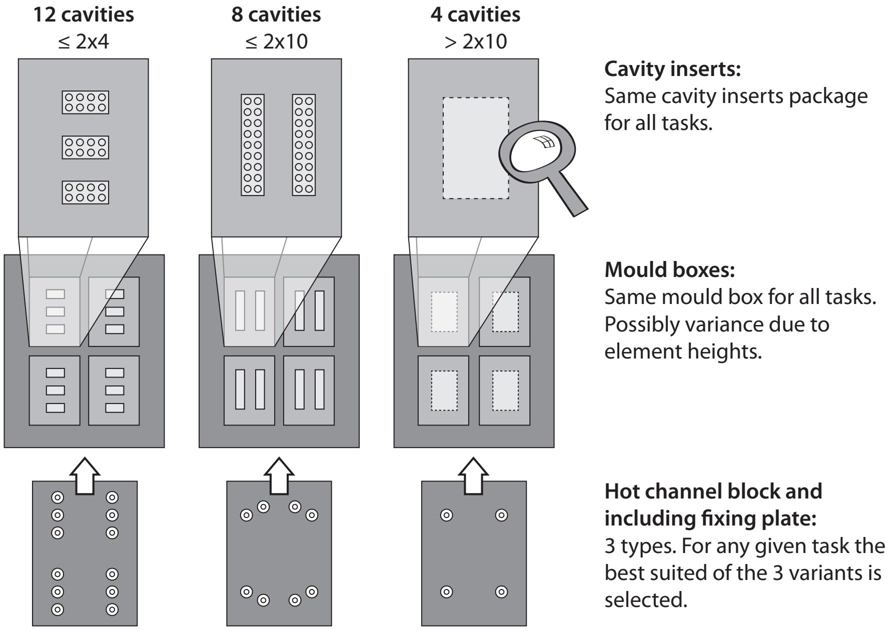


Figure 6.29: The development of the Module Mould platform was optimizing the mould boxes for a maximum number of cavity inserts that could be reused across different mould box sizes.

No new effects were identified, but the existing effects were enhanced by optimization. The expectation of effects based on historic performance data from individual LVM moulds and the experiences from the use of them. These effects were translated into specific goals by the development team, and some of them were somehow strategic, more than verified by historic data (e.g. the goal of 80% use for new elements). The goals were based on the percentage of when a modular concept is chosen in opposition to a standard. Investments, lead time and level of quality were some of the goal parameters. There was not made any total cost calculation during the development phase, but few calculations on historic data from individual moulds were made.

6.7.7 Establishing insight: Performance analysis of module moulds

Due to the previously mentioned lack of knowledge of the actual performance of the Module Mould and the organizational split and discussions of belief it caused,I made an economic performance analysis on production data. The analysis attempted to measure the performance of module moulds and the total cost, not at least because of the diverging perceptions of the solution, which was clearly represented in the organization. The analysis was based on data from 1133 moulds that was made in the period 2004 -2007 and production and maintenance data from 2006 and 2007. Different subgroups of the moulds were compared and Module Moulds and Standard Moulds were only compared where they were replaceable. There had not been made any preparations of such an analysis in the development of the platform. Hence it was a challenge to get the relevant figures withdrawn from the ERP system and other local system and compare and validate them by multiple sources. It was expected that elements from Module Moulds would have a lower total cost than elements from Standard moulds, made up from lower mould investment and maintenance cost and slightly higher production cost. In the following the prerequisites for the analysis is described, then a simple calculation model is applied and the result is discussed. A more detailed analysis where relevant subgroups are compared is then made and the results are discussed.

Prerequisites and conditions

The calculations are based on a number of prerequisites and modeling of different factors and other that it does not take into account. They are listed and described below and for the ones that are not taken into account, it is commented if they are in favor of Module Moulds or standard moulds.

Included as influencing factor in the analysis:

- Shot/Element variations
- Use frequency and seasonal differences
- Equipment variation
- Interest of investment from mould production date
- Mould size distribution

Not considered as in influencing factor (in favor of Module Mould):

- Batch size variation

Not included in analysis (all in favor of Module mould):

- Value of lead time
  - Earlier production enabled
  - Fewer wrong decision (due to more decision time for critical elements)
- Interest of investment during delivery time
- Value of mould box return system

The results in the following were calculated for both element number and shoot to eliminate the possibility that the results were due to a tendency to place bigger elements in one or the other mould type. To make a more fair comparison, it has been checked that the average use frequency of the Module moulds and the standard moulds was similar during throughout the seasons the two years, the production data was taken from. The production in LEGO Group is very dependent on season, due to peak periods. There was also checked for equipment variation, which showed no variation. The mould data did however show a relative overrepresentation of small moulds in the standard solutions, which affect the average investment cost, and this has been taken into account in the analysis. However the data was not checked for similar batch sizes, which may have an effect, and should be done in future studies.

The value of the shortened lead time or the value of the box return system has not been included in the analysis. The calculations include the payment of interest of the investment from the time when production was started, but not the interest of the investment during the delivery period. The standard moulds are approximately 150.000 DKK more expensive than Module Moulds and have approx. 10 weeks longer lead time. Finally the potential value of reused mould boxes is not accounted for, because the return system pr. See does not work.

Simple average calculations

For a mere the average of the data, Standard elements total costs were significantly lower than Module Mould elements. Within different subgroups the result varied: For one rather representative subgroup the standard solutions cost 74% of the Module Mould solutions (see figure below)

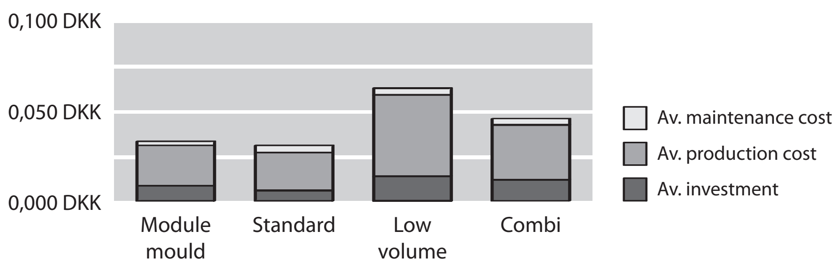


Figure 6.30: A simple average price calculation shows the cost allocation of the different moulds.

This mere average is though not a fair comparison, and the results varied a great deal within subgroups. The figure shows two graphs showing the cost distribution for two different subgroups.

In this subgroup the Module Mould solution was more expensive both regarding investments and production cost and was only at level when it came to maintenance cost. The Module Mould solution performed overall worse than expected. Especially the higher production cost had impact, being 10 and 50 times higher than respectively investment and maintenance.

Another subgroup showed that Module Moulds in that case were cheaper altogether, an example seen in Figure 6.31 below

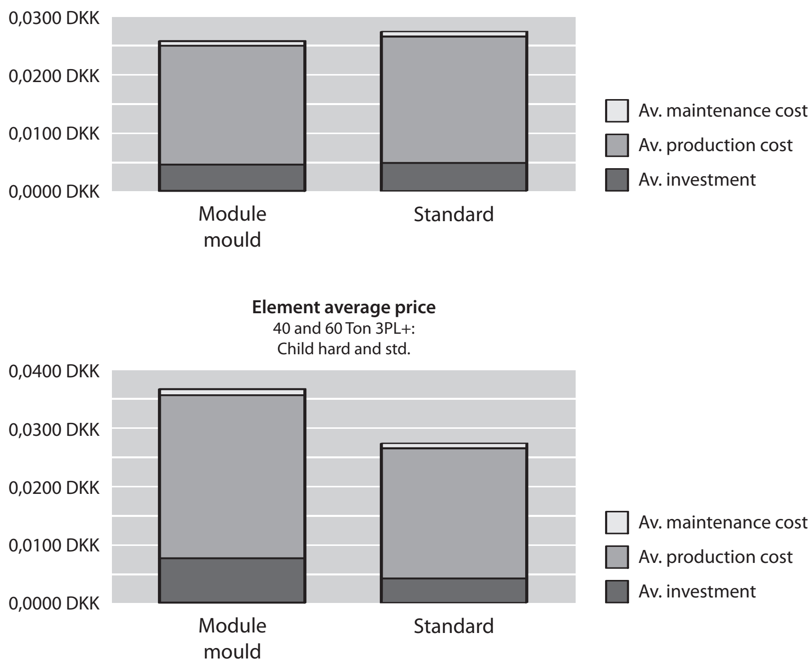


Figure 6.31: Prices for but similar subgroups, the one including one extra type of moulds (indicated by th "+" sign). Notice how big influence this specific type has on the average cost: On the left table the Module moulds cost less than standard moulds and in right table (where this extra type of mould is included) the average cost for the Module Mould are higher the for the standard moulds.

Comparable calculations

The above shown subgroup 40&60Ton 3PL are reasonable to compare because both Module Moulds and standard moulds are realistic alternatives, and the group is rather large, 459 moulds. Hence this subgroup will be used to compare in the following.

The above mere average cost distribution shows that the cost of elements made in Module Moulds exceeds those made in standard moulds. However it does neither take the interest nor mould size distribution into account, which is necessary to make a fair comparison of the total cost of the solutions.

The average mould lifetime is 10 years and the interest was set to 15 % of the average difference in investments in Module Mould and standard moulds. In LEGO Group the financial department uses different interest rates, depending on the period and risk, and that has great influence. The 15% interest is one of the lower and hence a conservative estimate of the savings due to the interest.

To make a realistic comparison, it was calculated how much it would have cost to make the Module Moulds as standard moulds instead. This total calculation was made with standard mould production and maintenance costs and the investments was based on the average standard mould cost, but takes into account the number of small and large moulds. In the data set the size distribution of the standard moulds were 363 small and 44 large in opposition to 40 small and 35 Module Moulds, which was not taken into account in the above calculation. In this calculation however an average cost difference between Module Moulds and standard moulds for respectively small moulds and large moulds was added to the investment to make a realistic estimate of what it would have cost if the Module Moulds were made as standard moulds.

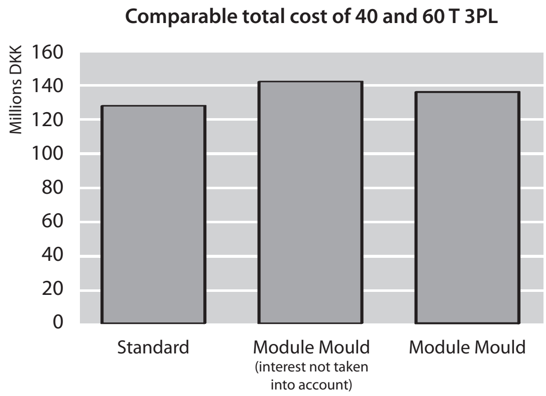


Figure 6.32: The graphs show total cost of standard moulds and Module Moulds, with and without the interest effect of the interest (mould size distribution taken into account).

The result of these supplements and corrections was a smaller difference in the total cost of the moulds (illustrated in Figure 6.32):

- The standard mould solution was calculated to be 96 % of the Module Mould solution.
- The impact of interest alone made the MM solution 4% cheaper.
- Approx. after 6 years, there is a breakeven between the total cost of the standard solution and the MM solution (out of 10 years lifetime). Until then the MM solution is cheaper.

The fact that many moulds are not used up, and hence add extra years to the interest period, pull the result a bit further in favor of MM.

Regarding the other goals of Module Mould, the analysis concluded the following:

- Module Moulds were used in almost 50 % of the of the new element moulds, compared to the goal of 80%
- The Module Moulds reduce the investments 24-31%, compared to the goal of 25 %
- The mould production lead time is reduced with 37% (12 weeks for MM compared to 19 weeks for standard moulds). The goal was only 30 %.
- The MM moulds have a quality statistic above 96%, compared to the goal of 95 %

The analysis also showed great variation of how well the platform performed within subgroups, which draws the attention to the fact that the analysis was needed to determine when is beneficial to use the Module Mould solution, and it emphasizes the importance of making the right grouping in a platform solution. In this case the bad subgroups made it appear as if the platform was a bad solution, pulling down the average, even though good subgroups showed superior results.

These results were calculated and the data were analyzed with support and control from multiple LEGO employees, and finally used as input for a new mould optimization process and presented in a meeting kick starting this process.

Concluding on the analysis

Most of the goals of the Module Mould platform was met or more than met. The platform was not used in 80 % of the new elements moulds, as intended, and it can to some extent be explained with resistance in the organization, due to the lack of convincing evidence of MM being the best solution regarding total cost.

The result of the above Module Mould performance analysis was rather surprising to the mould design and production management. They had expected that Module Moulds had a lower total cost than the standard mould, but was surprised by the impact of the higher production cost. As mentioned this study is conservative regarding positive factors in favor of Module Mould and it does not contain the value of the reduced lead time. Hence the difference of 4 % of total cost in the "most" comparable" subgroup may be so little, that it is fair to say that the cost is almost the same.

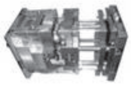
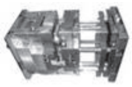
It is also important to keep in mind that the main goal of Module Mould was to reduce lead time and it is important to ask the management, whether the extra expenses of the module mould is worth the reduced lead time.

Concluding on the Module Moulds compared to the standard solutions we summarize below:

- Overall the Standard solution is slightly less expensive on a 9 year basis, but has a much larger investment in the beginning, whereas the Module Mould has a low investment, but higher production cost. Breakeven is at 6-7 years.
- There is however a significant issue of reduced lead time, which was a main goal, and it has not been quantified. It must be considered if the reduced lead time is worth the small extra cost.
- There is a need for a more differentiated strategy when using Module Moulds, because there are clear benefits for some subgroups and none for others.

The above calculations have not included the potential reuse of mould boxes, which the analysis also showed, had not been realized due to lack of incentive in the production and nobody had followed up on the issue.

Summarizing the Low Volume and Module Mould platforms

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Low Volume Mould platform (2001) 	Standard mould boxes with insert cores and mould gate solutions (for low volume elements). No specific goals	Reduced mould investments, shorter development and lead time, lower risk.	★★	Reaching the level of use and measuring and calculating actual platform benefits when choosing mould design. Use of platform: No goals from management. *Errors are multiplying due to reuse of new technical solution.*
Module mould platform (2005) 	Standard mould boxes with insert cores and mould gate solutions (for medium-high volume elements) used for 80% of all new moulds.	25% reduction in mould investments, 30 % shorter development and lead time, lower risk.	★★★	Reaching the level of use and measuring and calculating actual platform benefits when choosing mould design. Technical platform performance was not as good as expected

6.8 Can Platform

6.8.1 Platform background

The can packaging equipment platform was developed in the LEGOs equipment manufacturing department in response to a type of product packing, plastic "cans" in various sizes and with different lids, which was increasingly popular in LEGO some years ago. LEGO developed numerous different cans (as shown in the Figure 6.33 below), and for each can specific packaging production equipment was built, costing several millions of DKK. These continuous investments in almost identical equipment were the reason for the idea of reused equipment.

Figure 6.33: A few of the different cans LEGO has introduced

6.8.2 Platform description

The platform idea was to make packaging equipment (for filling the elements in the can) that could be reused for many cans, handling different dimensions and lids. The Can platform is a flexible packaging line that can handle different shapes of cans within a certain size range, and with a certain types of lid. The line is designed for easy configuration, so that it can fill various cans within a short period of time.

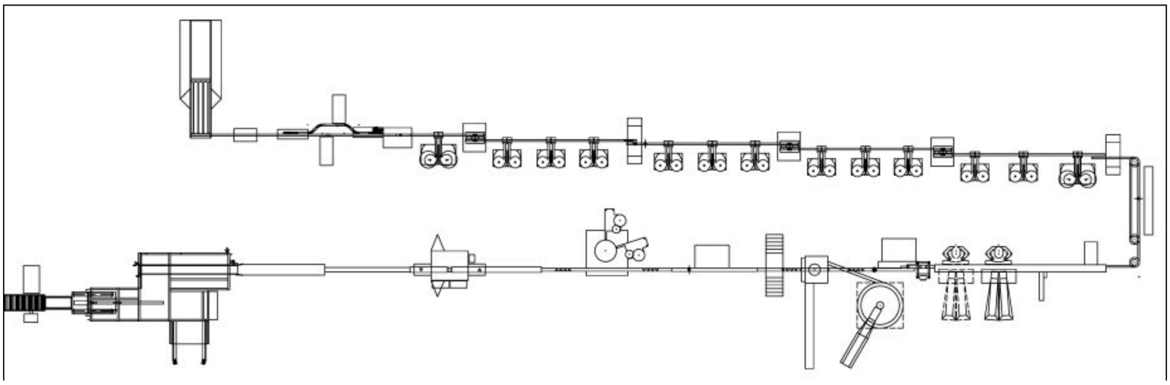


Figure 6.34: Technical drawing of the layout of the can platform packaging equipment. In the top of the line the different stations where different LEGO elements are dropped into the cans, and in the lower part a machine wraps a plastic foil is around the can, then the lid is placed on top and screwed on and finally the can is placed in a batch with the rest of the order.

Figure 6.35: The can platform consists of a number of specified main components, listed in the above figure.

6.8.3 Platform effects, goals and performance

The main desired effect from the platform was to improve sales due to the variety of cans that the packaging platform enabled. Also reduced rebuilding costs of the packaging line was supposed to make the platform solution cheaper, because rebuilding should not be necessary: The platform was set up with the goal of reusing the packaging production equipment, which should be designed to be so flexible that it could handle more than one specific can. Rough expectations lay on possibly 50 % reduction of the rebuild cost. Considering the required investments, breakeven would be reached within 3 years. This expectation was not based on historic data, but on the development teams' expectations of how the cans would develop the following years.

There was however not made any goals for the platform, but the investment in the packaging platform are compared to the investments made in different similar packaging equipment, which is show in Figure 6.36.

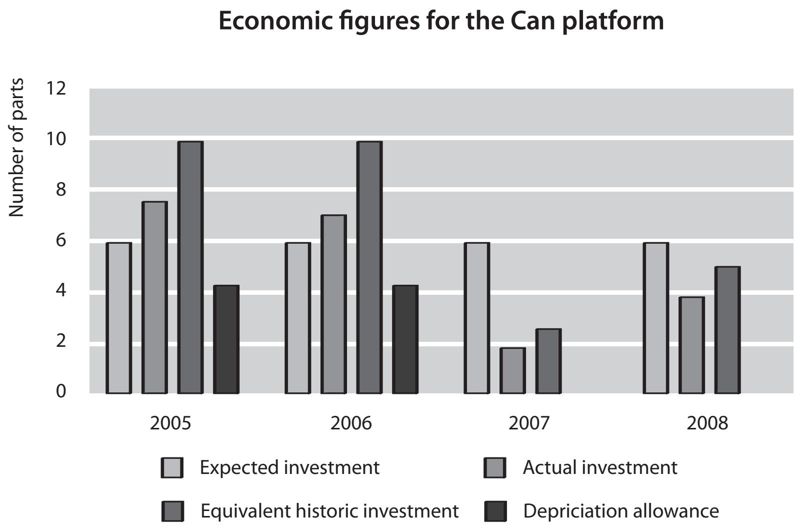


Figure 6.36: The actual investments compared to the historic and expected investments and depreciation allowance

As the figure shows that the actual investments are higher than the expected for the first two years (2005-6), not even taking the depreciation allowance into account, which should be added to the expected investments. The investment in the platform was 8 mio. DKK. which was depreciated within two years. However the investment was still lower than the previous average investments. The following years (2007-8) the platform was used much less than intended because the need of cans was overestimated. This meant that the investments were very low, because few cans were produced. The total investment in the platform solution has been app. 2 Mio.DKK more than the estimated investments of having individual solutions in years of 2005-8. Altogether the platform did not meet the expectations, first craving more investments than expected and later being redundant, making the platform a less beneficial investment.

6.8.4 Challenges and reasons for deviations

The platform was designed based on historic parameters and it locked the height and width of the cans, but and unfortunately it did not leverage the expected effects for two reasons:

- First, the following seasons design of the cans was outside the platform dimension scope, having many special functionalities
- Second, the trend with cans was unstable and faded

As the first bullet describes, though flexible, the platform apparently wasn't flexible enough or flexible on the wrong parameters: Unstable market demands, lack of involvement or willingness to commitment of the marketing department and lack of influence of the platform development team caused that the many of the following cans, designed in the product development after the platforms introduction, were outside the dimension scope of the platform. It also played an important role that the actual potential of rationalising the area was smaller than as described in a the following section, meaning that the platform would have limited economic impact.

In this context the platform designers mentioned, that it was in an era in LEGO were no requirements were made to the product development and they describe it as a one way process, when something was designed, it was just up to the equipment production department to make it, no questions asked. The platform was hardly ever fully used, before the can trend faded and there was much smaller need the following years.

Concluding on the characteristics of the can platform, it is difficult to develop a platform, when both the product (or package) characteristics and the market demand are unstable.

6.8.5 Platform development process

The development process of the can platform started with an analysis of historic data on the existing cans. The analysis both involved economical issues of cost and investments and the characteristic of the cans and the production and packaging process.

The economical part of analysis showed that the cost of rebuilding the equipment was actually not as big as expected, see Figure 6.37. However since the potential of a reusable solution was still considered to be there, the platform development process was continued. The focus of the platform was directed towards improvement of sales by supporting a variety of attractive can design options.

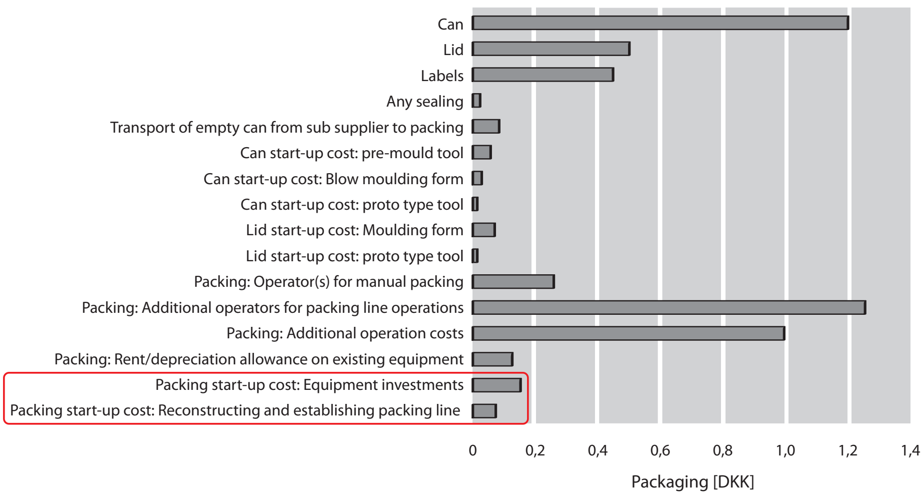


Figure 6.37: The average distribution of cost of a can. The size of investments and cost of rebuilding packaging equipment (marked with the red line) were lower than expected.

The result from the analysis of the different can and production characteristic were described in a Product Family Master Plan (PFMP)[Mortensen, 2000], shown in Figure 6.38. The different alternatives in terms of

- Height
- Width
- Cross-section
- Number of parts

were displayed to show the necessary variance for each dimension.

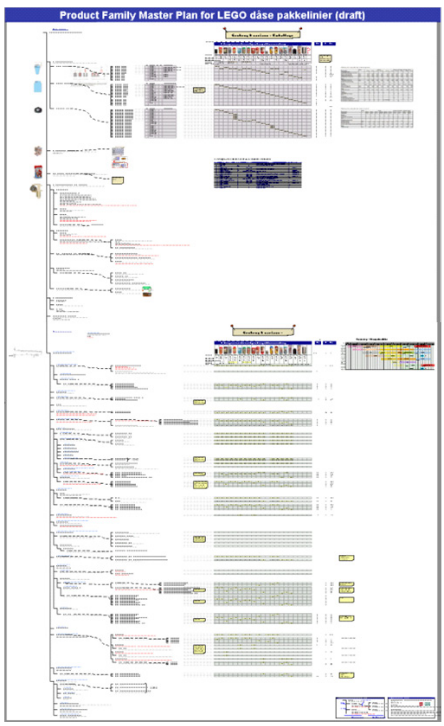


Figure 6.38: The Product Family Master Plan for the cans, showing the alternative existing solutions and key economical figures.

The packaging equipment was in similar way analysed and based on the characteristics from the PFMP, alternative concepts for a platform packaging solution was developed.

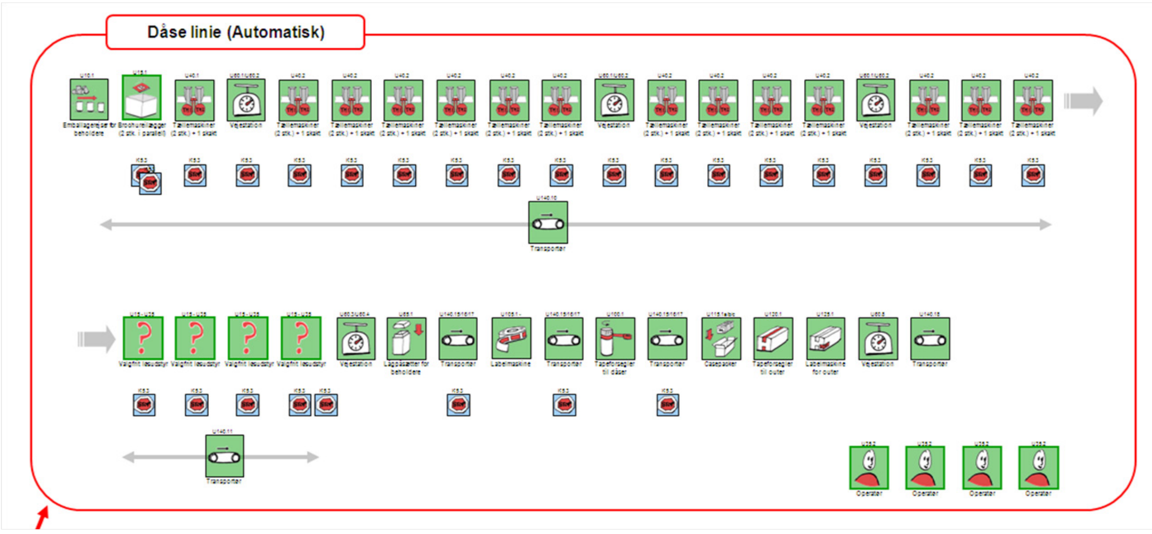


Figure 6.39: The typical design of a can packaging equipment, described by the function of each handling station. In the design of the packaging platform equipment similar representations was used to model the equipment.

The ideas for the platforms were based on four different scenarios:

- Packaging equipment platform for all the previous cans
- Packaging equipment focusing on round and oval cans
- Packaging equipment for all future and existing cans, based on dimensional design rules (as seen in Figure 6.40)

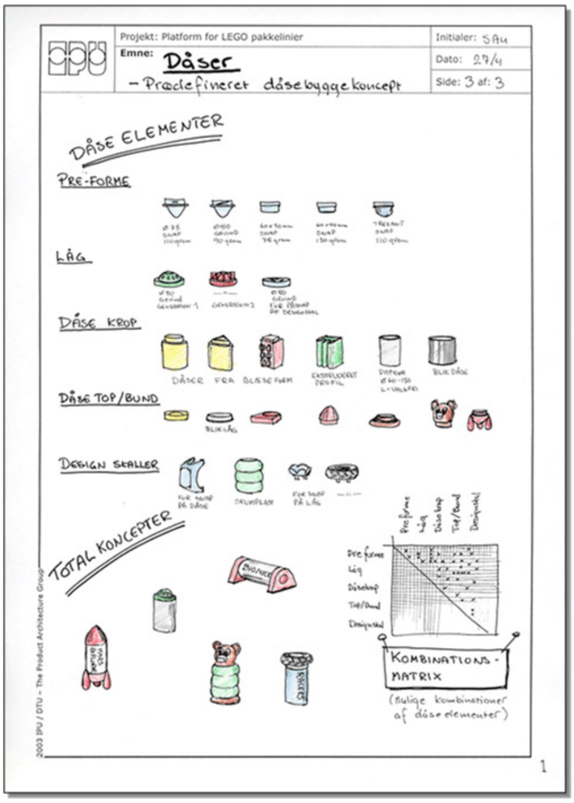


Figure 6.40: One of the alternative platform concept was that all the different parts of the cans had predefined dimensions, that limited the freedom of design, but enabled reuse of the packaging equipment.

The potential effect and the viability of these effects were use to choose between the different scenarios. The final solution was roughly based on the last scenario with the fixed dimensions. The specification of the fixed dimensions was based on the historic cans, and according to the platform owner not discussed thourougly enough with the can designers.

As mentioned the expected effect was to offer a variety of solutions at a low price, due to lowered investment. A prerequisite for this was of course that the new cans were designed within the fixed dimension, but no goals were set to ensure that this prerequisite was fulfilled.

Summarizing the Can platform

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Can platform (2004) 	Packing can platform with reusable elements and supported by fitted flexible production frame. No specific goals.	Improve sales with design freedom and reduce cost of rebuilding production equipment.	★	Outdated platform scope. Not possible to set up suitable and beneficial platform solution due to too unstable market demand conditions

6.9 Wheels

6.9.1 Platform background

LEGO s assortment of tires, hubs and rims had slowly been increasing to 101 different components and it was questionable if this high degree of variance was appreciated by the customers. Even when new wheels were introduced, no old ones were discarded, meaning the number continuously grew. The cost of having so many wheel types was the cost of having multiple unutilized moulds in stock with little prospect of being exhausted. Also cost of obsolete elements and production changes was higher than necessary. Actually the mould investments for new wheels were the double of what was actually required in the products, as shown in Figure 6.41.

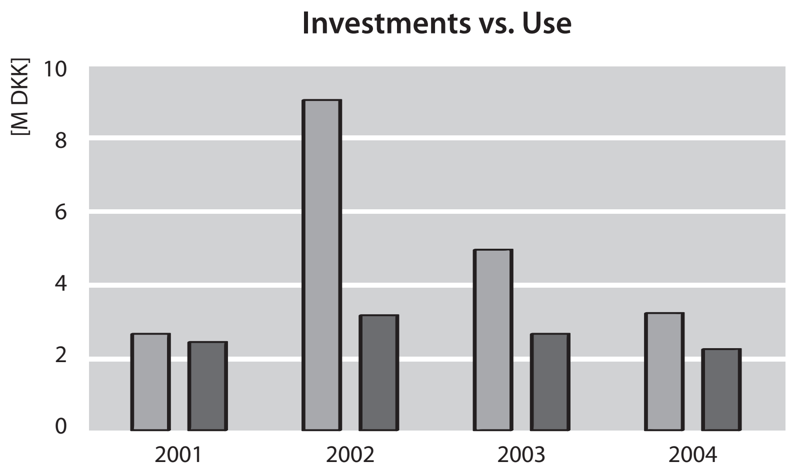


Figure 6.41: The number of used wheels is much lower than the number that investments in moulds equal.

Hence the number of wheel variants should be minimized and based on necessary requirements. The collection of wheels should be more generic so it could be shared across products to a greater extend.

Similar projects for revising the wheel assortment had been initiated times before. Each of these projects had failed however, primarily because of lack of commitment in the organization, but perhaps due to the financial crisis in LEGO it was easier to create an understanding of the necessity of the platform.

6.9.2 Platform description

Platform elements

The Wheels platform consists of 42 (extended to 44) wheel, cap and rim designs, which were simultaneously designed to cover the requirements for wheels in the different products: Some of the best old components were used, but also new components were created. Some of the types were however only designed and specified if there was no urgent need for them, but they could be realized when the need was there (the moulds not manufactured until then).

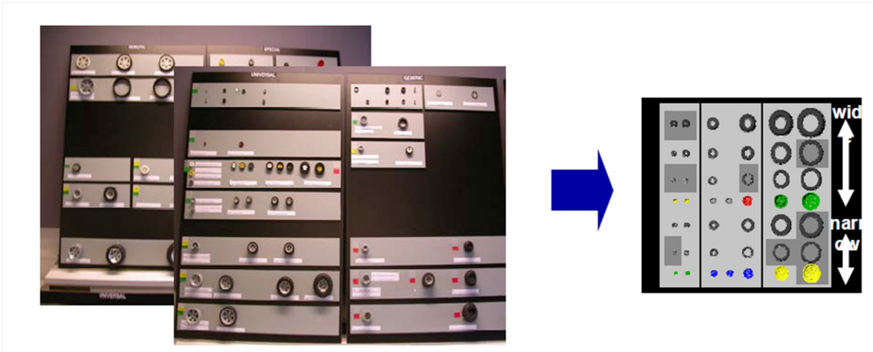


Figure 6.42: The previous assortment of wheels was replaced by only half as many in the Wheels Platform.

The Wheels Platform also limits the number of new future component and reduced the number of existing components to increase the utilization of moulds. Since it was possible, minor adjustments of designs were made to align the wheels with the production equipment in order to improve the performance of the production equipment.

A new wheel design principle was introduced with the Wheels Platform: Different types of wheels were designed so that they shared the same rim. Previously the rim was used to differentiate or style the products, but to keep the number of rims low and reusable across many products the new design this differentiation is made in a capsule that can be added to the rim, if desired. Figure 6.43 shows the principle.

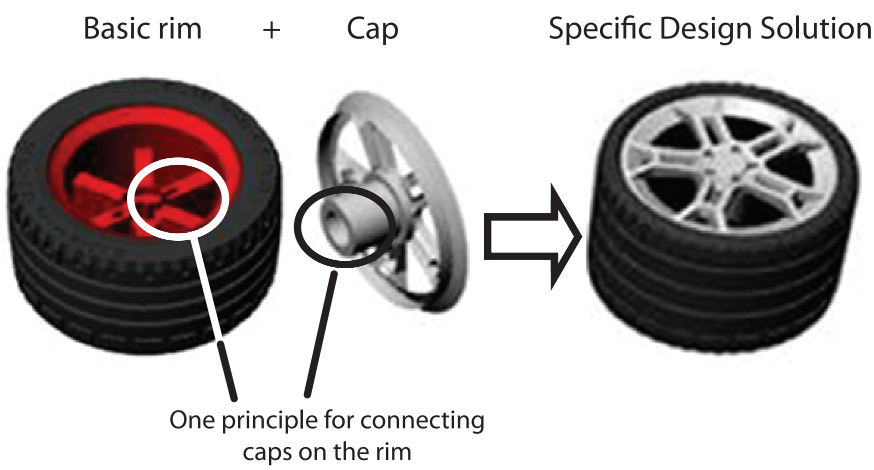


Figure 6.43: The wheel design, where a capsule can be added to the rim to style it.

Similarly the axels were standardized, only allowing five types.

Production equipment

The platform standards for rim circumference is utilized in the production equipment, where only three dimensions reduce the necessary tools

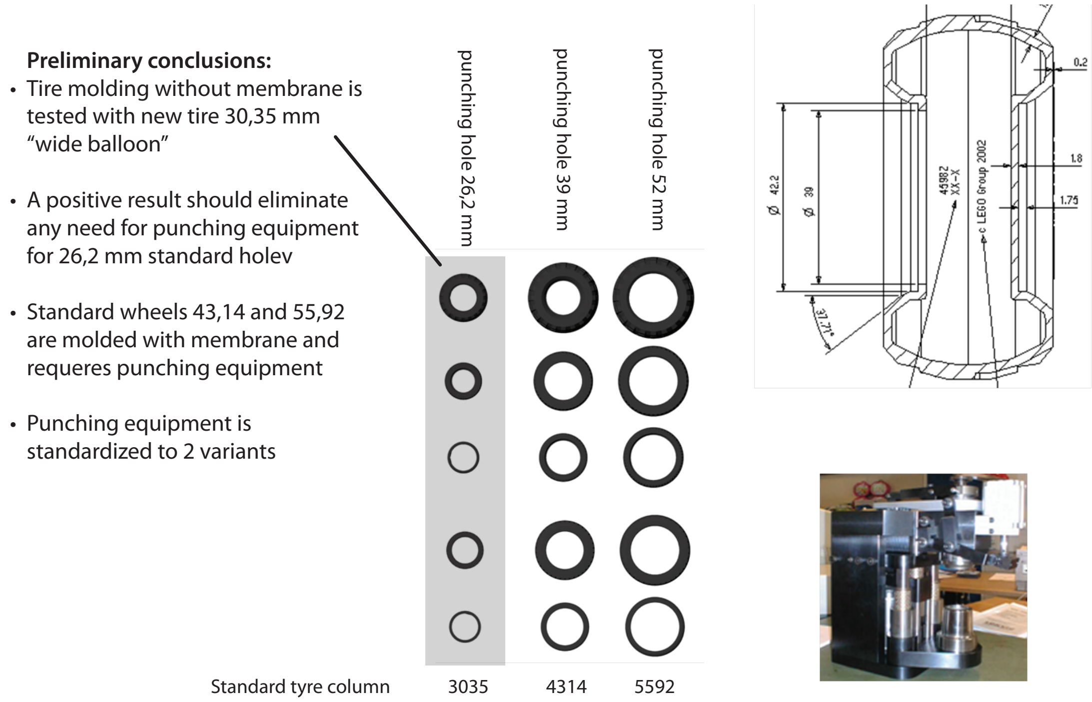


Figure 6.44: The new wheels designs were aligned with the production equipment, here by enabling use of the same punching equipment for making the holes in the wheels (LEGO material, slide from presentation)

Platform information system and calculation system

Practically all the product designers in LEGO are impacted by this platform, and hence many people have to be informed about how to use the platform, the arguments behind it and updated about changes. For this purpose an intranet page with information about the platform, its use and prerequisites was made. Different design scenarios (like the ones in Figure 6.45 below) were used to explain, when to use which elements, why and what the consequences were.

The platform elements were similar to the rest of the LEGO elements integrated in the LEGO building software tool and PDM- based calculation system. Furthermore the reduced production costs are reflected in the calculation system, where a number of wheels are cheaper compared to the previous alternative.

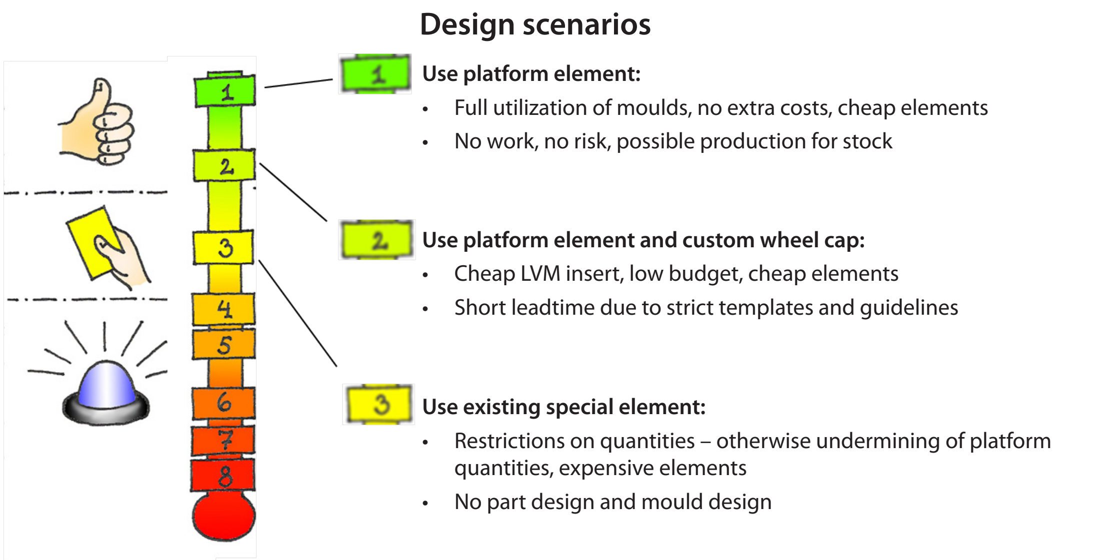


Figure 6.45: Example of how the use of the Wheels platform was explained in platform information material. Here are the cost levels illustrated and the consequences of each level are explained. (LEGO material, slide from presentation)

6.9.3 Platform effects

- The effects of the Wheels Platform were to
- Clean up in the wheels assortment and reduce the cost of having multiple different wheels elements
- Reduce continuous mould investments and in the number of existing moulds
- Reduction of cost for the individual element due to higher production volume

Having a high number of elements, where many did not provide any significant value from a customer viewpoint was costly both in terms of the handling in the LEGO PDM system, bounded investments in the many moulds and higher costs pr element due to low production volumes. Also a number of existing moulds that were not fully exhausted were scrapped to reduce complexity and avoid erosion of the platform.

By limiting the number of wheel elements, new wheel elements are only rarely introduced, and compared to the previous situation the size of the mould investments are dramatically reduced on that account.

6.9.4 Platform goals and performance

The goals for the Wheels platform were to reduce in the investment, that most of the wheels used in LEGO should belong to the platform and to keep the number of designs stable:

- Investments in moulds should be reduced to 60% after four years and continue on that level
- 90 % of the produced wheel should be within the platform frame, consisting of
- 42 types of different wheel, cap and rim designs

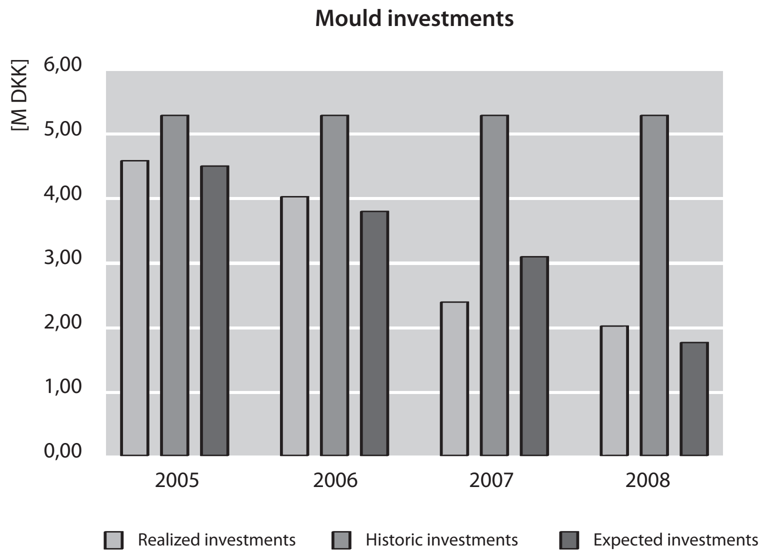


Figure 6.46: Mould investments of the Wheels Platform

The investment goal was very close to being met, the realized investments being below or slightly above the expected investments. Compared to the historic investments it is however clear that the level of investments have been lowered.

The goal of having 90% of the volume of wheel designs within the platform were almost met, see Table 6.5

Year	2006	2007	2008	2009
Total volume of wheel elements (mill.)	442	373	487	703
Volume of platform wheel elements (mill.)	392	337	430	632
Percentage of platform wheels – Target: 90%	89%	90%	88%	90%

Table 6.5: The production volume of all wheel designs and platform wheel designs

According to interview with the platform owner and the data from the PDM system, the goal of having 42 platform wheels was not completely met, because to new of wheel designs were added after a period of time, raising the number of designs from 42 to 44.

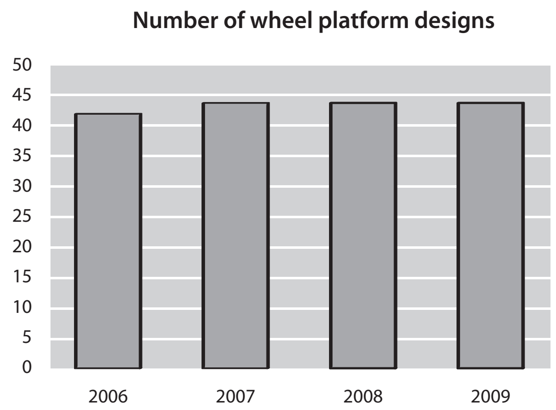


Figure 6.47: The number of Wheel Platform designs

Even though it changed the business case and the cost reductions, the extra wheels only comprise 5% of the total number of wheels, and hence the platform did still produce significant results.

6.9.5 Challenges and reasons for deviations

One challenge was that the wheels platform was not used as intended because the platform users did not understand and manage to apply the platform the way it was designed. Many more resources than expected was spend by the platform owners in Designlab to implement, discuss, adjust and inform about the platform and its updates. These processes had not been taken into account and it was surprisingly time consuming.

The platform was the first of its kind affecting the product developers and hence they saw the way it changed their work processes as a burden, and changing this work culture was an unforeseen challenge. The designers were not use to being limited in the way that the platform did, was not familiar with platform thinking and they encountered many problems with the platform, for a number of reasons:

- They thought that the platform elements compromised the quality of the products without offering any substantial benefits and hence considered it an unattractive trade off.
- They did not understand the rules for when the platform should be applied
- They saw it as an extra burden to adapt to the platform solutions and its requirements

All this caused that the platform wasn't used as intended and new elements were introduced on request from the designers. As one of the platform developers said:"Looking retrospectively at it, they (the designers) had not been enough involved in the process of defining the platform and the wheels".

The platform was however used, because it was clearly stated from management that it should be, but there was problems because the designers spent many of their own and the platform development teams resources on questioning the platform, its usefulness, why the specific wheels in the framework had been selected, what was introduced when and where the information could be found.

6.9.6 Platform development process

The analysis from the element platforms (previously described) was used to estimate the effects of the significant reduction in the number of wheels. These figures made a rough guideline for the effects of reducing the number of wheels.

Since similar projects had been started previously, experienced element design guides from Designlab had already a suggestion for potential candidates and design for the new wheels. This suggestion was used as starting point, and was use two ways:

- To show to the designers and representatives from manufacturing and supply chain and receive their input and

- To base the economical and financial calculations on.

The input from the designers were however limited, since the there was relatively few that participated in the introduction meetings, maybe because they did not understand the consequences of the platform on their own work and hence prioritized other tasks.

The number of wheel elements of the platform concept was made a future goal of the platform together with the goal of 90% of the volume of wheels should be within the platform elements. These goals were set to ensure that the beneficial effects would actually be achieved and should guide both product developers and platform owners in the future.

A challenge in platform-based product development is to ensure that old elements are phased out, when new are introduced, so that you don't end up with the double number of components instead of a reduction. Early in the process it was decided that something had to be done to ensure that the project did not end up in this state. Hence it was decided that some of the existing moulds, which were used very little, should be scrapped, despite that they were not exhausted. This meant that new investments for similar wheels, but adapted to the Wheel platforms guidelines, must be made. This was done to make a clean cut and reduce complexity and maintenance costs and ensure that the platform benefits weren't eroded. It was difficult to decide upon this issue but it was subject of discussion and still is.

The foundation for this decision was a thorough economical analysis of historic data on previous moulds, showing the cost of having this high number of mould that justified the scrapping of the un-exhausted moulds together with the risk of platform erosion.

The management were very focused on the economic figures, and it was a long and iterative process to develop a fair presentation of the platform, highlighting the most likely scenarios and the quantifying of the benefits that the previous analysis had not shown.

The platform project encountered a rather long implementation process, phasing out elements and introducing new ones, which had to be planned and coordinated with the various products. The detailed tactic for phasing out elements was made to handle this process.

As mentioned above in the description of challenges and reasons for deviations, the implementation process encountered some challenges that had to be addressed. Besides the introduction of additional elements, the platform introduction was followed up by a project trying to develop support for the product designers' use of the platform. Even though the platform team had addressed these issues making information about the platform and e.g. had made an FAQ and explicit design scenarios, it was not covering the need for information and support, which had to be handled in a separate process afterwards..

Summarizing the Wheels Platform

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Wheels (spring 2005) 	A collection of generic wheels based on a pre-set no. Of rims Caps used for variance. 90 % of the wheels volume in LEGO must be platform wheels.	50% reduction of wheel types and reduced investments in moulds that optimise reuse of production equipment.	★★	Making the product developers use the platform elements, understand the platform possibilities and update. No benefit for user and undesired trade off. Complex extra burden for product developers to use platforms.

6.10 Pre-Pack Platform

6.10.1 Platform background

In the search for areas to rationalize and reuse, it was identified that a number of LEGOs products had a very similar content, see Figure 6.48, and that this could be utilized in some way. This platform and how it was modelled is also described by Munk & Mortensen, [2006].

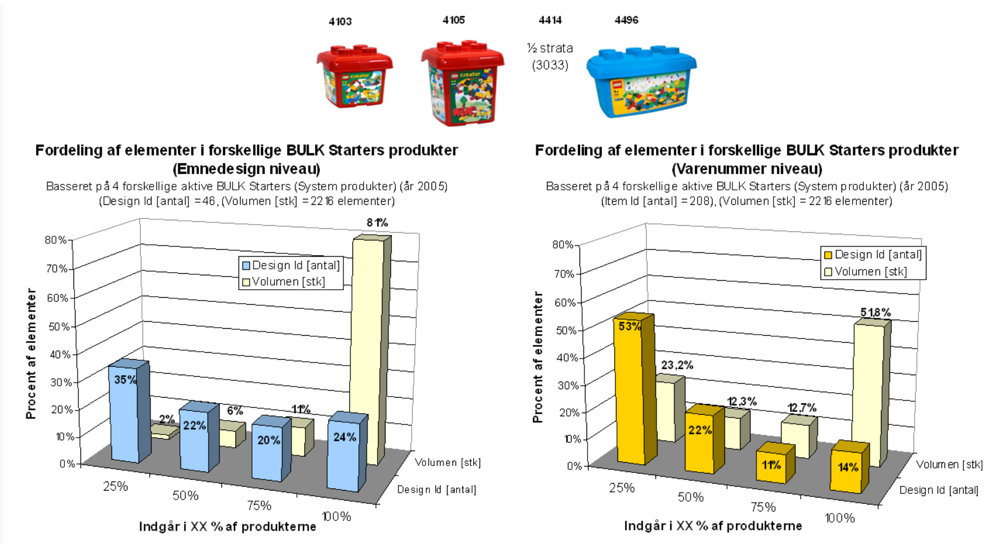


Figure 6.48: Slide from the development process showing how many LEGO elements that are in the same products

6.10.2 Platform description

The Pre-pack platform covers aprox.16 products, where 6 products were introduced and 6 products were phased out every year. Each product consists of a number of pre-packed bags with bricks. The Pre-pack platform consist of

- A number of pre-defined pre-packed bags
- Guidelines and goals for how and when these bags must be used
- Modelling and tracking tools for the product development and production process

Prepacked bags

The core of the Pre-pack platform are the standard bags, containing different combinations of elements, in different sizes, types and colors, see example in Figure 6.49. Based on these different bags it is possible to develop or configure major part of the products in the product family very fast and then add the extra elements that make the different products unique.

Figure 6.49: Example of a Prepack Bag

Instead of having 16 products that on average contains 2-6 different bags, i.e. 59 different bags, the same 16 products can be made with only 24 because 6 standard bags provides 80% of the contents, as illustrated in Figure 6.50 below.

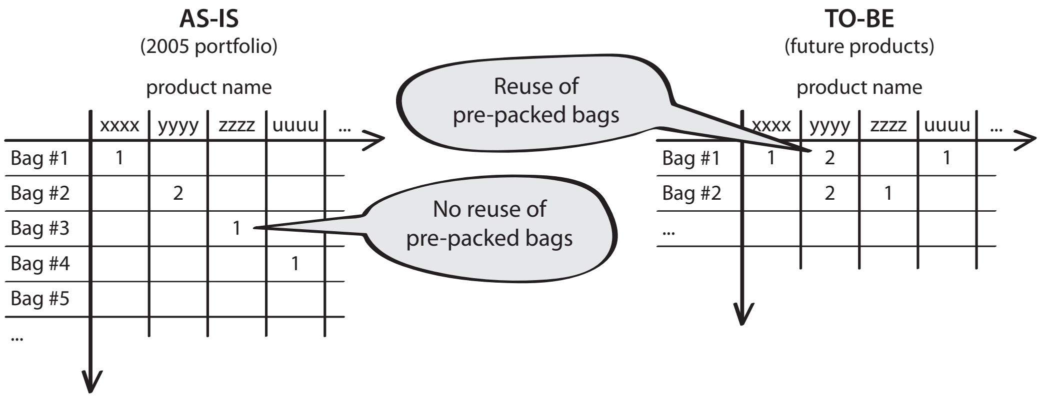


Figure 6.50: The platform and the standard bags make it possible to configure the various products from a few bags.

Processes and guidelines

The introduction of the platform meant that the product development task must be performed differently: Now the entire range of products is considered simultaneously and is committed to meet the platform goals. The development and selection of which standard bags that were realized is also addressed (see Figure 6.51). The standard bags are accompanied by a set of guidelines for how they can be used, and they have new aspects the product development process and as well as in the production planning and production process. Also in the production planning, the demand for the standard bags must be considered across products to register the total demand, and not only on individual product level, as done previously. This way the production level can be regulated towards the demand and produced in low season.

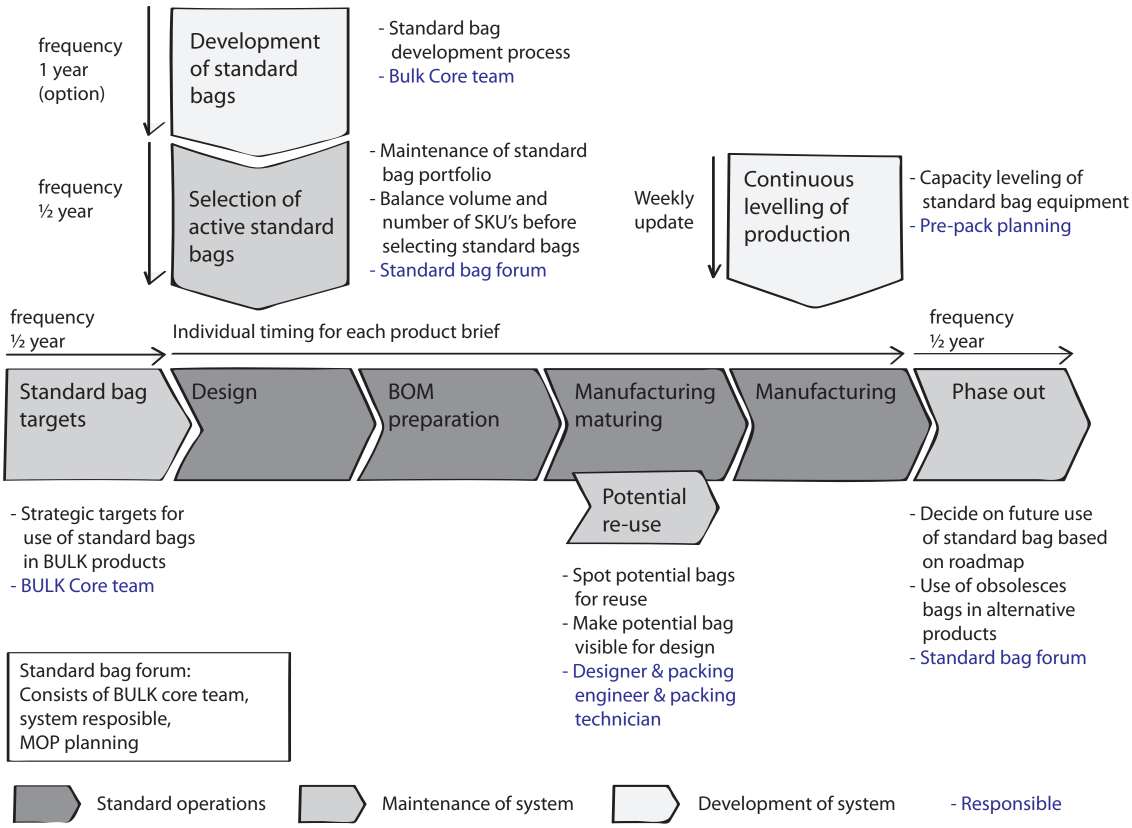


Figure 6.51: The development of new work processes was both necessary in the product development (design) phase and in the production (manufacturing phase)

Tools

The new aspects in the development and product planning process required an overview that was not provided with the existing tools. Hence there was developed two tools supporting these processes. The bag configurator (see Figure 6.52) support the product development by making quick product concepts based on standard bags. The configurator presents relevant data of price, no and colours of elements and the product developer can evaluate how good a solution it is.

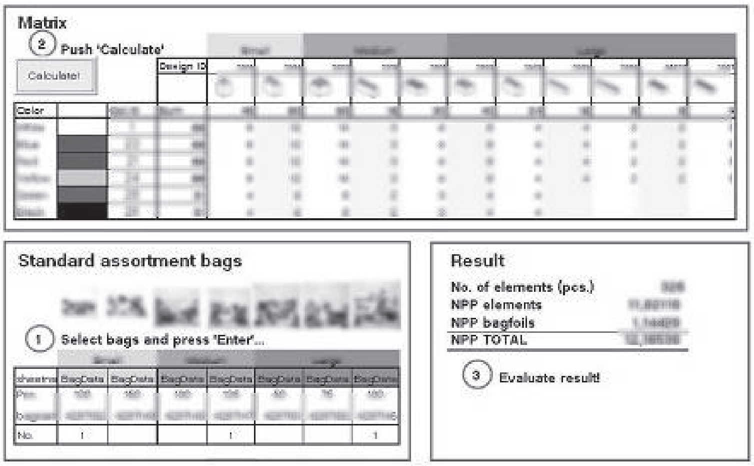
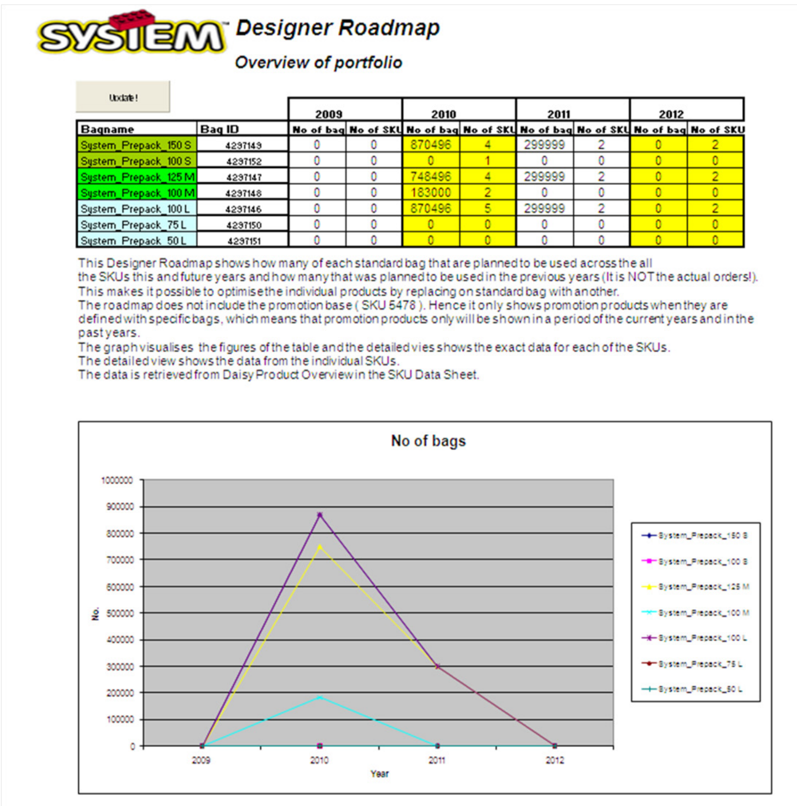


Figure 6.52: Screenshot of the modelling tool shows the current price and coverage of the selected parameters "design" and "colours" with a combination of module standard bags and their price (Blurred on request from LEGO Group).

Another platform tool was introduced in the production planning, showing the forecasts of the different standard bags across, so that the production planning knew the total demand across time and could produce 80% of the bags and optimize based on those orders.



SYSTEM Designer Roadmap

Overview of portfolio

Update!

		2009		2010		2011		2012	
Bagname	Bag ID	No of bag	No of SKU	No of bag	No of SKU	No of bag	No of SKU	No of bag	No of SKU
System_Prepack_150 S	4297149	0	0	870496	4	299999	2	0	2
System_Prepack_100 S	4297152	0	0	0	1	0	0	0	0
System_Prepack_125 M	4297147	0	0	748496	4	299999	2	0	2
System_Prepack_100 M	4297148	0	0	183000	2	0	0	0	0
System_Prepack_100 L	4297146	0	0	870496	5	299999	2	0	2
System_Prepack_75 L	4297150	0	0	0	0	0	0	0	0
System_Prepack_50 L	4297151	0	0	0	0	0	0	0	0

This Designer Roadmap shows how many of each standard bag that are planned to be used across the all the SKUs this and future years and how many that was planned to be used in the previous years (It is NOT the actual orders!).
This makes it possible to optimise the individual products by replacing on standard bag with another.
The roadmap does not include the promotion base (SKU 5478). Hence it only shows promotion products when they are defined with specific bags, which means that promotion products only will be shown in a period of the current years and in the past years.
The graph visualises the figures of the table and the detailed vies shows the exact data for each of the SKUs.
The detailed view shows the data from the individual SKUs.
The data is retrieved from Daisy Product Overview in the SKU Data Sheet.

Figure 6.53: The tool used in production planning to see the forecast of the different types of prepacked. This is similar to the roadmaps used in other platform projects.

6.10.3 Platform effects

The main effects of the Pre-pack Platform was

- Reduced development time (app. 25%)
- Reduced risk because of the distribution of bags over products and time
- Reduced production cost due to low season production and economy of scale

The use of standard bags in the product development frees resources from checking, gathering and set up the bags in the system. The reductions in the productions cost are due to the major sales peak around Christmas in LEGO. It is very difficult to predict the market, so in general they try to postpone the production as much as possible to avoid obsolete goods, This makes the production scheme very busy, and a large amount of money is spend on temporary workers in that period. Having the same bags in 16 products makes it much less risky to produce to stock, and hence it can be planned to be produced in optimal batch size and in off peak periods, saving the expenses for extra workforce, which is a major expense.

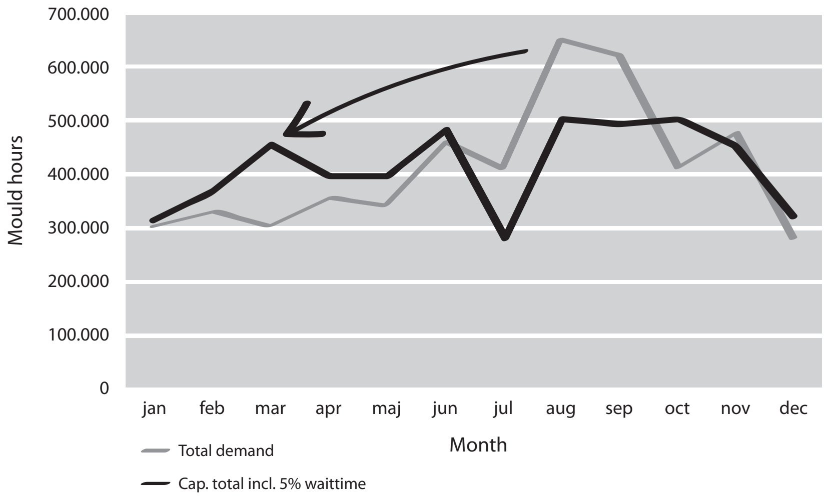


Figure 6.54: The reuse of standard bags makes it possible to level out production peaks with minimum risk.

6.10.4 Platform goals and performance

The goal of the platform was to base in average 60 % of the content of 16 products on the common bags and to keep the types of bags on the same low level, half of the original level. Based on statements from the platform owner and data from the PDM system from the years 2006-8 (Figure 6.55), it can be confirmed that the platform goal was met:

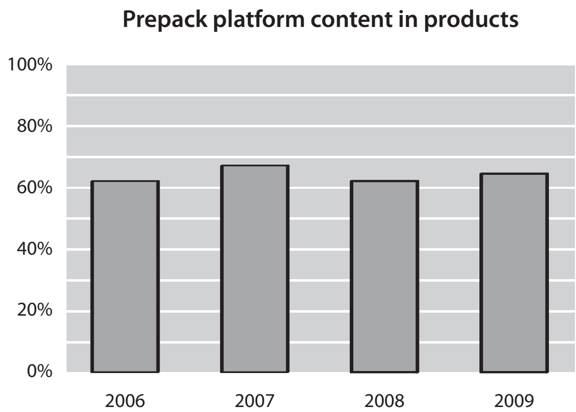


Figure 6.55: The goal of a 60% reuse level in the product was met in the period from 2006-10.

On top on meeting its goal, the platform pre-packed bags were used in 6-9 extra products besides the 16, which was intended.

Reaching the goal has resulted in :

- Reduction of the no of bags with 50%, hereby reducing product development time with 25 % compared to the previous years
- to reduce production costs with 50 % and production hours significantly due to bigger production orders and low season production 80 % of the bags
- No investments were needed to implement the platform, and the only expense for the platform was the development costs.

6.10.5 Challenges and reasons for deviations

Since the platform met its goal, there are no reasons for deviations. Despite this result there have been some challenging issues like the fact that the calculation and data system do not support platform and cannot show the economical advantages of the pre-packed bags. As it is the platform solution reduces the workload from designers, it is beneficial for them to use it, but only relying on the knowledge and goodwill of the designers is a very vulnerable situation.

Another challenge was that the production planning department was involved rather lately in the platform development process, ant this caused some unexpected problems, because the platform solution didn't fit the work procedures of this department. The issue was resolved by developing support tools and change some work procedures in the production planning.

6.10.6 Platform development process

The development process started out with an analysis of the potential products of the platform, and how many elements were common for the different products. In the early phases of the project alternative conceptual packing solutions and equipment were considered, but due to the necessary investments and LEGO's financial situation the starting point was to exploit existing production equipment. Three reuse solution concepts were identified, and then the effects of each solution were considered, see Figure 6.56.

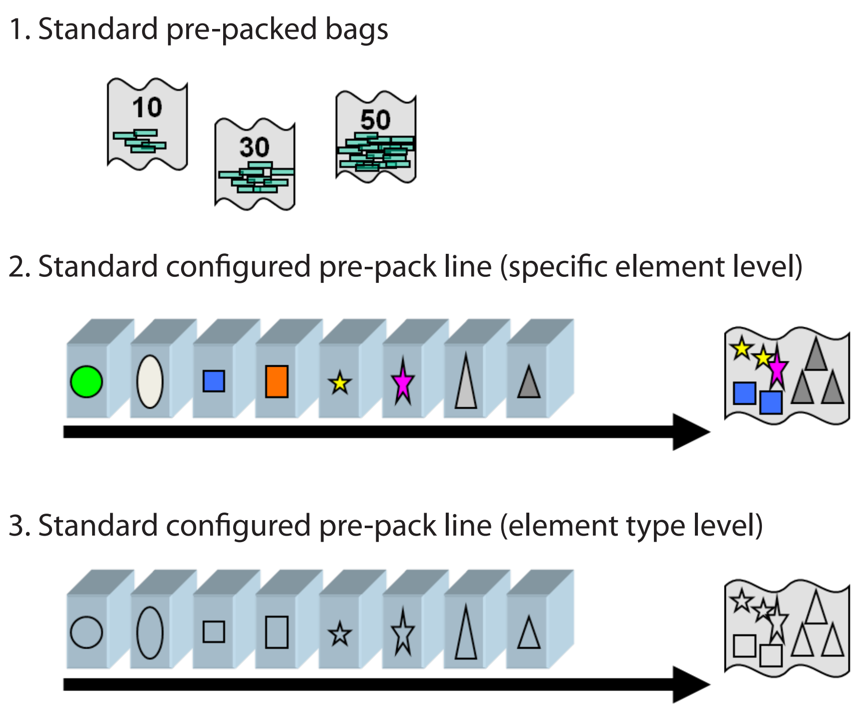


Figure 6.56: The three concept solutions, each exploiting that there are common elements in many of products. The first one was chosen, due to the possibilities of producing to stock in low season. The other solutions are based on dedicated equipment, where various specific elements (2) or types of elements (3) can be combined into a bag.

The effects of concepts platform were identified via representatives in the cross-functional project team, including product designers, packaging planners, manufacturing engineers, packaging production planners and financial representatives. This study of the effects revealed that the most significant effect was the cost reduction with low season production. This directed the further development of the project, which was then focused on the development of standard bags. The challenge of this was to make the optimal combination of bricks in the module bags – the grouping of the bricks in bags that would give highest degree of reuse across the products to exploit it in the production - and still meet the requirement of variance for the individual product.

Rough concepts for bags were made by experience product designers and alternative combinations of bags were evaluated based on product concepts and their production fit and cost. The different product concepts were refined and were introduced the year after. These product concepts were used to specify the approximate goal for future products of a 60% reuse level, which received commitment from the experience product developers. Based on this reuse level the expected effects were calculated.

Summarizing the Pre-pack platform

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Pre-pack Platform (spring 2005) 	Pre-packed bags with common elements. 60% reused product content within product family.	50 % reduction of bag types within product line Reduced production costs and time saved for product development and production.	★★★	Calculation and data system do not support platform. Including production planning department at a late stage in the platform development process.

6.11 Decoration Five Star

6.11.1 Platform background

The Decoration Five Star Platform was initiated to accommodate the variety in the decoration of the LEGO elements. A huge equipment park was the result of previous year purchase of dedicated equipment for the products that were no longer in production. The picture below shows one of the many pieces of dedicated equipment and how it was described and analysed with benefits and drawbacks as part of the preliminary process for the development of the decoration platform.

Figure 6.57: An example of one of the dedicated equipments that LEGO had several of.

Many of the machines were too specific to be reused for new products and had often been dimensioned for the peak demand, meaning that these rather big investments were bad business.

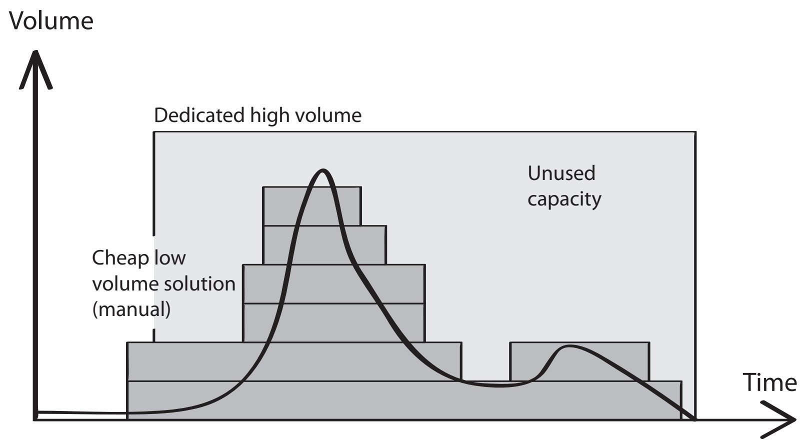


Figure 6.58: The need of decorated elements (the red line) can be meet in different ways: With one piece of dedicated high volume equipment (as the blue square indicates) or with many pieces of flexible low volume equipment.

The idea was to develop semi-automatic machinery that was more flexible and adjustable and capable of handling most of the different elements that should be decorated in opposition to previous equipment that was designed for one specific element or decoration (see Figure 6.58 above).

Automation level 1	WHAT -	This level is a manual decoration equipment
	WHY -	This level will fit to low cost countries Easy to train new operators Low start up cost Possibly to get within 3 months Low volume < 1.000.000 pcs.
Automation level 2	WHAT -	This level is a manual decoration equipment with a pick and place module
	WHY -	This level willl fit to low and higher cost countries Easy to train new operators Possibly to get within 3 months Medium volume 1.000.000 pcs. < 2.000.000 pcs.
Automation level 3	WHAT -	This level is a more automate operation equipment with a pick and place module
	WHY -	This level will fit low and higher cost countries Medium volume 2.000.000 pcs. < 4.000.000 pcs.
Automation level 4	WHAT -	This level is a automated decoration equipment
	WHY -	This level will fit to lower and higher cost countries High volume 4.000.000 pcs. < 20.000.000 pcs.
Dedicated equipment	WHAT -	This level is a fully automated equipment
	WHY -	This level will fit to high cost countries High volume > 20.000.000 pcs.

Figure 6.59: The five different levels of production equipment that supports different production volumes with assigned equipment

With five levels for different volumes it is automatically decided which equipment an element must be decorated on (see Figure 6.59). It is also part of the strategy, that elements can be easily transferred and decorated at LEGOs production facilities abroad, enabling test setup and specification in Denmark and upscale of production (possible manually) elsewhere.

6.11.2 Platform description

The Five star decoration platforms consists of basic pieces of production equipment and a common software that makes it possible to combine many pieces of equipment and easily specify and test the production process

Standard equipment with same interface

The standard equipment consists of a printer, with five colours and a roundtable that has eight stations. Each of these stations can have a function attached. Standardized solutions for the most common functions e g. feeder module, two or one sided decoration module with various numbers of colors, laser module, laser module, safety testing, drying and fixation, have been made, so that the equipment can quickly be adjusted to fit specific solutions. The roundtable can also be connected to moulding equipment, reducing the two processes to one.

Standardised software

An important part of the platform solution is the common software that enables the same programming on all the equipment and presents the data in the operation phase the same way. The software has a common interface for all pieces of equipment which also eases the process for both production process designers and operators.

So far six pieces of equipment operate in LEGO – one in Denmark where the production process is specified and five in a production site in the Czech Republic, where the production volume can be increased with manual labour. The modules can be combined freely due to the standard setup and the common software, which also eases the setup time and operation process

6.11.3 Platform effects

The main effects of the Decoration Fivestar Platform are

- Less investments in decoration production equipment
- Flexible equipment that eases up and downscaling production volume
- Shortened development time for the production equipment
- Shortened production process design time and setup time in production

The smaller investment is over a long term period, because to introduce the platform, significant investments has been made in the roundtable equipment. The flexible equipment requires a rather big one time investment, but also mean that less investment should be made in new equipment the following years.

The time it previously took to development or ordering of specific production equipment has also been decreased, since it only takes time to develop the add on solutions, and not the entire equipment. Similarly it also reduces the time it takes to specify the production process and the setup in the production benefit from the experience with the same type of equipment.

6.11.4 Platform goals and performance, challenges and reasons for deviations

The platform did not have any specific goals, but was established in expectation of a future reduction of investments in decoration equipment.

The new decoration platform equipment has meant an extra investment in the start up phase, but has made it possible to save approximately 30 % on investment the following years, which means that payback time has been 2-3 years.

The platform is however not being used as must as it was the expected. The reason for this deviation is that the product designers still choose parameters that require the old equipment, mainly due to lack of knowledge of the existence of the new platform, its parameters and possibility of providing relatively cheap decorations. Hence the platform has actually been providing excess capacity, meaning that the investments were not utilized as intended, and the platform did not meet all of its expected effects.

6.11.5 Platform development process

The decoration platform has similar to the wheels platform been the subject of more unsuccessful attempts, but the previous projects however had made useful analysis on which the final project could build upon. Studies were made of historic elements and their decorations and what the requirements for equipment that should support this should be. Multiple data was gathered and analysed. Figure 6.60 below shows how the existing equipment covers the parameters of size of decoration and output level. Each piece of equipment is represented by a colored square. The figure illustrates also how difficult it can be to make meaningful representations of complex problems, which are often present in product platform development: Looking at the figure it appears that there are many types of production equipment that covers the same area, but the fact is that these different types of equipment cannot replace each other anyway, because there is a number of critical factors, which are not represented in this model.

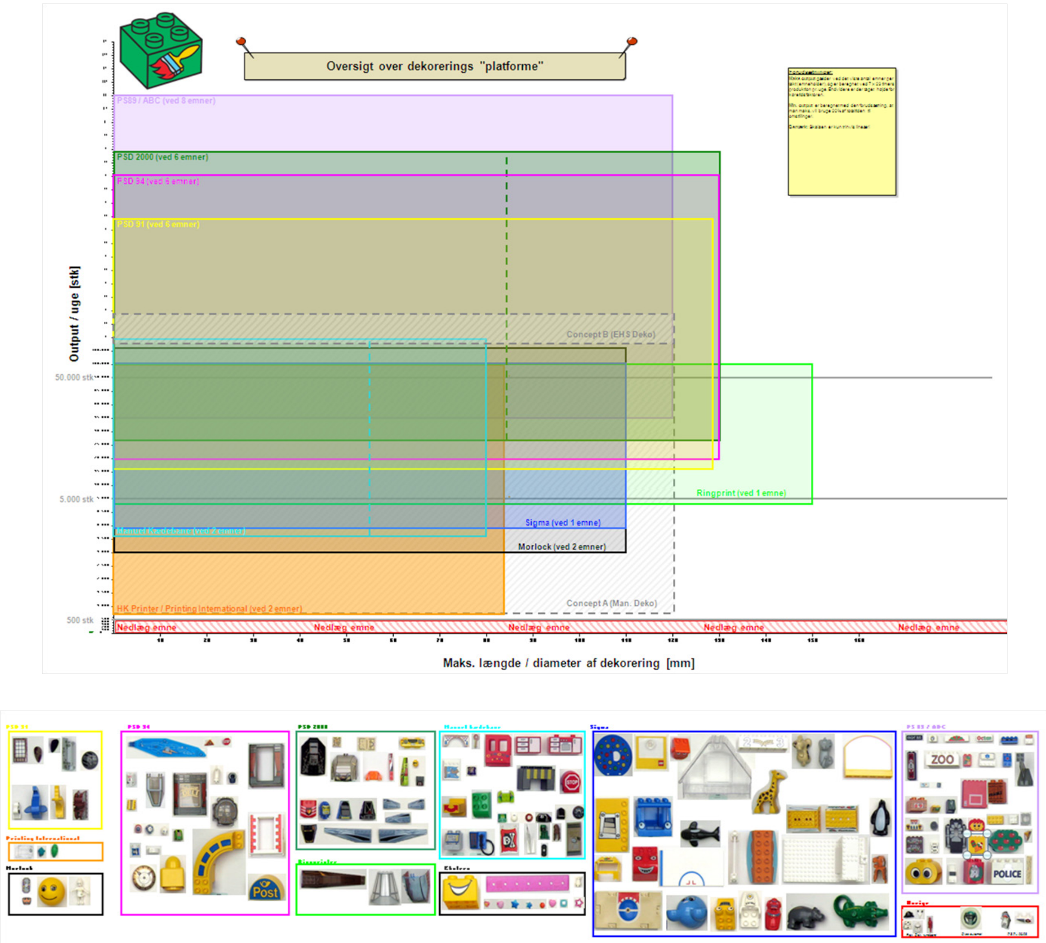
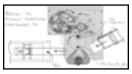


Figure 6.60: Visual representation of production volume and decoration size of the different pieces of decoration equipment in LEGO. Below are different examples on elements that belong to each group.

These studies were rather intensive, but did not result in any substantial decisions about how to develop the platform, possibly due to lack of a clear idea of what a decoration equipment platform should actually support and a concept for how it should be done.

However after a period of time a second project was initiated, where a more limited focus for the platform requirements was specified, aiming at the above semiautomatic solution, based on a piece of equipment that was already working in the production. This equipment was made the basis for future equipment standardisation, because it was relatively cheap, flexible and hence considered a safe investment. The effects were identified based on input from experienced production equipment designers and procurement workers. The effects were however not quantified or translated into specific goals, only the required investments were quantified.

Summarizing Decoration Five Star Platform

Platform name and implementation year	Reuse assets, rules, and goals	Expected effect	Performance 06-08	Challenges and reasons for deviations
Decoration Five star (2006) 	Decoration printing equipment with flexible function modules and interface to moulding equipment. Print has max size. No specific goals.	Reduced equipment investment and equipment flexibility for varying product volume.	★★	Make the designers aware of this possibility.

Part 7
Analyzing and concluding on the LEGO platforms

This chapter analyzes the LEGO platform cases in order to answer the research questions about the process of identifying and estimating platform effects, platform performance and the reasons for deviations between expected and achieved effects. Suggestions addressing these reasons are made together with general recommendations for platform-based product development. Finally I introduce an overview model, a framework describing platform-based development as a system with a flow of elements and activities.

7.1 Identifying and estimating effects

Based on the cases from LEGO I now seek to answer the research question:

RQ1: How can a process of identifying and estimating internal effects of product platforms be described?

This is relevant to know how the estimates are made and what effort have made to make them viable to put the platform performance into perspective. To answer this question a descriptive model has been developed consulting platform developers in LEGO, incorporating the findings from the platform cases. The descriptive model is then compared to the models and methods described in literature. Finally the general approach to effects and goals in relation to platforms are discussed.

7.1.1 Descriptive process model: Identifying and estimating internal effects

To generalize on how well the effects have been achieved in the LEGO platform cases, a descriptive model for the process of identifying and estimating internal platform effects has been established. The process is a generalized union of the processes for the individual platforms. In the text below it is described, when the platforms varied from or was unsuccessful with the described process. This process occurs during the platform development phase, and hence the platform utilization phase is not included in this model.

It is a simplified model that generalizes on the many aspects of the development process and must be applied as such. It aims to improve the understanding of how different the platform development team and representatives from different life phase systems are involved in the identification and estimation of effects and specification of goals. The model consists of four phases and refers to the results and input and output of the different phases as "working objects". Within each phase the "working objects" are described. Working objects includes the ideas, concepts, analysis, estimates or conclusions that are continuously being modified according to new input, if necessary. The team members and other involved persons are referred to as "producers", because they produce these working objects, providing and analyzing information.

The model describes the phases in the platform development of the project from the point of where the project has been initiated and established with a team until the implementation and delivery to a platform owner and the evaluation in a post-development phase. The description focus on the effects and goals and hence many aspects of the platform development process has not been included and the model cannot be used as a platform development model as such.

The process has four phases:

- First phase: Concretizing the platform idea and analyzing effects of status quo
- Second phase: Identifying effects from life phase systems
- Third phase: Estimating and quantifying effects from scenarios, specifying goals and adjustments
- Post-development phase: Goal evaluation and revision

Each step in the model is supported by examples from the cases, underlining the description.

The model with phases, the major working objects and producers are depicted in Figure 7.1.

The process changes focus: In the early phases (1,2, and partly 3) alternative the platforms are investigated to discover the different possibilities regarding platform assets and their technology and the effects estimated, presented in business cases, as described in the process of identification of effects and specification of goals. Later the focus turns toward an understanding of the platform as an organisational system. The more operational aspects of the platform is designed (i.e. the platform system), specifying the processes (e.g. use, maintenance, tracking) and tools that enables this (e.g. guidelines, goals, presentation of platform assets, architecture and modules), altogether the platform system, that will ensure that the platform-based product development is actually realized in products. Hence the focus on identifying and estimating the effects is naturally first and subsequently the specification of goals later in the process.

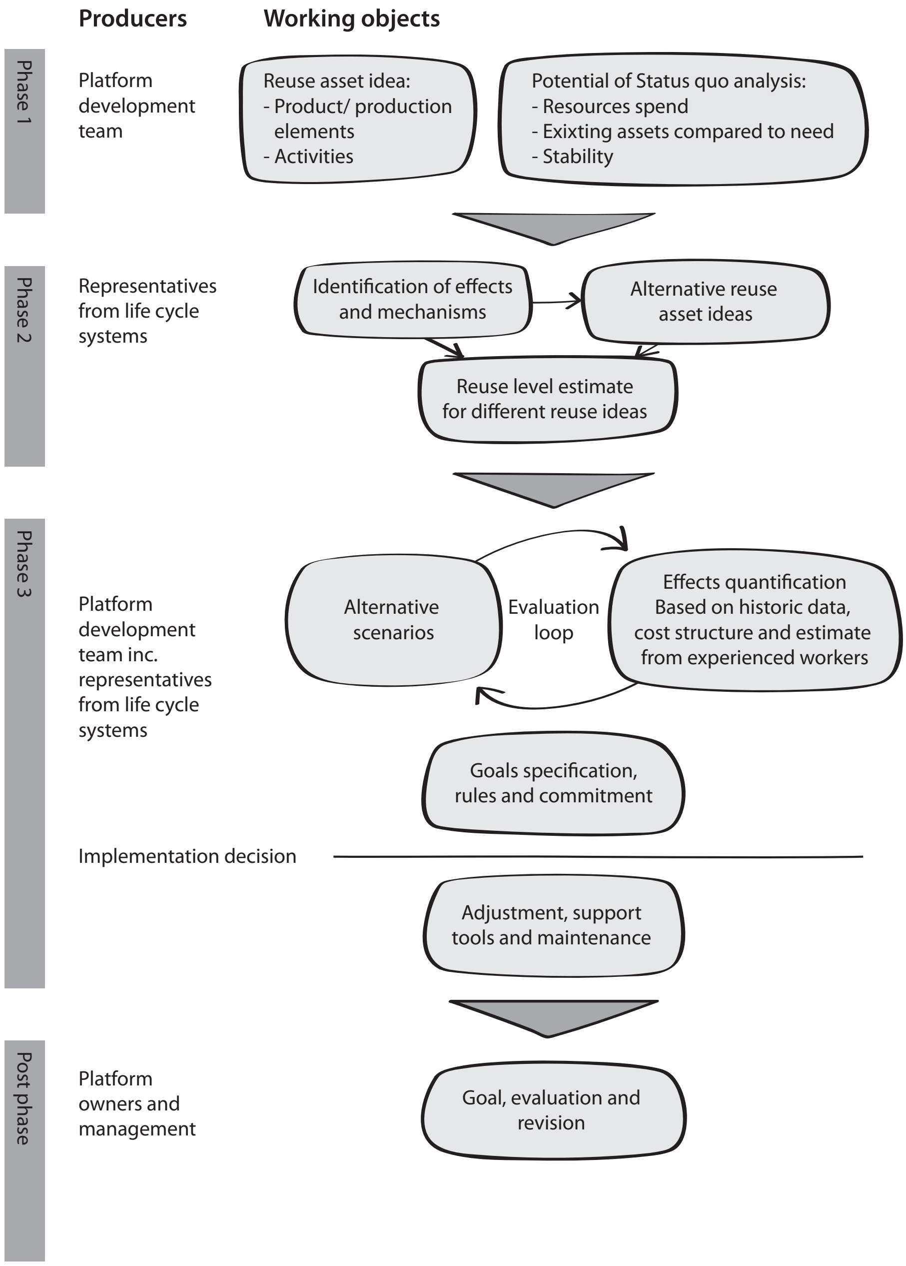


Figure 7.1: The model describing the process of identifying and estimating platform effects.

First phase: Status quo analysis and development of platform idea

In the first phase of the process of identifying effects and specifying goals, a platform development team has been assigned to the project. Their starting point is either or in some cases both

- An idea of potential reuse of an asset in specific department.
  This idea is in first phase made more concrete in terms of design concepts, and it is clarified if there are critical aspects that prevent it from being realizable.
- An analysis of the status quo of a specific area or product group, looking at e.g.:
  - The need, e.i. the historic distribution of products or elements with a certain characteristic, and the stability of it.
  - Resources spent (cost, investments, time) and how they are distributed.
  - Existing assets coverage on critical parameters.

Figure 7.2 is an example of how the need for a certain solution was illustrated, here from the analysis in the development of the Low Volume Mould platform, showing how many of moulds that could benefit from the platform.

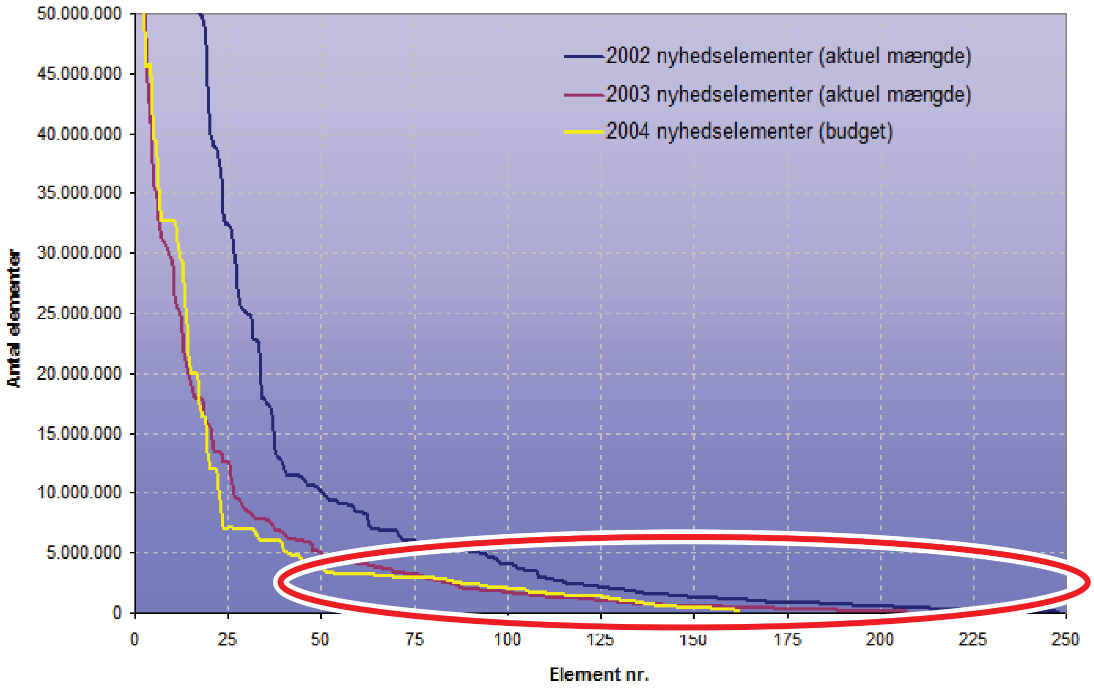


Figure 7.2: Distribution of the volume for the different elements in LEGO. The potential Low Volume Moulds are within the red circle. From the project documents of the Low Volume platform project

Another example of how the status quo situation was described is from the Five Star Decoration platform, where the capability in terms of production capacity and decoration size of existing decoration equipment in terms of was visualized in the diagram in Figure 7.3. This shows how many different types of equipment, which potentially could be reduced, that covers the same area of stabile parameters,

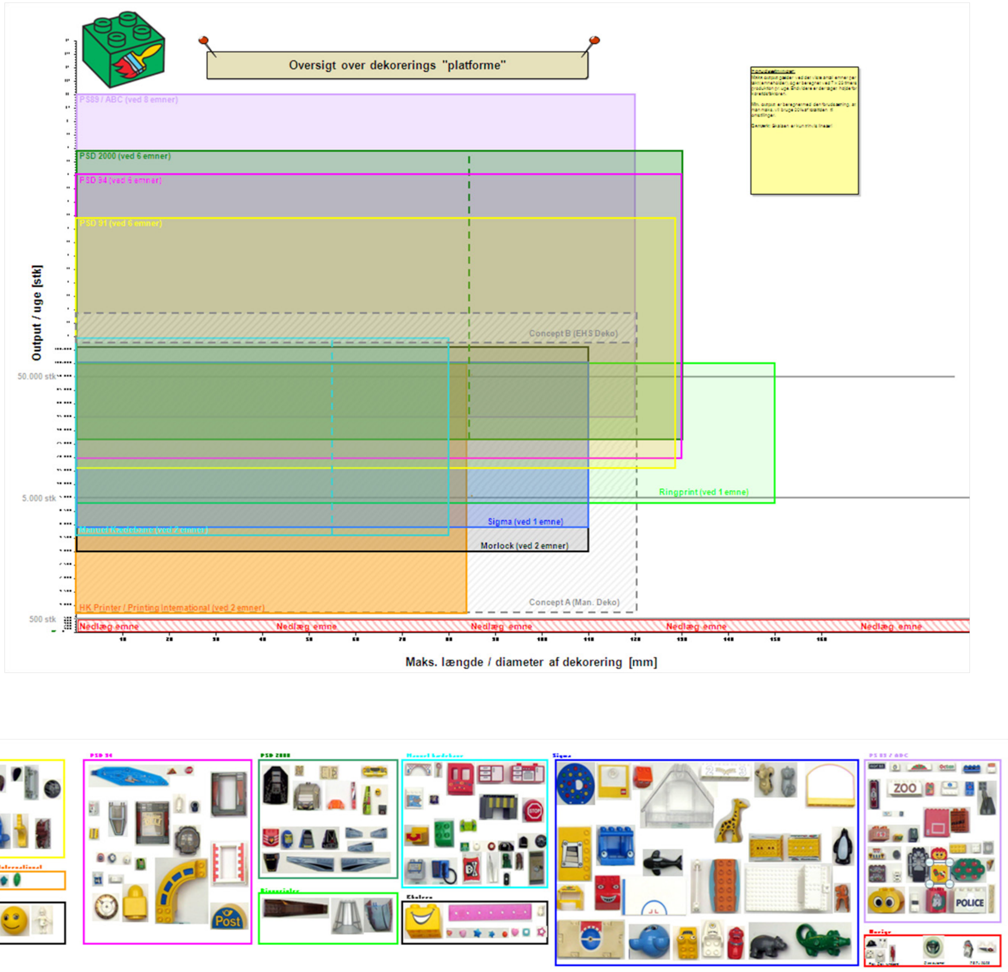


Figure 7.3: The capacity (output/week) in relation to the size of the decoration shown for the different decoration equipments in LEGO, color codes referring to the examples of elements shown in the top

The economical analysis from the development of the can platform is an example of how resources are spent within a certain area. In this case the analysis showed that the potential of improvement for the platform was smaller than expected, simply because the relative size of the resources spent on can packaging equipment was smaller than anticipated. The analysis is part of a Product Family Master Plan (PFMP) made as a status quo analysis for the LEGO Cans, shown in the figure below. The PFMP is a modeling tool, showing a product family, the different components and their variance (and to some extent the consequences) from the view point of marketing, product development and production/supply chain [Mortensen, 2000].

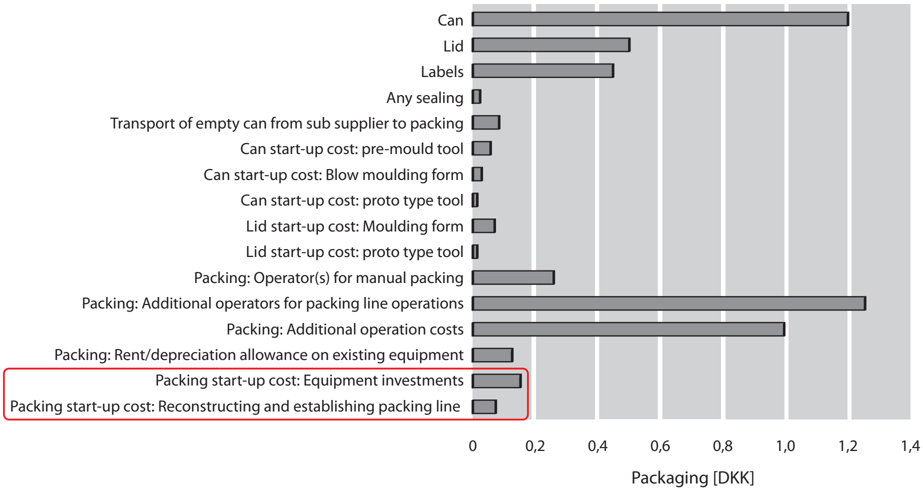


Figure 7.4: Average distribution of cost of cans and the packaging process. The red line marks the cost of the can platform target area.

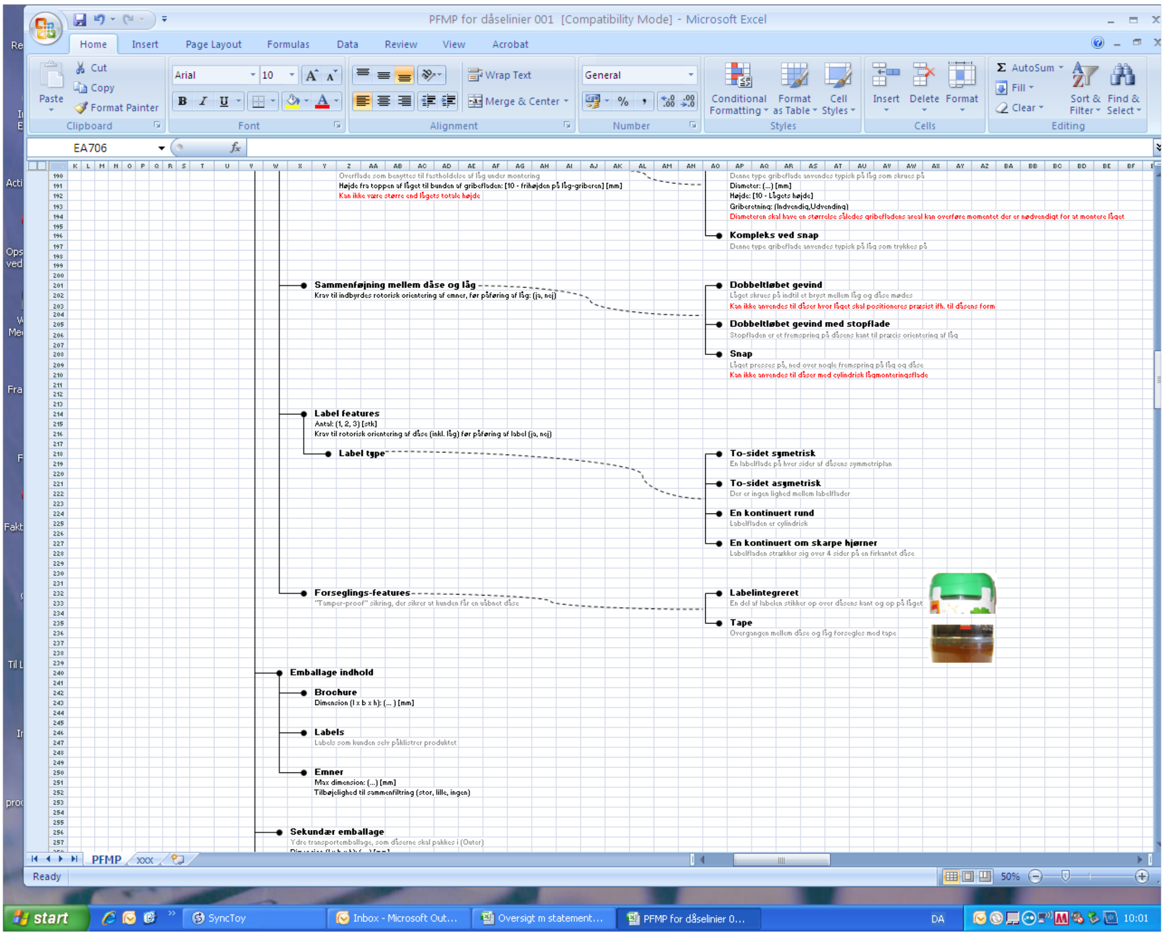


Figure 7.5: The Product Family Master Plan (PFMP) for the LEGO cans (LEGO Group, 2004).

In most of the platform cases there has been a thorough approach to the data that was relevant for the platforms. Even though LEGO has substantial data on their products and production processes, it is a challenge to do the relevant data mining in the databases: both getting the data, getting the right and relevant data and interpret it in a sensible way is a challenging task. Different stakeholders interpret the same data in different ways and have different understandings of what is cause and effect. The different explanations have to be tested, before the conclusions are drawn, and some aspects will more be a matter of belief that cannot be quantified. In that case it is often up to management to decide whether the platform should be realized or not.

Second phase: Identification of effects and alternative platform ideas

In the second phase a search for effects or related reuse ideas is made across the different life phase systems. This is usually done by introducing the concrete reuse idea and possible the results from the analysis to other representatives from other departments or life phase system, using the terminology from Theory of dispositions. These department representatives include:

- Product developers from different product segments
- Technical specialists
- Financial and logistics analysts
- Supply chain, sourcing and procurement representatives
- Manufacturing designers
- Production planners and worker
- It system workers

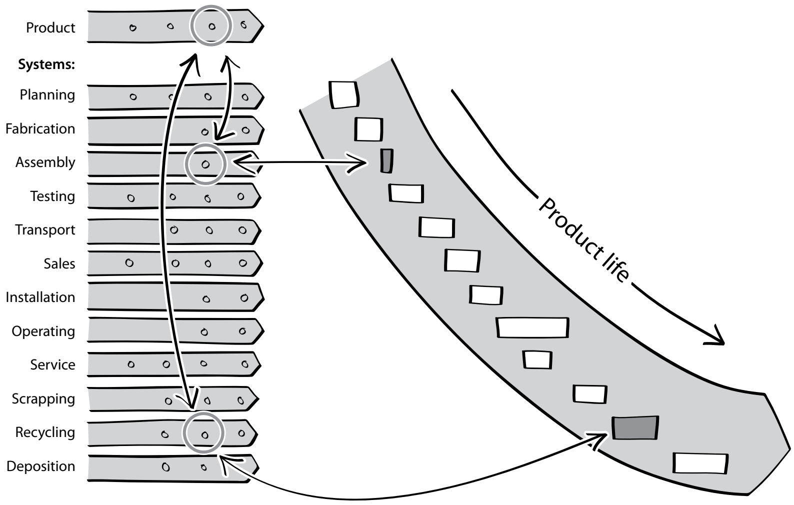


Figure 7.6: Like the Theory of Dispositions illustrate how there are different effects of a product design in the various life phases, the same goes for a product platform.

The platform idea was presented for different life phase system representatives, so that they could identify the potential effects and influence platform characteristics, and also to identify other possible solutions or modifications that could enable beneficial reuse. This corresponds with the Theory of Dispositions, and in the above figure the platform solution has replaced the product, and is in similar way being aligned with the different life phase systems to achieve specific effects.

Concrete, specific and viable ideas for reuse assets were the best starting point for making the identification of effects. Some specified characteristics of solution made it possible for the representatives relate it to their own work and describe which and what affect it would have. It was an advantage when the representatives were capable of explaining the mechanism instead of just the referring to the sole effect. It is however important to "open" the representatives mind so that they come up with suggestions and don't only see limitations of the suggested platform. Figure 7.7 shows an example from the Pre-pack platform of the effects that were identified by the representatives from the life phase systems.

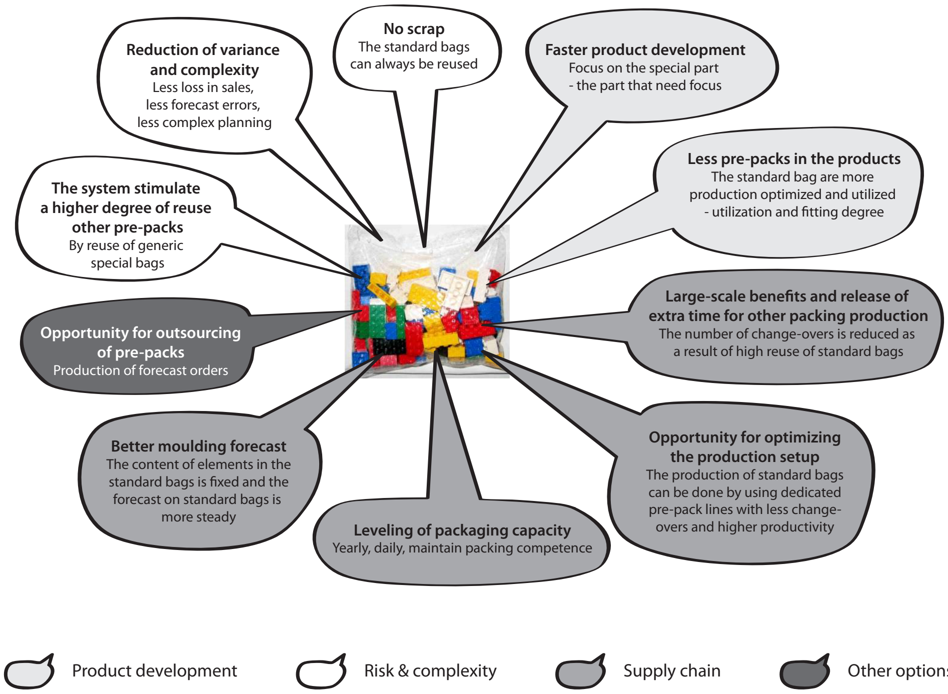


Figure 7.7: Example from the development process of the Pre-pack platform: Overview of the effects, that had been identified by representatives from various departments. Remove GCC innovation

The presentation of the concept could provoke other ideas or ideas that improved or modified the solution, making it possible to achieve even bigger effects. In many of the cases reuse ideas had been considered by experienced or champion employees before, but they hadn't had the resources to investigate the potential of this solution. The representatives were also often asked to make an estimate for a given idea to which degree a solution could be reused (e.g. in 30 % of the products) to get an impression of the potential.

Third phase: Platform scenarios, effects estimation and goals specification

In the third phase the modeling of effects was a part of the development process of alternative platform solutions. The identified effects were quantified in LEGOs case in terms of cost or time, based on historic data or experience from previous similar cases. This makes it possible to compare their impact, prioritize them and improve the design and get a more comprehensive understanding of the total effects of a potential platform solution. The process is as many other development processes iterative as the quantification of effects was used to evaluate the platform and led to adjustments, which were then again leading to different effects.

It was common that the representatives from the central life phases systems (where the most important effects are achieved) were included in the platform development team to ensure that the platform solution was aligned with critical characteristics of existing life phase system (e.g. locked element dimension in a definitive size fitting the packing equipment). The team included or had access to experts from the support functions like logistics/supply chain, finance and IT system workers. They were important, when the potential benefits of the platform was quantified because they have understanding of and access to the data that are the foundation for the arguments for the platform.

Alternative platform scenarios

With new ideas and a comprehensive list of potential effects, the platform concepts were supplemented by estimates on what effects they would create. The alternative concepts were usually modeled as viable scenarios, and as a central part, what the consequences in terms of specific effects. The specific effects that are looked into were in LEGOs situation often financial effects.

The scenarios in the LEGO cases were explored in the different dimensions, shown in Figure 7.8 within the areas of product, production/supply chain and market (the overall grouping corresponds to the one used in Integrated product development [Andreasen & Hein, 1985], and the Product Family Master Plan [Mortensen, 2000]

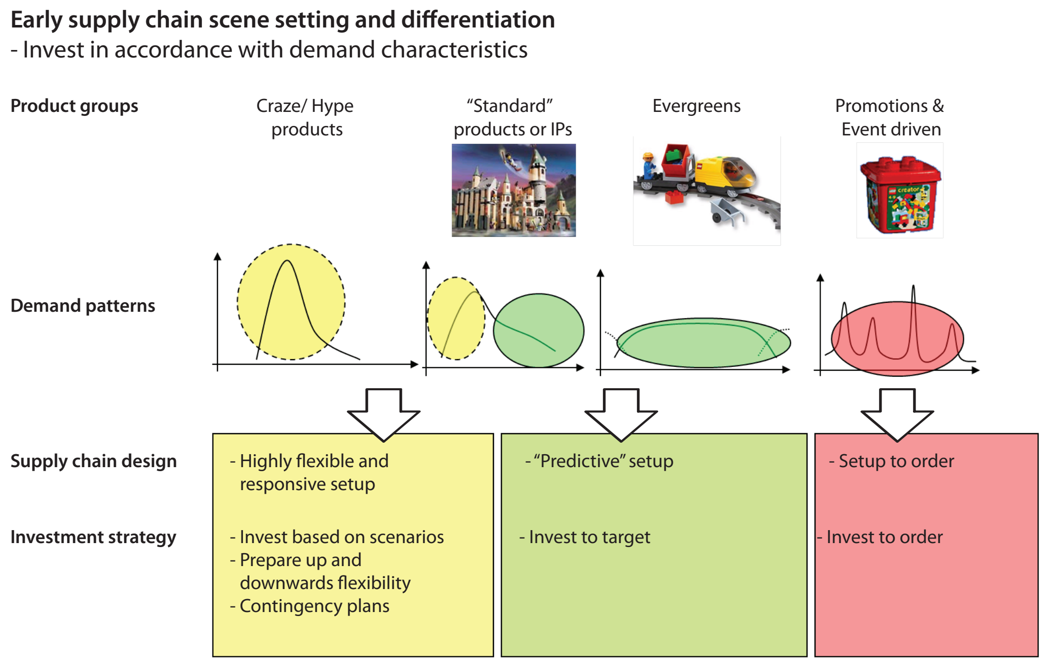


Figure 7.8: Scenario dimension: Scenarios were defined with the characteristics of market, product and production/supply chain aspects (that are all interdependent, as indicated by the arrows) and considered with the corresponding effects.

The dimensions from Figure 7.8 are elaborated below:

The market dimension were in the LEGO platform cases not as much in play, because it was the general approach to keep the products rather unperturbed by the platform solutions. Hence it was mainly a matter of being responsive to the market demand type, if it was a high demand product with big strategic performance or a less significant product with stable or lower sales curves, as depicted in Figure 7.8.

In the product dimension, the product scope (which product that should be included in the platform) was considered (and also how the products that were not included should be handled). The reuse level (how "much" of the products that should be reused) was also varied, depending on the options. Alternative technical solutions were also relevant to consider. Finally the overall module structure or architecture should correspond to the above choices, meaning that all the above mentioned characteristic are dependent.

The production/ supply chain dimension that were modeled in the LEGO cases were concentrating on the option of outsourcing or keeping production in house, the technical solution, reflected in the choice of equipment and how the production should planned, in terms of stock, batch size and production periods. The modeling was rather detailed in many of the cases in order to be able to make a well founded estimate of e.g. the cost savings of producing bigger batches. This was possible due to the historical data and the existing production planning models.

Viable scenarios were made with varying parameters, but the overall strategy was however often selected rather early in the process- rough designs and estimates showed the direction - and then a significant part of the time was spent on making estimations of consequences both in terms of potential benefits and risk and how they would be in worst, best and the most viable case. Generally the focus was on the most viable case, but with rather conservative estimates. Often the result was a total cost estimate and description the effects for a certain platform scenario, which was thoroughly described with of the products, platform concept and reuse assets and comments on risks. The platform concept was often described in different plans and overviews, such as roadmaps, product architecture and commonality and differentiation plans (the contents of the platform concept and how it was modeled will however not be further described in this work, as many other descriptions of this exist in literature). The above results (slowly developing) were presented to the management in a number of meetings with throughout the platform development process.

Estimating and quantifying the effects

The identified effects was based upon prerequisites, especially market demand, from the most viable scenarios. It is central that different stakeholders, the representatives from the life phase systems and the management to some degree agree that these scenarios are realistic and relevant.

In LEGOs case cost or time effects were in focus, based on historic data or experience from previous similar cases. The calculations were based on assumptions of unchanged products and constant market, easing the quantification process, because it is mainly internal well-known aspects that shall be estimated. It was also an advantage that LEGO has vast amounts of detailed data, which was a prerequisite for many of the estimates.

It is however still a time consuming process, making quantified estimates for each individual part of the platform and its effects in the different life phase systems, but the result is a more reliable picture of the platform impact and also a note on how many places in the organization that will be affected by the platform, showing the size of the necessary change process. It is important to have a clear structure for how the effects are calculated. If not there is the risk that some effects are taken into account twice. Often the platform development team developed tools or calculation models showing the effects were developed to ease the calculations, when varying the different parameters, e.g. in case of the Pre-pack, Wheels and Module Mould platforms.

The quantified estimates was always compared with the existing solution (the result from the analysis of status quo from phase 1 to understand the potential. The calculations were made from one of two starting points

- *Difference based calculations*
  The calculations were centered about the differences between the platform solution and the existing solution. This way is a simple way of doing it, but it does not provide the overview. E.g. a platform solution may reduce the lead time with 3 days, but how much is that of the total lead-time?
- *Totality based calculations*
  The calculations were based on total effects from birth to grave. This solution is often too time-consuming to go through with and sometimes the data to support the calculation are very difficult to identify, not to say make a reasonable picture of the actual situation. The benefits are a more total overview and you get forced to start from scratch and rethink the total solution.

In LEGO the difference based approach was by far the dominating, the totality approach was only considered, when the platform involved e.g. buying completely new equipments or when it did not make sense to make the differentiation based calculations due to incomparable prerequisites of the solutions.

The below picture shows an example from the Low Volume Mould platform, one of many detail estimates, based on representative elements and interviews with experienced designers. In this case the lead time was the subject of interest. This detailed estimate was summed up with other estimates to illustrate the total consequences. Summing up the effects in terms of lead time, they can only be taken into account it they are on the critical path, and not just reduce lead time locally.

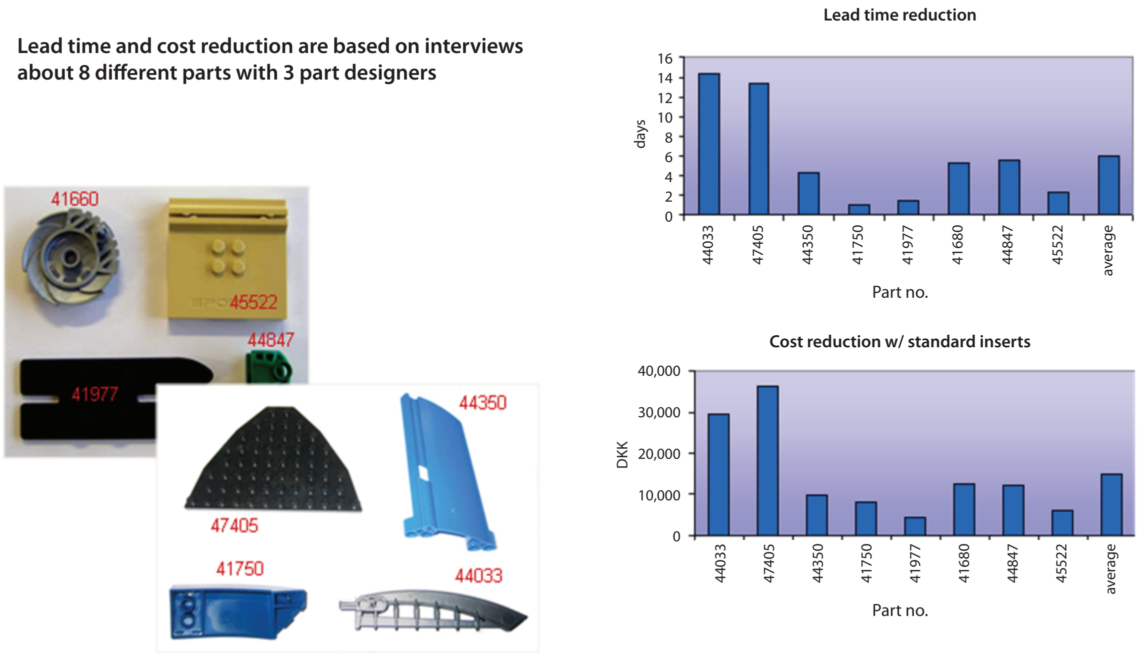


Figure 7.9: The estimate of the reduced lead time on mould design for representative elements with a sub-solution in Low Volume Mould Platform, based on interviews with experienced designers (Slide from the development of the platform).

In the LEGO platforms the financial consequences were in focus, and hence cash flow analyses and Net Present Value calculations (NPV) were requested as an important picture of the platform effects. In that context it was worth noticing the influence of e.g. interest rates, depreciation provision and calculated risks and bounded investments and be clear about the assumptions and the different consequences, as in real option analysis, showing the value of alternative investments.

The examples below show how the financial effects have been quantified for the Pre-pack platform using the difference calculation and for the Module Mould platform using the totality calculation.

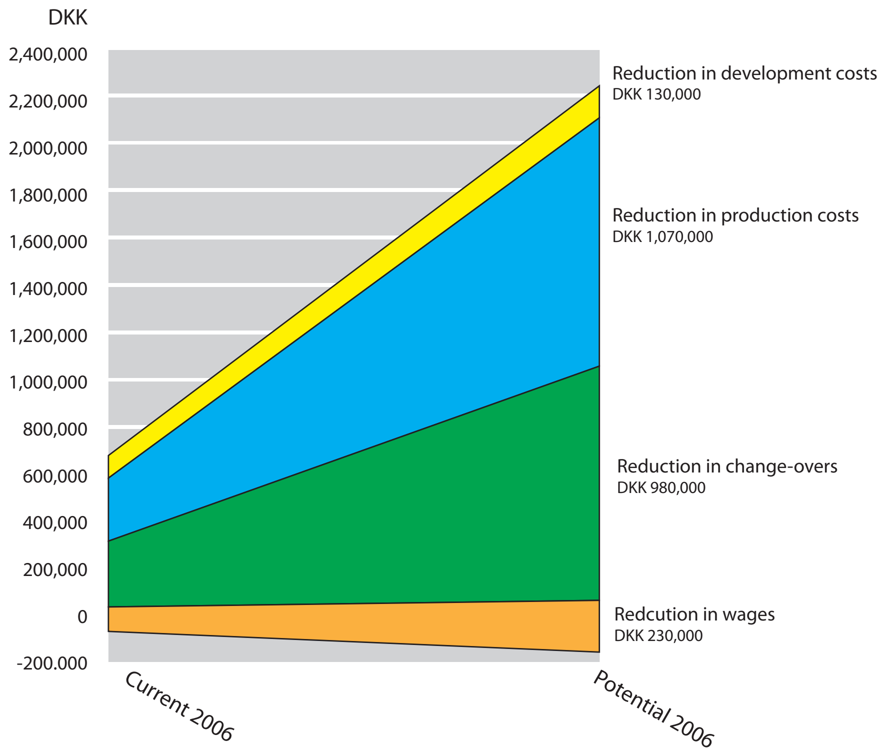


Figure 7.10: The different contributors, positive and negative(and their growth), to the total estimate of the cost reduction from the Prepack platform compared to status quo (difference based calculation). Text in English

Price at the end of year	**0**	**2**	**4**	**6**	**8**	**10**
Produced sum		793.183.391	1.586.366.782	2.379.550.173	3.172.733.564	3.965.916.955
MM solution (as today) [DKK]		**52.278.467**	**75.177.137**	**98.075.806**	**120.974.475**	**143.873.145**
Investment	29.379.798					
Maintenance cost		450.746	901.491	1.52.237	1.802.982	2.253.728
Production cost		22.447.924	44.895.848	67.343.771	89.791.695	112.239.619
Standard solution (with average std. mould price) [DKK]		**34.526.309**	**52.741.971**	**70.957.633**	**89.173.296**	**107.388.958**
Investment (total elements * av. std. element investment)	16.310.646					
Maintenance cost		505.367	1.010.733	1.516.100	2.021.467	2.526.833
Production cost		17.710.298	35.420.591	53.130.887	70.841.183	88.551.479
Standard (std. mould price = extra mould price + MM price) [DKK]		**57.392.927**	**75.608.589**	**93.824.252**	**112.039.914**	**130.255.577**
Investment	39.177.264					125.701.661
- of which is extra investment	9.797.466					
MM if interest of extra investment is included [DKK]		**50.588.404**	**72.942.028**	**95.119.875**	**117.065.257**	**138.703.203**
Interest of present year		1.690.063	2.235.108	2.955.931	3.909.218	5.169.941
Accumulated		3.159.683	7.338.364	12.864.669	20.173.207	29.838.750

Table 7.1: Example of calculation of the cash flow and total cost of investments (inc. development costs), interest, production and maintenance costs of the Module Mould platform over 10 years compared to the alternative solution with standard moulds. The calculation is similar to a NPV calculation. The red rings mark that until the 6th year the Module mould platform has lower total costs.

Specifying the scenarios in the above dimensions and quantifying the effects of each scenario, gives a more complete picture, which makes it easier to relate to and determine whether it seems viable or not. It is an iterative process that defines a viable and desirable final solution, going from different concepts studying their effects, which are not satisfactory and then back to the concepts to modify and improve them, and make new estimates of the effects and see if they are satisfactory. It must be noted that the data does not show the solution, but shows potential and provide arguments for the platform.

At some point in the third phase the platform shows potential or lack of the same, and it is decided to implement it or stop the project. If the platform is implemented, the more practical issues of the platforms get in focus, including the specification of operational platform goals.

Goal specification

The specification of goals built upon the estimates of effect from the life phase system representatives. The goals were sought to be operational to the platform users, meaning a platform user can easily relate the goal (and see if it is fulfilled) to the daily activities and the parameters he or she specify. During the development phase and the quantification of the effects the platform users usually participate and give feedback on the different concepts and to which extent a certain reuse solution can be used in the different products. This means that the platform use level they have estimated earlier is the forerunner for the actual specification of goals. The operational goals are often conservative to take unforeseen events into account and are in some cases supported by commitment statements from the platform users. These goals are used to calculate the expected effects.

The specification of goals is however not necessarily a natural a part of the platform development process, as three of the eight platforms do not have any goals. In that case the expected effects are based on the early estimates on platform use (made to promote the platform), but not connected to the real goals of the daily operations. The Figure 7.11 illustrates the process of estimating the two ways of specifying the goals.

Figure 7.11: When operational goals are set for a platform solution they are based on the estimates of how often the platform can be used, and the goals are used to calculate the expected effects of the platform (illustrated by the full line). In some cases there are not made operational goals and the expected effects are based on the estimated platform use (illustrated by the dotted line).

In the LEGO platform cases there were different types of the goals:

Types of goals

- Number of Platform assets (components, bags, modules ect.)
- Use level (number or percentage of assets that must be on average across products)
- Effects oriented (cost, time, quality)

The Element platform has a maximum number for how many components there should exist, and similarly does the Wheels platform. The Pre-pack platform has both a limit of the no. of bags that the product family should be based upon and a goal in terms of how much of the average content of the products should be from the platform standard bags. The LBS platform has no goal on how many different boxes that should exist, but has the use goal that 90% of all products should be in LBS boxes. Finally the Module Mould platform has both use goal and effect goal, respectively the 80% of all new moulds and e.g. 25 % reductions in mould investments and a quality goal of 95% first time approval.

The goals reflected a realistic estimate from experienced workers, but in some cases the goals were more strategic. In the cases where the platform goals were set, they were generally in accordance with the SMART principle [Doran, 1981], being specific, measurable, attainable, relevant and time bound. In some cases the relevance of the platform goals can be questioned, because some critical other measure were not include as e.g. in the Module Moulds platform, where total cost aspects were not considered. This meant that the platform did not deliver the expected effects, even though it met the derivative goals. Because the platform solution did not perform as good as expected, the overall result of the platform was a less advantageous economical solution than expected, but this was only discovered due to the independent total cost analysis of this thesis, because it was consider necessary in order to evaluate the platforms performance.

Adjustment and maintenance

The final part of the third phase was focused on final adjustment of the goals and platform solutions, and design of maintenance process. Final adjustments of the platforms were made to ensure that the goals were suitable and had commitment and that all minor details had been dealt with before the platform was implemented and the execution phase or platform use phase was initiated.

As part of the maintenance process it was decided how often the platforms should be checked, in which way, by whom and what the possible options would be if action was required. In the LEGO platforms there is usually a status once a year within the departments and the platform owner checks the status from time to time in between. The key checkpoints are e.g. the goals, which have been extracted from the ERP and PDM system. In some cases special automatic presentations of the data are made, in small programs or reports, modeling and visualizing the data in figures that makes it easy overview and follow the development. Not all platforms projects had this phase nor the focus on the follow up strategy, just as they don't have goals.

Post development phase: Platform evaluation

When the platforms had been implemented, applied once or twice and produced some results, they were usually evaluated and the problems raised were addressed. For some of the platforms it was particularly in this phase that it was discovered that a special effort was needed to improve of the platform, and extra resources were designated to do so.

7.1.2 The approach to effects and goals

The overall approach to effects and goals are reflected in the above process description can be characterized by

Identifying the effects and estimating them were based on the following approach:

- Many life phase system representatives involved, focusing on downstream and logistics too
- Focus on historic figures to investigate potential, quantification and facts-based arguments
- Modeling of alternative scenarios

Specifying the goals was characterized by:

- Goals were based on quantification of the estimated effects
- Aiming at operational goals, translated from the scenario and the effects and with the commitment from stakeholders

Importance of effects estimation and realism in goal-setting

In literature it is often mentioned the importance of having a comprehensive understanding of the consequences of the product platforms, but also that there is a lacks models and empirical studies that do so [Simpson et al, 2006]. In LEGO the case these consequences and how they were described and estimated were very central for the decision of implementing the platforms: The management was not seduced by the platform thinking, but they did provide the resources to make some of the more explanatory projects. The management did support the projects fully, when it was probable and realistic that it was a sensible decision. This support is very crucial, when it comes to get stakeholders involved in the design phase, and it was actually lacking in some of the platform development projects.

The potential of a platform idea may not be obvious to everybody, but it must be made provable to convince skeptics. In some cases it is obvious that there will also be drawbacks of implementing a platform solution, and hence it may be critical to quantify both benefits and drawbacks. It is by far easier to implement a platform if it is possible to make the benefits and drawbacks of the product platform provable. If you can't model them or estimate them, then it is uphill to convince other people and maybe not a good enough idea with substantial potential.

Quantification also enables improvement of the platforms because you see the effect of different characteristics, but it must be underlined that the way that the consequences are quantified must be realistic and this is by involving experienced workers and using historic figures.

However it is not said that a platform may not be a good solution if it is not possible to describe it this way, and it may sometimes be a matter economical technicalities if a platform is a "good business" or not – especially depending how your calculation models handle the many levels and aspects of risk, which are not treated in an appropriate way in many economic models. Economic figures can be difficult to use solely as judgment criteria for the "goodness" of a solution, it is necessary to use case scenarios and visualize the product selection and the economical and logistical consequences, risks and potential of such a choice.

7.1.3 Relating the findings to literature

Relating the process description to literature, it generally compiles with the small amount of existing literature:

Comparing to Suh et al [2007] approach, the described process supports his parts of his theoretical ideas about effects estimation empirically, especially the use and importance of historic data (like Simpson et al. [2006] also emphasize) and scenarios. The effects estimation in LEGO is however less mathematical and based on analytical functions and more based on estimates from experienced workers. The theoretical financial considerations made by Gonzales-Zugasti are also supported empirically, since similar approaches have been applied in LEGO. None of the platform projects were relying on metrics, despite its representation in literature [Erixon, 1998, Gershenson et al., 2004].

Like Kvist [2010] describes, the consequences are modeled with different charts and diagrams in combination with the technical descriptions of the reuse assets, and the process was characterized of a focus on fact –based quick approximate results, like Robertson & Ulrich [1998] recommends.

As mentioned previously there is little attention is paid to how the effects are identified.

Specification of goals for the LEGO platforms has not been consequently executed, but when it was done it was mainly in accordance to Doran's recommendations [1981]. However it is not always that all the relevant goals are specified, reflecting that the relevant effects have not been estimated. This goal-setting aspect is new platform-based product development, but natural consequence of the general goal-setting theory.

7.1.4 Concluding on identification and estimation of platform effects

Answering the question of how the effects have been identified and estimated, I argue:

The process of identifying and estimating effects can be described as a process consisting of four phases, being:

- First phase: Concretizing the platform idea and analyzing effects of status quo
- Second phase: Identifying effects from life phase systems
- Third phase: Estimating and quantifying effects from scenarios, specifying goals and adjustments
- Post-development phase: Goal evaluation and revision

The process starts with a search, based on presentation of possible reuse assets, where representatives from relevant life phase systems relate to it and reflect upon how it would change the product and their work. From the representatives reflections a number of effects and mechanisms can be identified and be used in the further development of the platform solution and to estimate the size of the effect.

Estimating and quantifying the effects is in done within different scenarios with varying parameters. The quantification of the effects is based on key historic data (cost, sales figures, investments, development time etc.) combined with estimates from experienced representatives from the different life phase systems. The approach to the estimation is thorough and facts-based, in order to ensure the most viable result. The data provides the core arguments for the product platform. The amount of data and the existing calculation models that were present in LEGO was a prerequisite for making the estimates. It is likely that the quantification of effects has been eased by the fact that the effects in question were internal.

The process of specifying the goals is a process that builds upon the estimate of the life system representatives (especially the platform users), balancing this with the size and importance of effects that can be achieved. The goals must be operational for the platform users and can be translated into effects or consequences and vice versa. Different kinds of operational goals are identified.

The existing theoretical contributions regarding fact- and data-based modeling and scenario-based approach to effects estimation are supported empirically by the descriptive model of the process. Likewise goes for the financial aspects of platform modeling, which occurred in LEGO.

The estimates based on experienced workers knowledge are however not paid much attention in literature. This is also the case with the process of effects identification and the process of goal specification, which is not described previously.

This answer is basis for the answering of the following research questions. The process of identifying and estimation of effects has been described as it was performed in LEGO and is a contribution to the product platform development theory, focusing on a process that has not previously been described empirically.

7.2 Platform performance

This section concludes on the performance of the eight product platforms in LEGO in order to try generalise on the complex issue of how they perform and answer the research question:

RQ2: Do product platforms achieve the expected effects?

First a performance overview is presented together with the prerequisites for the performance evaluation and which goals and effects that were expected. Then different types of effects are described and to which extent they have been achieved. The performance results are then related to the reports on platform effects in literature. Finally the importance of tracking of the platform performance is discussed.

7.2.1 Platform performance overview

Determining the platforms performance was based on how well they have met the expectations or goals set up in the design or preparation phase. As mentioned this categorization is a rather simplified way of concluding on the performance, but yet a step into the direction of achieving knowledge of the issue and necessary when comparing multiple cases.

The performance data were collected from LEGOs PDM and ERP systems data logs combined with interviews with platform owners, developers and platform users to ensure triangulation. Generally the platforms goals are related to the expected effects, and hence it is the data on the achievement of these goals that is used to assess if the expected effects are achieved. In some cases, when I (supported by the platform owners) found that the specified goals were not representing the expected effects sufficient, the relevant data have been identified from the data systems and analysed.

In the cases where there was no clear goal that could be measured to be verified, but only expectations (in some cases they were even undocumented), the evaluation of the performance was based on the responses from the interviewees, when they were presented to selected data, chosen by me to represent the platform effects.

Table 7.2 below summarizes the performance of the different platforms. The specific effects that have been achieved can be seen in the overview table in chapter 5 about the LEGO cases.

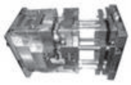
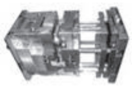
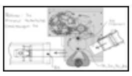
Platform name and implementation year	Performance 06-08	Challenges and reasons for deviation	Relative impact level (1-5)
Element platforms (system, technic, duplo, mind-storms, functions) (1958) 	★★★	Selecting reusable elements and finding the number of elements on sufficient level, balancing the building options and the complexity of many elements. Maintenance and platform erosion. Making the users understand the platform rules.	5
LBS (before 1990) 	★★★	Platform erosion: Addition of extra boxes undermines the benefits of the platform.	5
Low Volume Mould platform (2001) 	★★	Reaching the level of use and measuring and calculating actual platform benefits when choosing mould design. Use of platform: No goals from management. *Errors are multiplying due to reuse of new technical solution.*	3
Can platform (2004) 	★	Outdated platform scope. Not possible to set up suitable and beneficial platform solution due to too unstable market demand conditions.	2
Wheels (spring 2005) 	★★	Making the product developers use the platform elements, understand the platform possibilities and update. No benefit for user and undesired trade off. Complex extra burden for product developers to use platforms.	3
Module mould platform (2005) 	★★	Reaching the level of use and measuring and calculating actual platform benefits when choosing mould design. Technical performance was not as good as expected.	4
Pre-pack Platform (spring 2005) 	★★★	Calculation and data system does not support platform. Including production planning department at a late stage in the platform development process.	3
Decoration Five star (2006) 	★★	Make the designers aware of the platform possibility.	2

Table 7.2: Overview of the different platforms performance, the challenges and reasons for deviations and which criteria they were assessed by. The deviations refer to issues within the period of the study and performance measurement, whereas the challenges (written in italics) describe issues that have occurred and been addressed before the study.

In some of the cases the goals have actually been met, but due to unexpected and undesired side effects, the platform did not perform satisfyingly and has been rated as such. It is however not always discovered that these undesired side effects can undermine the results of the platform, because there is no control or tracking of these aspects. This was the case in the Module Mould platform was expected to produce good results, but a thorough analysis of the actual consequences showed a different picture. This also puts the evaluation of the other platforms performance in another light, because their performance is only evaluated in terms of the pragmatic goals, derived from key figures from the business case from the development phase, not their actual effect. Out of the eight platforms, five had specified goals.

Platform performance and types of effects

Concluding on the performance results of the eight platforms we conclude:

- Out of the eight platforms three performed satisfyingly and met their goal,
- Four platforms performed somehow satisfying but did not meet their goals and finally
- Only one platform was not performing satisfying

The specific performances can be seen in Table 7.3.

Symbol	Category	Product platform
★★★	The platform performs satisfying and meets its expected effects and goals.	Element, Pre-pack, and LBS
★★	The platform performs somehow satisfying and does not meet all expected effects or goals.	Low Volume Mould, Module Mould, Wheels, and Decoration
★	The platform does not perform satisfying.	Can

Table 7.3: Platform performance categories and the platforms that fall into the different categories.

For 3 of the platforms the number of elements in the platform was a goal in its self, reducing up to from 10 -50 % in production equipment investment and other connected costs. For one platform the development time was reduced with 50 % and production costs were cut significantly. Another reduced mould investments with 25 % and 30 % shorter development time. The remaining 3 did not have specific goals, but were expected to have different effects: one on mould investments and development time, the other on production equipment investments. The last one was expected to reduce cost of rebuilding equipment and provided more design freedom and hereby improve sales. Even though not all of the platforms had specific goals, there were some expectations to their effect.

The LEGO platforms produce significant results and the platform-based product development initiative is considered a success: 7 out of 8 platforms perform satisfyingly or somehow satisfyingly.

In general the older platforms (Elements and LBS) that have been used for over 20 years do achieve the expected effects, which may show that they are capable of delivering a good solution and desired effects. It may also show that after a number of update loops the platform has matured and has been: The platform reuse assets have been optimized based on experience with the platform, information and maintenance support is present and the level of expectations regarding effects. This shows that it is possible to achieve results with platform-based product development for long periods.

There is however still room for improvements within the group of platforms that did not achieve all the expected expectations (within varying limits), and I will take a closer look at this answering research question 3.

The platforms create effects in both product and production equipment development and in the manufacturing of the products, such as reduced development time and cost and production cost and risks. The main results are listed below in terms of type of effect. The percentages describing the improvement refer to the areas within the platform scope and not on product family level:

- Reductions in number of components (up to 50 %) and future limitation (3 platforms)
- Reduced product development time (up to 25-30 %) (4 platforms)
- Reduced production equipment development time (up to 30%) (7 platforms)
- Reduced production cost and investments (up to 25-30 %) (6 platforms)
- Reduced risk of obsolete products or production facilities (6 platforms)

In general the LEGO platforms have been focusing on internal effects (often via rationalization) and the platforms have been perceived as a way of supporting and focusing the variety that was already present in LEGOs products. Hence there has been little risk in the market dimension, and hence the performance results are more similar to internal projects like Design for Manufacture, implementation of new software systems or production equipment.

All the mentioned kinds of benefits have been reported in literature, see section "3.3 Platform effects: Potential benefits and risks" regarding platform benefits.

The benefits listed above have, besides from being internal, a downstream oriented focus, i.e. benefits are achieved in the realization phases, namely production and distribution, in opposition to the benefits from creating new market offerings and in the more preparation-oriented product development phases. This emphasizes the potential of such benefits and the need of identifying and quantifying effects from these life phase systems, as they are major contributors in the present cases, when it comes to platform effects. Existing product platform literature do point to these types of benefits, but they are not in focus, relative to the potential impact, which is shown in the LEGO cases. Due to the downstream type of benefits shown in the LEGO cases, the area may deserve more attention as input and argument for platforms in the platform literature.

LEGO have also experienced challenges regarding the risks of platform-based product development, which will be discussed in details later in section "7.3 Reasons for deviations between expected and achieved effects".

Comparison to state-of- the-art platform performance

The LEGO platform performance results are in accordance with both the success stories and moderate reports of poor results in literature, but they show a more comprehensive and detailed picture of the variety of performance and failure and the achieved effects are documented and verified. This verification of significant achieved effects strengthens the validity of platform-based product development as a powerful approach to create significant benefits and gain competitive advantage. The LEGO platform cases moderates the rather one-sided success stories with less radical and less successful projects, which platform-based product development has also resulted in. It also shows how many different applications and possibilities the platform-based product development can have within a single company. The fact that the achieved effects were relatively close to the expected effects also shows that it is possible to make viable estimates, as done it the described process in the LEGO cases.

The results are in general more moderate (reductions in different areas of 20-50%, see previous section) than the most highlighted success stories (e.g. up to 70 % reduction of costs, 30%-80 % reduction of development or production time, 50% improved quality etc. [Sanchez, 2000, Robert & Ulrich 2000]). These results however go for not only one, but eight product platforms, which shows the impact and potential of product platforms in many dimensions and the quality of the work of the platform development teams in LEGO.

One could of course argue that the goals were met because they were not ambitious enough, but considering the achieved effects and relating them to platform results reported in literature, they are high and ambitious, and have yet been realistic since they have been achieved. The above answer is a contribution to the verification of platform effects, as they are comparable and have been confirmed by different sources over 3-4 years.

From Tanikonda's [1999] study of platform project performance in literature it is indicated that platform development projects did not differ in terms of success compared to single product development projects. Direct comparing it to success rates in ordinary product development is from my point of view not appropriate due to the aspects of organisational implications and system design that ordinary product development does not have. It can however give some perspective: In ordinary product development only one of eleven considered products is successful and launched products have a success rate of approx. 60 % (Page, 1993, Adams, 2004). 7 out of 8 platforms perform satisfyingly or somehow satisfyingly in LEGO and in that context the results achieved with the LEGO platforms are definitely noticeable and worth studying when it comes to state of the art platform development.

Projects failing before implementation

In this study only the performance of implemented platforms are studied, but it is also interesting to know how many projects were initiated and how many of those that got to the implementation. It is not the focal point of this study, but as mentioned there have been a few platform projects that have been aborted, but surprisingly few (1-2) according to my studies. The pattern from LEGO shows more many attempts and different approaches to utilizing the recognized reused potential have been necessary together with the right timing or window of opportunity. That means that the failure projects are often revitalized, when a new approach, idea, knowledge or situation emerges.

Importance of tracking platform performance

Studying the performance of the LEGO platforms it became clear that the actual checking of the goals had been achieved was not systematically done in three of the eight product platforms. These did not have specific goals, which was maybe partly the reason for the lack of performance check, because it was hard to know exactly what should be checked. In those cases, it the performance check was made as part of the work in this thesis or on request in connection to it. The rest of the platforms performances were tracked, but mainly on derivative measures, not showing the actual effect of the platforms.

As described previously it may be sufficient and practical for some platforms to have operative and derivative goals (like no. of elements), but for other platforms the lack of tracking on the actual effects can actually mean that they don't deliver the benefits, they were supposed to and that it is not discovered.

Tracking the platform performance should be done for at least four reasons:

- It is important to know if the platform benefits are actually achieved and how different parts of the platform contribute.
- To adjust or improve the platform, data on its actual effects must be gathered
- Future platforms should be designed based on the knowledge of previous platforms
- To have valid arguments and evidence for a platforms effect for the future product platform strategy

The final bullet is important in relation to the arguments in the debate about platforms, which often exist in companies: In some case the decision of applying platform-based product development and developing product platforms is a strategic decision, because it can be difficult to make it probable in financial terms that a platform is the best solution. In that context it is even more important to be able to show the consequences retrospectively and understand and possible justify if it was a good solution. Knowledge of consequences can be obtained by tracking key performance figures of the platform and use them in future discussions of when to apply platform-based product development.

The relevance and level of tracking depends on the desired benefits: If the desired benefits are reduced development time, it is rather obvious and easy to follow and control, if the planned products are developed faster based on the platform (e.g. that it is possible to develop 6 instead of 3 products). But especially in large platform solutions, where more than 6 products are related to a platform, it may soon be an advantaged to have an overview, systematically tracking the platform performance.

Enabling tracking – part of the product platform development

Based on the experiences from LEGO platform cases, it seems beneficial that it is considered carefully in the development of the platform how the issue of tracking should be addressed. Often it is closely linked to the integration in the PDM and ERP systems (which are part of the platform solution) and it can best be considered at this stage which data that are relevant to track and how it should be represented.

In LEGO the data systems structure was changed to represent the desired data, and hence this decision has to be made upfront when the platform system is designed, to adapt the ERP, PDM and platform systems to each other. Often the different data logs are required to track a platform covering many products compared to tracking a single product, and hence the data systems in their existing form can't deliver these requested logs. It is in the design of such data mining options, that future information about the platform performance must be provided. E.g. how different subgroups perform in the production system and if the platform should be applied differently.

For some of the LEGO platforms (Wheels and Element platforms) new data structures and characteristics were introduced in the existing PDM systems to make it possible to track the platform performance. It can however be a complex and big task, because a new data structures changes the entire system, which is often not desirable, because the platform tracking is only one of many applications of the ERP and PDM systems.

In LEGO it meant that for some platforms (E.g. Prepack platform and Module Mould) the tracking system was parallel to the existing data system and newer integrated in it, because this would cause too many undesired changes of the existing system. It does however require more effort and specialized knowledge to track the platform performance manually in these parallel systems, and this makes it a vulnerable solution, often people dependant solution.

The drawback of tracking is that it may be cumbersome, unnecessary in some cases and not worth the resources spent on it, but it is the only way of getting the overview of the actual consequences of the platforms. Hence it is up to each company to find a suitable of data management strategy that actually enables the data mining that is an important foundation for both product and product platform development and realization.

It is unfortunately not only a problem for product platforms, but also for many other projects that there is little follow up on how they actually perform. The data registration and interpretation issue is also relevant in many other aspects of product development, and a place where companies still struggle to find the right way and level of data management.

7.2.2 Concluding on platform performance

In order to answer the research question "Do product platforms achieved the expected effects?",I argue:

The LEGO platforms predominantly achieved the expected effects: Out of the eight platforms three performed satisfyingly and met their goal, four platforms performed somehow satisfying but did not meet all their goals and finally only one platform was not performing satisfying. Hence the LEGO platforms produce good results, especially the mature platforms, but there is still room for improvements.

The platforms create effects in both product and production equipment development and in the manufacturing of the products, such as reduced development time and cost and production cost and risks. The main results are listed below and the percentages refer to the areas within the platform scope and not on product family level:

- Reductions in number of components (up to 50 %) and future limitation
- Reduced product development time (up to 25-30 %)
- Reduced production equipment development time (up to 30%)
- Reduced production cost and investments (up to 25-30 %)
- Reduced risk of obsolete products or production facilities

The platform effects achieved in LEGO are thus achieved in both the early preparation/development-oriented and in the later realization phases, like production and distribution, but it is in the downstream phases where the most significant benefits have been achieved. The study of the cases does point to the importance of tracking their performance and the necessity to enable this.

Compared to other cases and studies described in literature, the effects achieved in LEGO are remarkable, not a least because they are significant in a comparable group of case.

The performance results are in accordance with both the success stories and moderate reports of poor results in literature: They contribute by showing a more comprehensive and detailed picture of the variety of performance and failure in a group of comparable platforms, studied in detail over time, and the achieved effects are documented and verified. The relatively small differences between achieved and expected effects shows that it is possible to make viable estimates, as done it the described process of the LEGO cases.

This verification of significant achieved effects strengthens the validity of platform-based product development as a powerful approach to create significant benefits and gain competitive advantage.

The LEGO platform cases moderates the rather one-sided success stories with less radical and less successful projects, which platform-based product development has also resulted in. It also shows how many different applications and possibilities the platform-based product development can have within a single company.

7.3 Reasons for deviations between expected and achieved effects

In this section I seek to answer the research question:

RQ3: What are reasons for deviations between achieved and expected platform effects and are they addressed by platform assessment criteria in literature?

I go behind the performance result of the product platforms in order to identify the different reasons for why some of the platforms did not achieve the expected effects. These reasons for deviations, challenges that have occurred and the joint picture the cases show are analyzed to point out tendencies. These are related to literature and existing assessment criteria to see if they are relevant and appropriate, aiming at proposing possible new relevant criteria.

7.3.1 Overview of reasons for deviations from the expected effect

The reasons for deviations from the expected effects in the work with platform-based product development from the LEGO case descriptions are gathered, generalized and grouped within the issues below. The numbers in parenthesis show how many platforms the issue is relevant for. The reasons for platform performance deviations and their specific occurrence are shown in Table 7.4. The issues are discussed one by one in the following

Reasons for deviations in platform performance	Element	Wheels	Prepack	LBS	Can	Decoration	LVM	MM
1. The platforms are not used (as much) as intended (6)	x	x	x			x	x	x
a. Design calculation and data models do not consider platform benefits and provide the argument for using them. (3)			x				x	x
b. No goals, benefits or rewards from management (3)					x	x	x	
c. The users consider the trade off platform provides unattractive. (3)		x					x	x
d. The platforms and their rules are difficult to understand and hence use (2).	x	x						
e. The platforms are not known (1)						x		
f. Platform development and use is an extra burden for the product developers (1)		x						
2. Maintaining the platform and avoid undesired changes of the solution, that erodes the benefits (2)	x			x				
3. The technical platform solution did not perform as expected (1)								x
4. Multiple errors due to reused new technological solution(1)							x	
5. Market needs have changed, and the platform solution does not fulfil the needs anymore (1)					x			

Table 7.4: Overview of reasons for deviations in platform performance.

The platforms are not used (as much) as intended

The most occurring reason for why the platforms' performance deviate from the expected, is relevant for six platforms in LEGO and has many aspects, which all contribute to the lack of use They do all however identify challenges for the product platform users (usually the product or production developers). The issue has been touched upon by Juuti et al [2004], who have also identified challenges in the platform utilization phase. There are different elements within this reason:

Wrong guidance due to calculation models

Existing calculation systems are used to decide whether a product should be platform based or not, which is the core issue in 1a. These do only consider the individual product and not the total solution, and hence not the platform benefits, which often favour the non-platform solution. Since the calculation present a quantitative result, where as the platform benefits are often not specified for the individual product, the designers often rely of the calculations models.

There is a tendency to that the designers don't believe in the platforms benefits, when they can't be assigned to individual components. It is though not necessarily a barrier for the platform use, if other aspects play in: In the case of the Pre-pack platform the calculation system does not support the platform solution, but the designers use the platform according to the goals, but they also have direct benefits of the platform, and obviously don't have the same wish to use a calculation system to justify or challenge the platform solution. If such a motivation is not present, it shows the importance of making a quantitative effect calculation of a platform. Andreasen et al [2001] emphasize the importance of understanding the importance of reuse to the business, which compiles with this finding.

No goals or personal benefits

Often management do not reward use of platforms or have set personal or team-specific goal for what is expected regarding the use of a platform, which is the case in 1b. Not having specific performance goals for some of the platforms was intentional in some cases, from the viewpoint that it would be up to the platform users to assess whether it was appropriate to use a platform in a given product. But this approach made it unclear when exactly to use the platforms, and just like in ordinary (product development) projects it is often beneficial and clarifying to have an agreed goal, and it enables a better estimate of the effects.

Of the three platforms performing satisfyingly without specific goals two of them performed somehow satisfyingly and the last did not perform satisfyingly. This may indicate that you can design a platform and achieve some benefits without setting goals for its performance, but that goals have a positive effect. This is also supported by studies by Locke, [1968]. The importance of clear targets and measures is supported by Nieuwland [1999] and Sanchez [2000] also describes how new kinds of incentives systems are necessary.

Often there is no desired personal benefit for the individual product developer, who is the one that decides to use the platform. The actual benefits of the platforms are often not helping the product defining user, because the effects are in a later life phase (like reduced production time or cost) or only visible on company level (like reduced risk), as depicted in Figure 7.12.

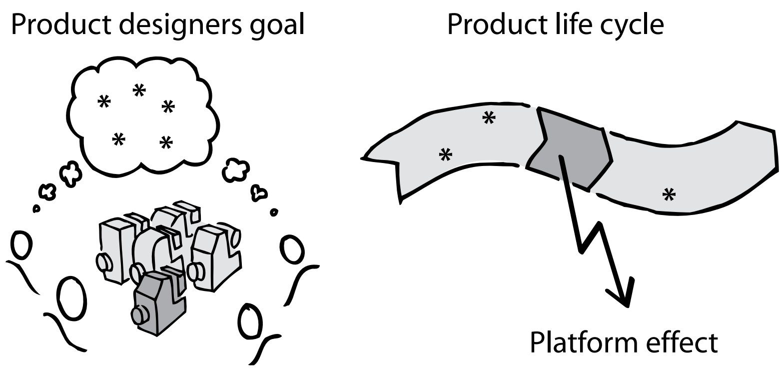


Figure 7.12: The product designers (platform users designing the product) do not benefit from the platform effects. Their goals (shown as stars in the figure) are different from and appear in different life phases than the platform effects. Hence the platform effects are less visible and important to the designers. This makes it a challenge to make the designers use the platform elements.

Unattractive solution

In some cases the product developer has to compromise or risk important product characteristics that may be key selling points from his or her viewpoint, leading to high sales number, which is often the most important goal, and this trade off seems unattractive (1c).Similar findings have been made by Ehrens [1997] also notes that if sales engineers and designers focus on individual requirements, they feel that sharing components compromise the quality of their products.

It can be difficult to say if such objections are fair, as the developed platform may not be good enough from a market point of view, but it may also be due to lack of understanding or prioritization of the benefits that the reuse from the platform users. In that case it may also be a matter of communicating platform effects as described in change management theory [Kotter, 1995]. It may also be due to undesired company development culture and values, where people recognise their personal sub-interests and fragmented departmental interest instead of working together for the shared vision of the organisation, which also requires a significant effort to change [Senge, 1990].

Platform-based product development imposes more work

The complexity of doing platform based product development alongside the ordinary product development is also taking up time. In one case the platform users mentioned that they had an extra burden, because they had to "use and fit into an extra system (the platform, edt.)" in the product development (1f). This is also supported by findings of Andreasen et al [2001] and by Halman et al.[2003] and Ulrich & Eppinger,[2001] describing consequences of increased development time and cost.

Lack of information and understanding

The above aspects can be categorised as motivational, where as the final two aspects have are related to ability and opportunity, using the framework of motivational performance theory [Blumberg & Pringle, 1982, Vroom, 1964]: The product platform users also state that not only is it difficult to learn and gain a greater understanding of the platform and how and when to use it (1d), but finding information about it (a major barrier for the platform) is just as challenging (1e). This issue of (lack of communication) is critical for the according to change management theories [Kotter, 1995] and is supported by findings from Ulrich and Robertson [1998] that describes the importance of platform knowledge sharing and utilization, and Simpson [2004], that notes that visible information is crucial.

Maintaining the platform and avoid undesired changes of the solution

The second issue regards the maintenance and undesired changes of the platform. The erosion of the platform solution often occurs when the platform solution has been used for a longer period, and slowly other solutions pop up around it, maybe because of new markets, trends or technologies have appeared or because there is less attention toward the platform prerequisites. These other solutions undermine the platform and erode the benefits. It is then necessary to reconsider the platform and is in most cases handled by frequent, and in some cases planned checks and updates on the platforms. The challenge of platform maintenance is also described by Ulrich & Robertson [1998].

The technical platform solution did not perform as expected

The third reason was relevant in the case, where it was discovered, by analysing the historic data from the platform operations, that production time and hence costs were higher than estimated in some of the platform applications. This higher cost had so significant impact, that it made the total cost of the platform much higher than anticipated, and hence it did not perform satisfying. The study of Tanikonda [1999] supports the crucial importance of the choice of and knowledge about platform technologies.

Multiple errors due to reused solutions

In one instance, reusing one solution in the production equipment caused problems as described in the fourth reason. The flaws of that solution was not discovered and had to be corrected in every single piece of equipment, which was costly. Hence it is important to make the reusable solution right because an error will spread not only to one product, but to the entire product family. Similar to the previous aspect Tanikondas study [1999] shows how the technological interdependency has influence.

Market needs have changed

The fifth and last issue, where the platform does not fit the market needs, only applies to a single platform. It is frequently agreed upon within the company that the solution is not appropriate and there is general acceptance of the fact that the area was not suitable for a platform because the variety was creating customer value. This aspects important influence is mentioned by many, among others Miller [2001], Halman [2003] and Jiao [2007].

7.3.2 Discussion of the reasons for deviations

The three less occurring reasons for deviations from the expected effects of the LEGO platforms have had the most significant impact:

- In the case where the technical platform solution did not perform as expected, the result was significant unnecessary production costs.
- In the platform where a new technical solution was introduced with multiple errors as result, a whole new platform design was made and the material was changed. This indicates the usefulness of basing product platforms on solutions that are tested reliable to some degree.
- The case where the platforms did not meet the market demands because they were unstable and had changed, the investment in the production equipment was considered a wrong investment. In that situation the attempt to standardise an area which was not yet stable was unsuccessful.

The issue of lack of use (addressing a number of aspects) is the most common. This issue must be considered an enabling factor, since it posits that a product platforms has been developed, but it is still a reason for why the expected goals are not met, which must be addressed. In some of the cases the lack of use has been possible to address with improved information and establishments of support systems, new processes and goal setting. This is similar to the cases of lacking maintenance and undesired changes, which also occurs, until processes of maintenance and tracking have been established.

However in the cases where the platform users don't support the platform solutions, it has been necessary to change the platform and its reuse assets itself. This emphasizes the possible consequences of too late or little involvement of platform stakeholders and users. Lack of involvement or too late involvement of critical uses and stakeholders has caused that the developed platform was less appropriate and had to be changed. This was however not discovered before the implementation of the platform had already begun.

7.3.3 Relevance and appropriateness of assessment criteria in literature

Having identified different groups of reasons for deviations from expected effects in the LEGO Platform cases, we now turn to assessment criteria suggested in literature. To study if these criteria are relevant and address the reasons for deviations, I compare the theme to each other.

In section "4.5 Platform assessment criteria", it was found that there was general consensus about following assessment criteria (see Figure 7.13);

- Platform assets characteristics
- Market /customer aspects
- Technical aspects (performance and stability) and
- Economical aspects (revenue, cost).

Frequently criteria regarding the aspects below are also often mentioned:

- Strategy
- Potential, uncertainty and risk
- Organisational capabilities

Criteria in platform assessment and development in existing literature

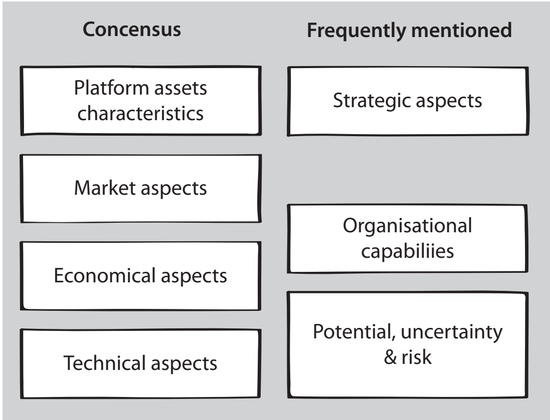


Figure 7.13: Criteria in existing literature on platform assessment

The reasons for deviations are related to aspects regarding (no. in parenthesis relates to the deviations):

- Platform use aspects (1a-f)
- The technical aspects (3,4)
- Platform maintenance and undesired changes(2)
- The market aspects (5)

Comparing this to the assessment criteria, they address the issues (platform maintenance and erosion may be considered an organizational aspect) except from the platform use aspect, which is only reported in studies of influencing factors.

The frequently occurring criteria in literature, the market and technical aspects, are relevant in the LEGO cases too: The most significant deviations from the expected platform effects were due to reasons related to these aspects. These did only occur in a few of the platforms, but the low occurrence of these aspects should not be taken as indicating that these aspects are not important. These aspects are central, critical and the foundation for the bare existence of a platform solution, which is also underlined by the amount of academic literature dealing with these aspects.

The lack of use of a platform may not be as critical as the issues regarding technical and market aspects, because the lack of use can often be dealt with via post development efforts and posit that a platform has been developed and is implemented. This may be the reason for why these issues have sometimes not been properly addressed in the development of the LEGO platforms and why it is not addressed in literature.

Comparing with the criteria in Figure 7.13, there is however no criterion that addresses the platform use aspects, which causes most of the deviations in the LEGO platform cases. Due to the lack of knowledge of this phenomena in literature and the relevance of it the LEGO cases, it is elaborated in the following section, aiming at proposing a criterion addressing the reason causing lack of platform use.

7.4 Addressing the lack of platform use

The lack platform use is not addressed by platform assessment criteria in literature. Hence a criterion to address the lack of use is introduced in the following and examples from the LEGO platform cases illustrate how such a criterion can be met.

The most occurring reason for deviations in LEGOs' platforms' performance is that the platforms are used less than intended (and hence achieve the expected effects) due to

- lack of motivation, because the calculation and explanations of the platform effects are unsatisfying and there is too little incentive to make an individual effort and overcome the barriers,
- lack of opportunity, because people don't know the platform, and
- lack of ability because people don't understand and hasn't been trained in how to apply the platform.

It is not sufficient to design only the platform elements and consider market, technical and economical aspects as the existing platform development methods from literature do. It is typical that the users of these less successful platforms oftentimes have little incentive to use said platforms: It is not incorporated in the platform set up and design and in some cases the platform users have not been properly involved in the development of the platform, ensuring that they become engaged and that the platform design reflects how they should use it.

It is not sufficient to consider only platform elements in the design phase; a more comprehensive understanding of mechanisms of the product development process, where it will be used, is necessary and should also be designed into the platform solution. Concrete solution elements ensuring user incentive in the use of platforms, which can be designed into the platform solutions, have not been identified yet, and this is an area to look into for future research.

7.4.1 Introducing platform user incentive criterion

Therefore a platform user incentive is introduced as relevant criterion in platform development, which should focus more on the mechanisms of the daily use of the platform. Including the user incentive in the design of the platform may lead to improved platform design, increasing the (correct) use of the platform solution so that potential platform benefits can be achieved. The knowledge about user incentive may also lead to more realistic goal setting and balance the expectations to platforms performance. Figure 7.14 presents this new addition to the existing aspects.

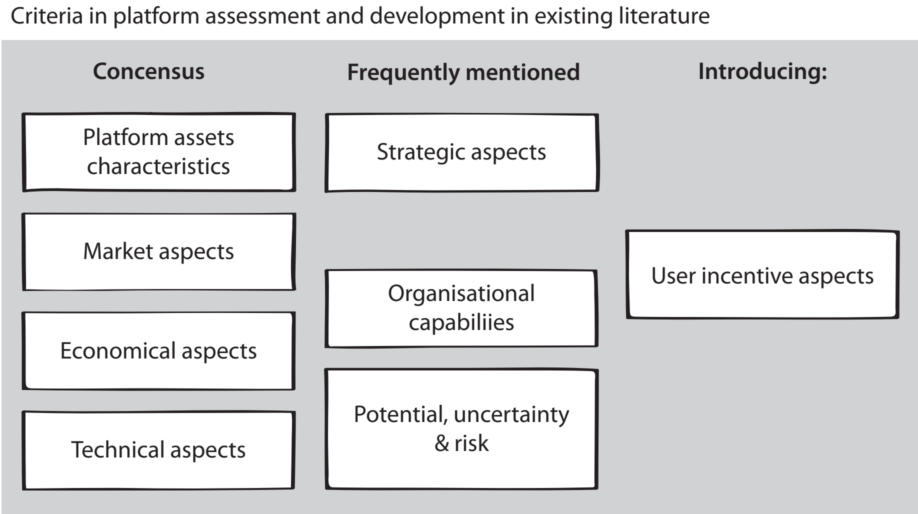


Figure 7.14: Design of a platform must not only meet criteria regarding platform elements, market, economical and technical aspects: It must also consider of user incentive.

This new aspect is not more important than the already in existence, but an addition. Further research should look into this and have the challenges regarding this criteria can be met.

It is a criterion which is openly defined, due to its covering of the varying aspects it addresses and the fact that what satisfies the criterion varies from platform to platform and from company to company. Its' aim is to ensure that it is addressed in the platform development phase, what incentive there is for the platform users to use the platform. The incentive may be obvious and maybe no initiatives are needed, but the issue should be addressed somehow and the eventual necessary effort of making it should be taken into account in the platform development process.

User incentive in the LEGO platform cases

Examples of how the user incentive criterion can be addressed exist in the LEGO platform cases. In LEGO the criterion have been satisfied by one or more of the following:

- Calculation systems , quantifying and show the value of the effects on individual product or item level
- Goal setting and tracking
- Making the platform solution the only one
- Adjustments of the platform solution
- Intensive communication of the platform concept and it use

- Involvement of the platform users in the platform development process

The calculation system however requires some system and data prerequisite, not to mention the challenge of making a calculation model that viably and reasonably describes the cost allocations. It is can however be a significant task, and it must be estimated if it is worth the effort to establish such a calculations system. If done sensibly, showing the platform benefits, it is a very powerful argument, working as incentive for platform use. The goal setting and tracking initiative has similar requisites, and as the goals have to be meaningful and the tracking needs often needs PDM system to capture the relevant data. This has been the case in the Pre-pack platform, the Wheels platform and the Element platforms.

Another way of satisfying the user incentive criterion is to force the use of the platform, by making it the only possibly alternative. The success of this approach is likely to depend on the company culture and product characteristics, and it was partly applied with success for the wheels platform. Adjustment of the platform solution has been relevant in LEGO, in order to make it a more attractive option for the product developers, on account of reduced production costs. This has been the case in the wheels platform and the LBS platform. Finally intensive communication of the arguments behind, the implications of and guidelines for the platform have been necessary for practically all the platforms, being an underestimated task in many of the projects.

Most of the LEGO platforms have an information support system to address the need of communication. A platform user support system can be compared with many other information support systems. The experience from LEGO indicated that such a system should not only describe the platform and its reuse assets or modules, roadmaps, product architectures etc. and if possible show the value of the reusing the platform assets via calculation models. It may also be relevant to explain the prerequisites of the platform and the reasoning behind the platform design. The information support system can also serve as a forum for feedback and input to the next platform generation. Finally it is also important that the system is easy discoverable and accessible. As in most other information systems it (as well as in the development of the product platform in general) it has shown beneficial to involve the platform users in the development to ensure that the system compiles with their need.

These examples are only initial suggestions of how the user incentive criterion can be addressed, based on experienced from LEGO, but future research should look into finding concrete solution elements ensuring user incentive in the use of platforms, which can be designed into the platform solutions.

It is however not always possible to prioritize the platform users and changing the platform design in this direction may not be beneficial for the overall solution. In that case management must take into account the extra resources in terms of developing support systems, information, management follow up or force that is necessary to ensure that the platform is successful. If this implies a change of culture of product development, extra attention must be paid and extra resources must be accounted for.

7.5 Concluding on reasons for deviations and platform user incentive criterion

In order to answer the research question:

"What are the reasons for deviations from the expected effects and goals of the product platforms and are they addressed by platform assessment criteria in literature?"

I argue:

The reasons for deviations from the expected effects and goals of the product platforms can be found within the following issues:

1. The platforms are not used (as much) as intended
   a. Design calculation models do not consider platform benefits and provide the argument for using them.
   b. No goals, benefits or rewards from management
   c. The users consider the trade off, the product platform provides unattractive.
   d. The platforms and their rules are difficult to understand and hence use.
   e. The platforms are not known.
   f. Platform development and use is an extra burden for the product developers.
2. Maintaining the platform and avoid undesired changes of the solution, that erodes the benefits.

3. The technical platform solution did not perform as expected.
4. Multiple errors due to reused new technological solution.
5. Market needs have changed, and the platform solution does not fulfil the needs anymore.

Two of the reasons are related to the technical aspects of the platform and one is related to market aspects. These have significant impact when it comes to the consequences of not meeting the expectations. Like the platform maintenance issue, they are addressed in product platform assessment criteria in literature

The most occurring reason is the lack of use, which covers a number of aspects. The issue concern platform use, maintenance and calculation, support and goal systems. These aspects still impact effective platform-based product development, and resources must be spent on them and attention must be paid to them. Product platform literature on assessment criteria does not address the issue of lacking use of product platforms.

To supplement existing platform assessment criteria in literature, I propose the introduction of a platform user incentive criterion, addressing the aspects of platform user motivation, ability and motivation. The criterion is openly defined, because it is covering many varying aspects addressing the lack of use of product platforms and the main purpose is to ensure that the issue is addressed in the platform development process. Examples from the LEGO platform cases show how the platform user incentive is addressed.

It is also shown how the platform user incentive criterion is addressed in different parts of the platform development process and how it can be described within the model of platform-based product developments internal life cycle.

7.6 Introducing the product platform system model

During the studies of platform based product development, I have lacked a framework how to describe the platform development and utilization internally in LEGO and how the platform works like a system interacting with different elements. In platform literature it is in general only the product related elements, the technical solution and in some cases and the documentation that are described, but based on the studies in this thesis I see a need of a more comprehensive understanding of the platform as a system beyond the before mentioned elements.

Most of the product platform literature address the development of the platform (the preparation phase), and only little the utilization in the product realization or operational phases and the rest of the platforms meetings with other life phase systems. It is however those systems that have been aligned with the product platform, and hence the benefits must be realized. This is also reflected in Elgård's model [1998], where only development activities are included.

Attempting to give more detailed understanding of the phenomena, I introduce a framework to understand of platform-based product development as a process where the platform has meetings with different internal life phase systems. This model is inspired by the model from theory of dispositions showing the products interaction in the meetings with the different life phase systems [Olesen, 1992], the concept of alignment between the structures of the different life phase systems and the products [Andreasen et. al., 2001] and the before mentioned model by Elgård [1998] of platform-based product development as a preparation phase (developing the platform) and an execution phase (utilizing the platform).

The model is also based on the LEGO cases of platform-based product development and illustrates the many interlinked activities and the long term, cyclic process involving many stakeholders in the company.

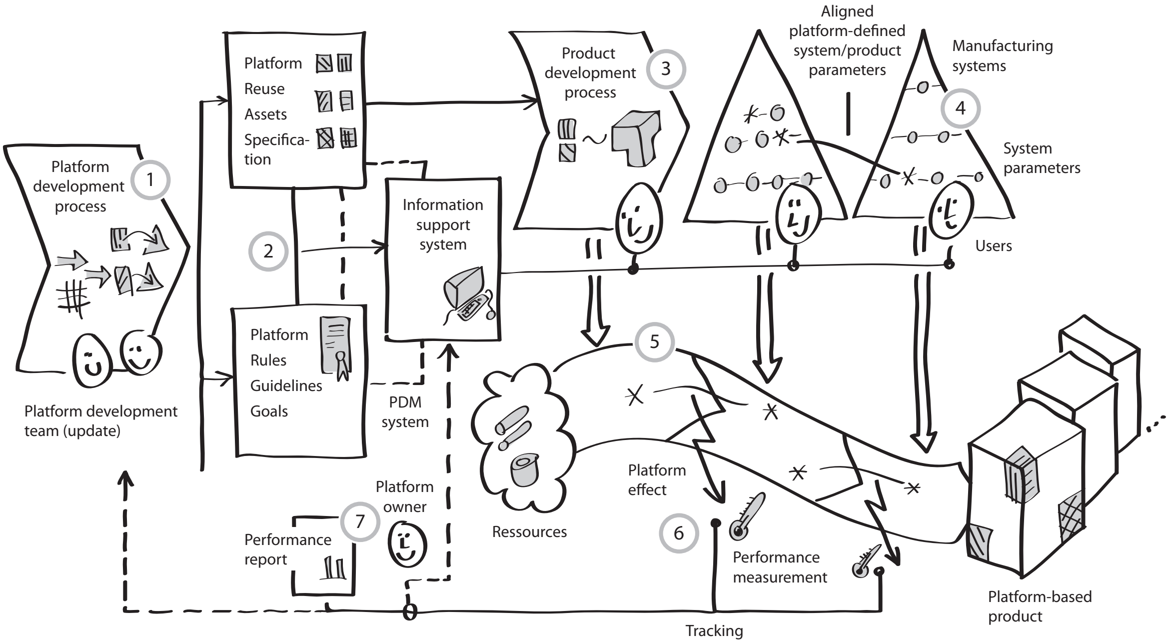


Figure 7.15: The product platform system model describes the process of platform-based product development as a process involving multiple stakeholders in the company.

The model is similar to a process diagram, showing elements and activities. The reuse assets and data systems are represented with input and outputs or meetings, combined with a platform products life cycle. The model hence shows (in parenthesis the number referring to the model).

- The development of a product platform and the platform development team(1)
- The platforms assets and rules or guidelines of how they must be applied and the information system that supports it (2)
- The development of a product and product developer (a platform user)(3)
- The manufacturing life phase systems with aligned parameters (illustrated with stars) and product manufacturer (a platform user) (4)
- The realization of a platform product from resources to finished product (5)
- The platform effects from the product realization and the measurement of them (6).
- The platform performance tracking and reports and the platform owner (7).

Starting from lower left corner, the platform development team designs and develops the product platform, resulting in the platform assets, elements or modules and the rules by which they must be applied, represented in roadmaps, specifications, goals and other directions. These are preferably integrated in the PDM system and linked to a communication system that makes it possible to retrieve knowledge about the relevant aspects of the platform. It is also through this communication that the relevant parameters (illustrated with stars) are chosen in the development of the individual product and in the aligned manufacturing systems. This alignment of the systems is creating the platform effects in the realization of the product. Finally the measurement of the effects of the platform shows the performance of the platform, which serves as feedback to the platform owner, maintaining the platform and eventually the platform development team.

The model, depicted in Figure 7.15, shows how such the platform system must capture the guidelines, rules, and the modules and architectural design. The relevant information about the platform is made accessible to all the platform users in the different operational life phases, creating the desired benefits, and valuable feedback is brought back to the platform development organization, and if necessary results in an update of the platform, an entirely new one or no platform at all, depending on the performance.

The model is framework for understanding the process in LEGO, providing an overview and linking the research questions. The questions are related to the model in the following, referring to its' numbering. The answer to the first research question describes the process of estimating of the platform effects (no. 6) is part of the platform development process (no.1 in figure Figure 7.15). Addressing second research question answers how well the platforms achieve the expected effects (no.6) in the realization of a product (no.5). The reasons for possible deviations are sought for in the product development phased (no. 3) and the manufacturing systems (4), answering the third research question.

The model also supports the understanding of the platform user incentive criterion and how it is addressed. Following the process arrows, starting in the lower left corner, the incentive is addressed in one or more of the following:

- In the platform development process (no. 3), by involving users creating understanding of the effects
- In the platform assets, being attractive options (no.2)
- In the use guidelines (no.2), providing goals and tracking the performance (no.7)
- In the communication system, presenting relevant information and showing the value of the effects

All these aspects can create the incentive for the platform users to use the platform assets, which creates the platform effects.

7.7 Recommendations based on the LEGO cases

Based on the answers of the research questions five recommendations have been made, aiming at improving the performance of product platforms. Multiple guidelines already exist (e.g. Robertson & Ulrich [1998], Nieuwland [1999], Andreasen et al, [2001] and others described in section "3.4 Platform design and development models" about platform literature). The findings from this study support many of the recommendations in from literature, but some of them have not been described, and I find that they could contribute to the existing recommendations on platform-based product development. The five recommendations concern the platform user incentive criterion, focus on down-stream effects, focus on data modeling and viable estimation and quantification of internal effects, facilitation of platform performance tracking and goal-setting and finally understanding of a product platform as an internal system in the company. They are described below:

1. *Platform user incentive criterion*
   The first recommendation responds to the identification of the lacking use of platforms. A platform user incentive criterion in the platform assessment addresses many different aspects that may cause that the platform does not achieve the expected effects. The criterion and how it can be meet is described in details in section "7.4 Addressing the lack of platform use".
2. *Focus on identifying down-stream effects*
   The second recommendation suggests more focus on the down-stream effects (in e.g. manufacturing and production planning), since these have shown great potential in the LEGO cases. If these effects are identified, they may provide the arguments for at product platform. The down-stream effects identification process in LEGO is described in section "7.1 Identifying and estimating effects".
3. *Focus on data modeling, viable estimation and quantification of internal effects*
   The third recommendation suggests more focus on the data modeling, estimation and quantification of internal effects based on these. In LEGO we have seen how viable estimates were made and verified by the platforms performance. The approach has shown its' impact in LEGO, combined with willingness to make decisions. Besides providing arguments for the platforms in the platform development phase, the quantification also enable calculation tools that assigns value individual platform assets in the execution phase, supporting platform users. The estimation and quantification of effects and examples of data modeling are described in "7.1 Identifying and estimating effects" .
4. *Facilitate platform performance tracking and goal-setting*
   The fourth recommendation is based on the experiences from LEGO. Here the results of tracking platform performance goals have ensured the platform effects were achieved, providing experience and arguments for future platform projects. It also ensures that the platforms are optimized and improved if necessary. This is basic goal setting theory, but not paid attention in platform-based product development. The effects tracking and goal setting is described in "7.1.2 The approach to effects and goals".
5. *Understand a product platform as an in internal system in the company*
   The fifth and final recommendation is based on the sum of the above recommendations, which altogether describes a platform as an internal system in the company: A system that interacts with other systems and goes through different phases. The Platform System Model (section "7.6 Introducing the product platform system model") illustrates the system, the process flow of information and activities. It also provides an understanding of a product platform's many aspects and the different challenges that must be addressed. The model supports the recommendation of a system-oriented approach to platform-based product development.

The above recommendations must be understood as guidelines and it must be taken into account that there have been special prerequisites in LEGO, making them relevant. In the next chapter the recommendations are presented to industry representatives to validate the relevance.

Part 8
Validating the research results

In this chapter the validity of the research findings is discussed. The results of this thesis should be evaluated on how well they are validated and also show how strong the results are and where they may benefit from stronger evidence. The findings are validated by comparing them to results from an industrial interview study. The overall validity of the study and how it has been challenged via feedback from academic fellows and peers, LEGO employees and industrial representatives is also discussed.

8.1 Industrial validation with company interviews

In order to validate the relevance and generalizability of findings they were presented to and discussed with representatives from 12 Scandinavian companies. First some common characteristics are described in a general input-output model and the companies are categorized into five different groups, depending on their approach to platform-based product development. Then the results of the interviews are compared with the answers of the three research questions and the recommendations.

8.1.1 Companies in the industrial validation interview study

12 Scandinavian companies participated in the interview. They all apply platform-based product development (from the group of 15 companies that was contacted, 2 did not apply platform-based product development and one had only been doing so for less than one year), see Table 8.1 and the methodology chapter for further details.

Company	Applies platform-based product development
Haldor Topsøe	X
BK Medical	X
Glunz &Jensen	X
Radiometer	X
Nokia	X
Martin	(for less than one year)
Grundfoss	X
B&O	X
Vestas	X
Coloplast	X
Oticon	X
Nilfisk	
Foss	X
Novo Nordisk	
Wartsila	X

Table 8.1: List of companies that were interviewed to validate the research findings

8.2 Platform Development Process Input - Output model

The companies had a similar approach to how the platform development teams worked with platforms – the input information and reactions from the surroundings and the output describing the platform. To give an impression of the concepts of platform-based product development in the companies, I introduce a model, describing the input to and output from the platform development process from the view point of the platform development team. The description is derived from interview notes, which were made during the interviews and provides an understanding of the platform development context in the companies.

The model uses the framework of Theory of Technical Systems to describe the platform development process. The model, depicted in Figure 8.1) describes input elements, resulting outputs and tasks of the development process itself. Like in the product development process there are both inputs and outcome and tasks to be performed, but they are different when developing a platform.

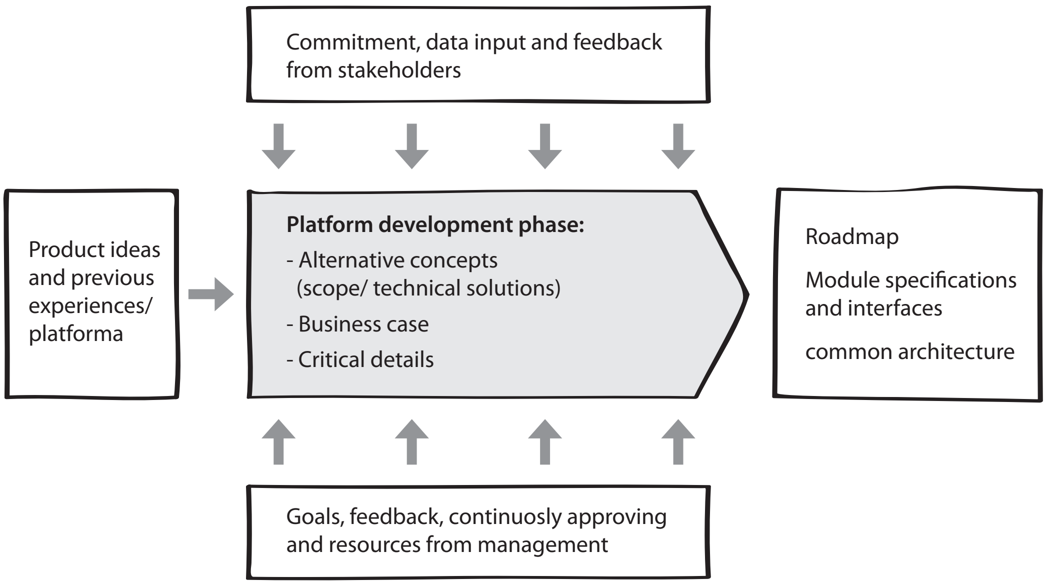


Figure 8.1: The Platform Development Process Input –Output Model

First of all the outcome is different: Instead of a product design, a system of partly defined product designs, described by a product/ module roadmap (showing which modules that are part of the different products and when), module specifications and interface designs and possibly also a common architecture description must be developed.

The information input is ideas for several products (and the reuse across them) instead of one often followed by a strategy to achieve on or more benefits with the platform design. Also there is input and feedback from management, setting the goals and providing the resources, from milestone to milestone. Often there are also a number of stakeholders (i.e. technicians, product development teams or the representatives from different of the products' life phases) which are affected by the solution and have to support the platform solution to make it a success and provide data input from the different life phase systems.

Within the process a number of tasks must be performed, like in single product development, in this case the creation of the contents for a number of documents and the supporting analysis:

- A business case is often required to describe the financial consequences of the solution
- A number of alternative concepts must be investigated, both regarding the platform scope and technical solutions, where new information is constantly found and must be incorporated in the solution and business case.
- Critical details may be clarified, if being crucial to the project foundation

The contents of these different elements are refined within different loops, analyzing and finding solutions for new occurring problems.

8.3 Categorization of platforms

The companies applied platform-based product development in many different ways and it was different assets that they reused: From small platforms of manufacturing modules for testing of product ideas and productions methods (Coloplast) to comprehensive platforms with physically reuse of modules in the products (Radiometer, Glunz & Jensen, Foss, Nokia, Martin, B&O, BK Medical), and in other cases specification and drawing reuse (Grundfoss, Haldor Topsøe and Wärtisila)

After the interview the companies were grouped in depending on w their approach to platforms and reuse. The groups emerged during the study and are described below and in more detail in Table 8.2. The group number partly reflects a maturity level, because the companies often start out with type 1,2 or 3, but it is not necessarily beneficial for a company to aim for the type 4or 5 if it does not suit e.g. the products, market requirements or product culture. The table indicates that the different desired effects are associated with different approaches to reuse and platforms.

Group 1: Random reuse

In the first group, the platform is based on random reuse, where assets of an existing product is used in a new, but it was not intended nor planned. The reuse exists in 2-3 products.

Group 2: Overlap

Most companies fall into the second group. In this group the platforms cover 4-6 products and the modules are usually used in 2-3 generations of the products. The modules are shifted, so that e.g. a number of modules overlap those 2-3 generations, while a number of modules are renewed, and vice versa for the fourth- sixth product generations. The products and platform is developed by the same product developers. The desired effect is the reduced development time that makes it possible to introduce products, upgraded with new modules, more often.

Group 3: Rationalization

The third group is where a number of products exist (developed on individual basis and possibly in need for an update) and it is identified that there are common requirements for them and a technological solution that can be reused. The products (6-12) are then redesigned as a group, based on a platform, which rationalizes the total product group, aiming at cost reductions, reduced lead time in production or reduced complexity. The platform development team can consist of both product developers and technical specialists, but often only in a limited period of time.

Group 4: Strategic – product family based

The fourth group of companies has platform-based product development as strategy, meaning it is the standard way to develop and realized products. Modules are developed to a set of requirements, aiming at a group of 6-12 products, a product family, which products exist both at the same time and across generations. The modules are developed in a platform organization parallel to the product development organization. There are system s to support this in place, both organizationally in terms of platform owners and departments, and data management wise with documentation practices. The desired effect is mainly to increase the revenue with a high number of products with great variety, which would be too complex and time consuming to develop on individual basis.

Group 5: Strategic – functionality based

The final group of companies also applied platform-based development approach as standard as part of the strategy like the fourth group.

There are system s to support this in place, both organizationally in terms of platform owners and departments, and data management wise with documentation practices. In this group the modules were developed for functional and interface requirements in an organization parallel to the product development organization. The product development process is more of a configuration process, because almost all functionalities have dedicated modules. For the products in this group quality and low failure rate is important, and by reusing solution , the risk is minimized and the development time reduced. Hence the module are primarily reused across product generations.

Platform type	Random	Overlap	Rationalization	Strategic – product family based	Strategic- functionality based
No. of companies	1	5	2	2	2
Platform and reuse approach	Random reuse, based on individuals' insight and agreements. Little if any coordination nor planning "Use what we have" strategy	Planned reuse of designed modules, based on overall architecture and future modules and products Modules developed with carrier product, having top priority	Update of a larger group of product variants (often at same time) Modules developed based on product group characteristics and tradeoffs	Planned reuse of designed modules, based on product family architecture Modules developed based on carrier product with top priority	Modules contains functions, that can be configured to the individual customer – planned reuse or by demand from the customer Modules developed based on functional requirements, adjusted to interfaces
Desired effects/ drivers	Not clearly defined	Mainly development time (inc. quality tests, production setup ect.) Also cost reductions due to economies of scale, when used in many products at the same time	Cost reduction due to economies of scale Lead time in production Complexity reduction	Enables product variety (recognized as necessity): Only way of developing multiple products variants at the same time Development time	Development time Quality and safety
Market characteristics	-	Specialized, relatively homogene	Differentiated and consolidated	Differentiated	Consolidated
Speed of technological development	-	Medium	Both slow and medium	High	Medium
Modules reused over product over time or at the same time	Over time	Over time, occasionally at same time	At the same time and over time	At the same time and over time	At the same time and over time
Typical no of products in platform	2-3 products	4-6	6 -12	6-12	All in company
Documentation and tools	No platform documentation	Use of tools like roadmaps architecture and module description	Use of tools like roadmaps architecture and module description	Use of tools like roadmaps architecture and module description	Use of tools like roadmaps architecture and module description
Organization and platform owner	No organization Unofficial owner	Parallel Platform organization Official owner	Platform development team in limited period	Total platform organization Official owner	Total platform organization Official owner

Table 8.2: The characteristics of the five different groups of product platforms. The grouping and the characteristics emerged during the interview study.

8.4 Interview structure

The company representatives were usually a platform owner/ developer and a platform user (often product developer). At first they were asked to tell about how their company worked with platform-based product development and about their product platforms, in order to understand their perception of platform-based product development and its core concepts and ensure that it was in line of this research. This was done both to be able to ask relevant question and to assess if they were relevant as data source. After their own description they were asked follow up questions, concerning relevant issues they had not addressed (See the interview guide, "Appendix 2: Material for industrial interviews").

Then some of the LEGO cases a platform case from the danish company Grundfos to illustrate the span of the platform concept were presented together with different aspects of the answers to the research questions and the recommendations. Then they were asked the following questions, reflecting the research questions and recommendations:

- What effects they expected their product platforms to achieve (to ensure that the comparison was relevant) and to which degree their platforms achieved the expected effects (reflecting research question 2) to validate the conclusion on how well platforms perform.
- Describe the challenges they had encountered in their work with platform-based product development, what the reasons there may be for deviations in the expected effect in order to validate phenomena of lack of platform use as a reason for deviations (research question 3). In this relation they were also asked to comment upon the introduction of a user incentive criterion.
- Comment on the relevance and appropriateness of the model for identifying effects and specifying goals, which was presented to them (reflecting research question 1), compared to the similar processes in their own company to validate the relevance of the model.

The interview guide and presentation material can be seen in "Appendix 2: Material for industrial interviews". The answers from the interviews can be seen in "Appendix 3: Data from industrial interview", and are summarized below.

8.5 Validating achievement of expected product platform effects

To see if the findings from LEGO regarding the achievement of expected effects also apply for a sample from industry, I compare how well they have achieved their expected effects.

Regarding what effects the companies wanted to achieve with platform-based product development, there were many different types, which are listed in Figure 8.2.

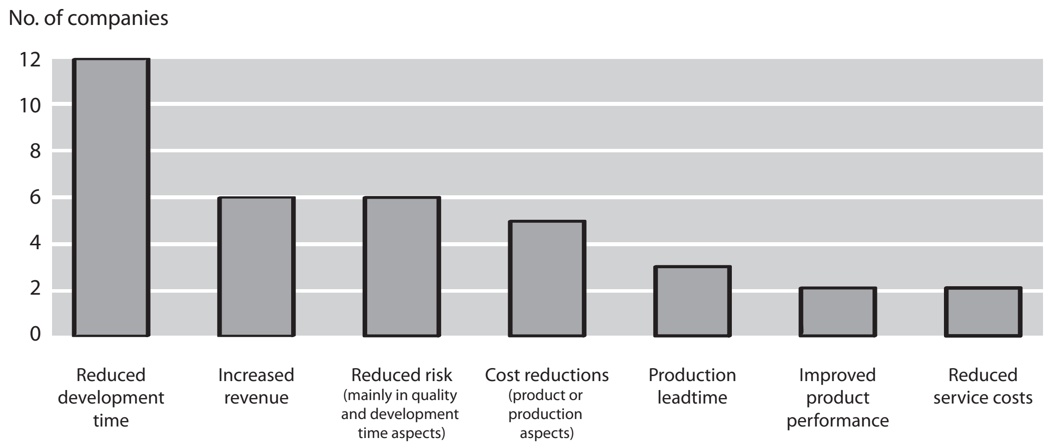


Figure 8.2: Expected effects from platform-based product development. The effects the interviewed companies expected from platform-based product development

Using these companies in comparison to LEGO, it must be noted that in LEGO the general focus was primary on cost reductions and secondary reduced development time. Only five of the twelve companies have the same focus and hence I put extra focus on this subgroup, hereafter referred to as "the subgroup".

The companies were on different level, when it came to actually ensuring that the expected benefits were achieved.

- 9 and all 5 of the subgroup of the out of the 12 companies state that they in some cases measure the effects and have some specific goals. It is mainly the development time that is in focus, some state that it is not possible to measure the cost reductions or that they don't have the data that enables such a measurement. All companies however supported the recommendation of tracking platform performance and setting goals.
- Regarding the achievement of the expected effects and/or goals, all 12 state that they are successful in applying platform-based product development time, but half of them also state that they achieved fewer effects than expected. This goes for 3 in the subgroup. It must however be noted, that one year after the interview one of the companies scaled down the strategy of platform-based product development, due to lack of results and a new market strategy.

The overall picture shows that the companies do achieve significant results with product platforms, which supports the conclusion from the LEGO study, but also often less results than they expected. This is even more significant in the subgroup, where this is the case for 3 out of 5 companies. Two aspects are however worth noticing concerning the validity of this data:

- It is based on statements from one or two company employees and has not been confirmed by actual data. According to Breakwell[1995] the interviewee may have various conscious or unconscious motives not to tell the truth. This may be the case when the platform owners or user are interviewed, that they give a more positive image than real life exaggerating the positive result. That is why the analysis of the data always must be done with the source and possible motives in mind.
- 1/3 of the companies do not keep track of the platforms performance, despite they recognize it as important. This makes the statements about the performance less valid. This indicates that the need of platform performance tracking is also relevant in the industry

Comparing only the subgroup (aiming to achieve similar effects as LEGO), it seems that the LEGO platforms are performing better than subgroups platforms: 3 out of 5 companies state that they achieve less results than expected, whereas the LEGO platforms leveraged less effects than expected in 5 out of 8 cases. This is however not fully comparable as it compares number of companies that have achieved effects with individual product platforms in LEGO, but it gives an indication of the performance relation.

In general half of the companies state that they achieve the expected effects.

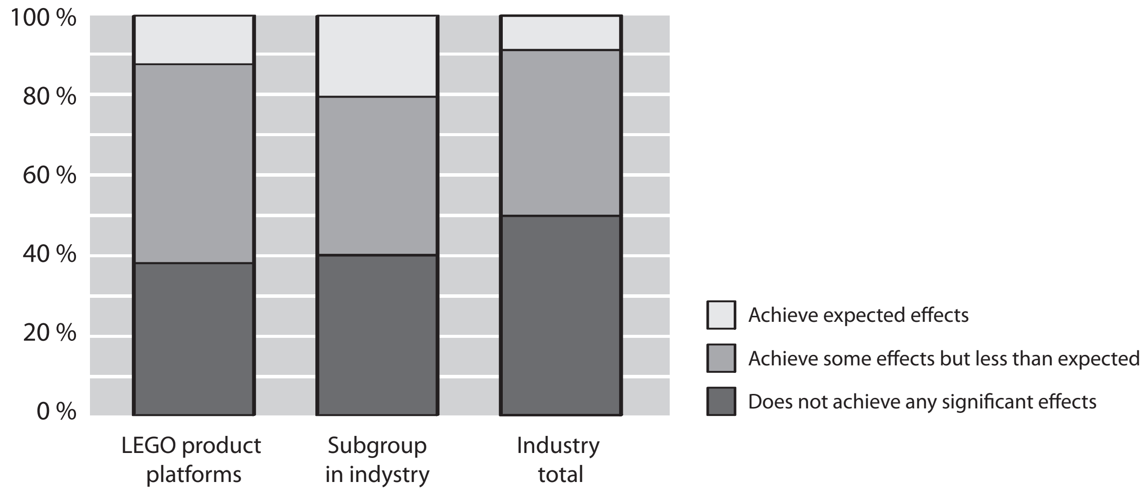


Figure 8.3: Platform performance in the industrial subgroup vs. the performance of individual platforms in LEGO.

Therefore the LEGO specific answer to the second research question is supported by the industrial validation study. It is worth noticing that half of the companies report that they don't achieve the expected effects and that 1/3 of the companies do not track their platforms performance, despite recognizing the importance of it.

8.6 Validating the lack of platform use as deviation reason and relevance of platform incentive criterion

It is necessary to validate that the platform user incentive problematic is relevant outside LEGO, i.e. in other companies, and that it is relevant to introduce a platform user criterion as assessment criteria in platform-based product development. Hence the company representatives were asked what challenges they had encountered and what reasons that had caused the platforms to not meet the expected effects (if that was the case). It was put as an open question to get their spontaneous and uninfluenced feedback, and the resulting statements are shown in the two lists below, showing respectively the challenges and the reasons for deviations. The list of deviations must also be understood as challenges, but they also led to lower platform effects:

Challenges in platform-based product development (Industrial study)	No. Of companies
Specifying interfaces, making the right cut and technical solutions	6
Cooperation between platform and product development organization (incl. work affiliation)	4
Getting data to calculate platform benefits	3
Making benefits viable to management and other departments, e.g. sales organization	3
Making the right fit between price and performance (avoiding overen-gineer and maintaining competitiveness)	3
Making supreme solutions (compared to product development organi-zation and suppliers)	2
Organizational maturity: work organization and affiliation	2
Make mangement keep sticking to the platform	2
Dealing and agreeing with steering committee with leaders from differ-ent departments (different interests and viewpoints)	1
Making platform documentation	1
Integrating the product platform in company IT systems	1
Portfolio decisions and the overall scoping of products and their fea-tures	1

Table 8.3: Challenges in platform-based product development (Industrial study)

Reasons for deviations in platform performance (Industrial study)	No. Of companies
Platforms users don't use the platforms	3
Practical design problems: EMC and thermical problems	3
Bottlenecks in supply of platform components	2
Platform errosion	2
Platform development time is longer than expected	2
Market conditions change	1
Production conditions change	1
Making too big and hence difficult platforms and modules	1
Geographical distance between platform users and product developers	1

Table 8.4: Reasons for deviations in platform performance (Industrial study)

The lists only show, how many companies that mentioned a certain issue (and some of the issues may overlap slightly) and not how big an issue it was, hence it only shows occurrence and not necessarily importance.

The list holds much interesting data, which has potential and may deserve a more thorough analysis. This is however not the scope of this research and I will only conclude that most of the challenges and reasons for deviations in the list in are recognized in literature and that the issue of the platforms not being used by the platform users is mentioned by three companies (two are in the subgroup).

Going deeper into the reason for this lack of use in the three companies, they state the following reasons:

- The product developers don't use the platform solution, because they don't like the tradeoff they entail.
- Internal calculation models do not support the platform solutions
- The product developers have not received enough information about platform
- Changed market demands have made the platform solution a bad choice
- Platform use is an extra burden for the product developers

The explanations are similar to the ones causing the lack of use of platforms in the LEGO cases. The major part of them also underlines the need of thinking along the lines of user incentive in the platform use.

After the immediate statements presented above, the companies were introduced to the findings from LEGO regarding lack of use of the platforms and were asked to relate to them. Now the company representatives were specifically asked about whether the platforms were used as much as intended, and in this case half the company representatives responded positively, doubling the number that mentioned the issue on their own initiative.

The following list shows how many of the 12 companies that found the different reasons for the lack of use identified in LEGO, were also relevant in their company (the number in parenthesis):

A. Design calculation models do not consider platform benefits and provide the argument for using them. (6)
B. No goals, benefits or rewards from management (6)
C. The users consider the trade off, the product platform provides unattractive. (4)
D. The platforms and their rules are difficult to understand and hence use (3).
E. The platforms are not known (3)
F. Platform development is an extra burden for the product developers (5)

These statements illustrate that the lack of use of product platforms is not solely found in LEGO. Note the high number of companies mentioning that platform-based product development is a burden; they also argue that it is the only competitive way to develop these products.

The other 6 companies stated that the problem of lack of use of the platforms was not relevant in their case. In these cases the platform use is defined based on products and the structure is in place for all products and no other solutions were allowed.

All companies however agree that there must be some sort of motivation. 11 of them were positive towards the recommendation of having a platform user incentive criterion in some form as part of their platform development process, verifying the relevance of the criterion and the first recommendation. 7 companies (and 3 in the subgroup) believe that the product platform should be accepted from platform users to some degree, but some of the companies also stated that sometime they don't have the time to go through the process. Finally one representative said that the product developers just had to use it, which is also a strategy for platform use.

The companies responses to the rest of the reasons for deviations in LEGO can be seen in "Appendix 3: Data from industrial interview".

The above findings support the answer to the third research question and that the lack of platform use is a reason for deviations in platform performance is supported by industry, and the recommendation of a platform user assessment criterion was likewise supported.

8.7 Validating the model of the process of estimation

The answer to the first research question resulted in the descriptive model of identifying and estimating effects. To validate the relevance of this model, it was presented to the company representatives and they were asked to compare it to their own process and comment how relevant the model was in that context:

- 4 companies (2 from the subgroup) stated that it was a similar process they went through, however in some cases without the goal setting activity and evaluation process.
- 3 companies stated that they were aiming for such a process, but they were not there yet, since they were not as thorough in the modeling of scenarios and making of specific estimates were made, one of the companies substantiated it with lack of the relevant data.
- 5 companies stated that the process was not so relevant to describe their process, either because
    - They did not involve so many stakeholders(mainly the product developers) or
    - They have a core product determining the product platform at large, and hence there were little efforts put in the modeling of the total effects of the platform, only for the core product or
    - The product platforms were more strategically than financially reasoned and not so much focused on estimating the internal effects, which are in focus in the descriptive model.

Altogether the model received approval with more than half of the companies as being relevant, however in 3 cases partly as a prescriptive model more than prescriptive as it was for some companies. None of the

12 companies said that it was not relevant. The support to the model also complies with the recommendation of data focus and quantification of effects, where 5 companies agree, 5 agreed with comments ("It is not always necessary", "It is not always possible to estimate realistic numbers"), and two representatives disagreed, because their platforms were strategic projects.

The representatives were also asked to comment upon the recommendation of a downstream focus, when identifying platform effects and 7 supported this, whereas 5 replied that it was not relevant or in focus in their platform-based product development. The final recommendation regarding the understanding of a platform as a system that needs to work inside the company illustrated by Product Platform System model was supported by 11 of the companies, whereas representatives from one company did not perceive product platforms in that way.

Based on the above evaluation of the model the answer to the first research question is supplemented with the fact that the model received moderate support in the industrial study, where half of the companies recognized it as relevant. And that the representatives also regarded the model as describing a more thorough analysis and modeling, than it was the case in the companies.

8.8 Concluding on industrial validation

Based on the series of industry interviews I conclude the following regarding the validity of the research results:

- The tendency that product platform do deliver significant results, but not effortlessly and not always as good results as expected, was confirmed. The companies were in general though more focused on effects in the product development (reduced development time) compared to the focus on cost and downstream effects in LEGO. The results regarding platform performance in LEGO appeared to be slightly above average compared industry.
- There were multiple different challenges and reasons for the platforms not always leveraging the expected effects. Among these was the issue of lack of use of product platforms, which was also confirmed to be a relevant issue to address in industry as in LEGO (but not the most critical).
- The reasons in industry for lack of use of the product platforms are similar to the ones found in LEGO and supported the notion of thinking of platform user incentive. A platform user incentive criterion in the platform development assessment was also supported by the companies.
- The descriptive model of the identification of effects and specification of goals was regarded as relevant by more than half of the industry representatives and similar to the process in their companies. The representatives also regarded the model as describing a more thorough analysis and modeling, than it was the case in the companies. This indicates that the platform development processes in LEGO has been profound in identifying, modeling and estimating effects and specifying goals.
- The recommendations derived from the LEGO platform cases regarding having a platform user incentive criterion, tracking and goal-setting in platform performance and platform system understanding was fully supported, whereas the recommendation about focus on data and effects estimations was not supported by two companies and the recommendation about having downstream focus in identifying potential effects was not regarded relevant in five of the companies.
- Based on the company interviews, five different approaches to platformbased product development was idenfied, illustrating how different reuse strategies are related to the expected effects of the platform. A model describing the in- and output of the platform development process was also introduced.

8.9 Overall validity evaluation

In the methodology Olsen's approach [1992] to validity and its characteristics, internal logic, truth, acceptance, applicability and novelty value was introduced. These characteristics will be used as a framework to discuss and evaluate the validity of the research results.

- *Internal logic*
  A research result is internally logic when consistency between the research motivation, the hypothesis and the research results exists. In addition, the research has to comply with known theory that is accepted. The writing of this thesis hopefully demonstrate the consistency between the research motivation, the hypothesis and the research results exists. That the research complies with known accepted

theory is hopefully demonstrated in the sections with literature studies and also in the presentations in academic forums and published articles.

- *Truth*
  A research result can be claimed to be true when the theoretical and practical implications of the result can be used to explain phenomena that are founded in reality and not just theory.
  This research is based on 8 case studies in LEGO and the phenomena, it explains, are hence found in reality. To further assure this relevance of the research results and their implications, it was compared with industrial empirical data from 12 other companies. In order to assure the truth regarding the description of the cases and the data, the research results were based on triangulation (having minimum three sources) and systematic comparison of those different sources.
- *Acceptance*
  A research result has to be accepted by a research community and industrial practitioners in order to be valid. Via discussions, conference presentations and publishing of the main results in journals, acceptance in the research community is achieved. LEGO employees have participated in the development of models and have provided acceptance for how they describe the phenomena. Industrial practitioners have been presented for the findings and supported them and the relevance of them via the company interview study.
- *Applicability*
  The research result has to be applicable in practice in a real industrial setting. Since the results are derived from cases, where the actual actions have been carried out and have been successful to large extent, they have at least shown their applicability in LEGO. The benefit of having a high number of platform cases from same company is that they reflect a more comprehensive picture of how the product platforms are actually used, than individual success stories. All the platform cases being from LEGO means that generalization of the findings can be argued, since they are based on data from one company. Many of the findings are not product specific and based on very different platforms from different areas of the organization, but based on the mentioned prerequisites it is still possible to generalize some aspects and make the findings relevant for other companies, but other studies are necessary to support the above findings. To strengthen and perspective the conclusions, a study of multiple companies on the same aspects is conducted to compare the results to.
  The general applicability has been investigated in the interviews with the industrial practitioners, where e.g. the applicability of a user incentive criterion is seems reasonable, since the companies support this initiative, but it only indicates the general applicability, which must be further investigated.
- *Novelty value*
  The research result has to have newness, i.e. have to provide new approaches or new realization. The novelty value of the findings is show by the fact that no other study is this comprehensive in terms of verifying internal performance of product platforms this thoroughly. Furthermore the research identifies and documents a new reason for why platform do not always deliver the results and introduces new criteria addressing this issue. Finally the research introduce a descriptive model for how effects are identified and goals specified based on successful product platforms, a process which has not been described previously. Altogether this research provides new realization of product platform performance and how it can be improved.

Based on the above evaluation of the validity, I find that altogether the research results do fulfill the validity requirements to a satisfying degree, but there is still a need to explore the applicability and to develop independent research results that confirm the findings.

Part 9
Conclusion

In the conclusion the results of the thesis are outlined: The answers to the research questions, the models that have been introduced and the recommendations, that have been presented. Limitation and academic and industrial implications are also discussed.

9.1 Concluding on the research

The aim of this research was to improve understanding of platform-based product development by studying platform performance in relation to internal effects in companies. The thesis describes the process of estimating the internal platform effects, documents performance of product platforms, i.e. if the expected results are achieved, and identifies the reasons for why the achieved effects in some cases deviate from the expected. These aspects are addressed by answering the three research questions below, based on the long term study of eight LEGO platform cases and the industrial study. The concluding answers to the research questions are presented in the following:

9.1.1 Answer to the first research question (RQ1)

RQ1: How can a process of identifying and estimating internal effects of product platforms be described?

The process of identifying and estimation internal effects can be described as a process consisting of four phases, being:

- First phase: Concretizing the platform idea and analyzing effects of status quo
- Second phase: Identifying effects from life phase systems
- Third phase: Estimating and quantifying effects from scenarios and specifying goals
- Post-development phase: Goal evaluation and revision

The process description is based on studies of eight platforms in LEGO. The process starts with a search, based on presentation of possible reuse assets, and representatives from relevant life phase systems relate to it and reflect upon how it would change the product and their work. From the representatives reflections a number of effects and mechanisms can be identified and be used in the further development of the platform solution and to estimate the size of the effect.

The estimation and quantification of the internal platform effects is based on key historic data (cost, sales figures, investments, development time etc.) combined with estimates from experienced representatives from the different life phase systems. The approach to the estimation is thorough and facts-based including financial aspects, in order to ensure the most viable result. The quantified effects are then summed up, either based on the differences from the existing solution or based on total figures, to represent the platform effect together with a presentation of the platform concept.

The estimates are often reflected in operational goals for the platform users, and different kinds of operational goals can be identified. When the platform has been used and knowledge of the actual effects is achieved, the platform may be revised.

The model received moderate support in the industrial study, where half of the companies recognized it as relevant.

9.1.2 Answer to the second research question (RQ2)

RQ2: Do product platforms achieved the expected effects?

Product platforms predominantly achieve significant effects: In the LEGO study, three out of the eight platforms three performed satisfyingly and met their goal, four platforms performed somehow satisfying but did not meet all their goals and finally only one platform was not performing satisfying. Hence the

LEGO platforms produce good results, especially the mature platforms, but there is still room for improvements.

In the industrial study it is reported that half of the platform achieve the expected effects, but this is however on a less valid basis, as 1/3 of the companies state that they don't measure the platform performance despite recognizing the importance of it.

The expected platform effects reported in the industrial study are:

- Reduced development time
- Increase revenue
- Reduced risk (mainly in development time and quality aspects)
- Cost reductions (product or production aspects)
- Production lead time
- Improved product performance
- Reduced service costs

The LEGO platforms create internal effects in both product and production equipment development and in the manufacturing of the products, such as reduced development time and cost and production cost and risks. The main results are listed below and the percentages refer to the areas within the platform scope and not on product family level:

- Reductions in number of components (up to 50 %) and future limitation
- Reduced product development time (up to 25-30 %)
- Reduced production equipment development time (up to 30%)
- Reduced production cost and investments (up to 25-30 %)
- Reduced risk of obsolete products or production facilities

It is in the downstream phases where the most significant benefits have been achieved. Compared to other cases and studies described in literature, the effects achieved in LEGO are remarkable, not a least because they are significant in a comparable group of case. The achieved effects are more moderate than the ones described in literature and the achieved effects are documented and verified. The cases contribute by showing a more comprehensive and detailed picture of the variety of performance and failure in a group of comparable, yet different platforms, studied in detail over time. The study also shows how many different applications and possibilities the platform-based product development can have within a single company.

The relatively small differences between achieved and expected effects shows that it is possible to make viable estimates, as done it the described process of the LEGO cases.

This verification of significant achieved effects strengthens the validity of platform-based product development as a powerful approach to create significant benefits and gain competitive advantage.

9.1.3 Answer to the third research question (RQ3)

RQ3: What are reasons for deviations between achieved and expected platform effects and are they addressed by platform assessment criteria in literature?

The reasons for deviations from the expected effects and goals of the product platforms can be found within the following issues in the LEGO platform cases:

1. The platforms are not used (as much) as intended
   a. Design calculation models do not consider platform benefits and provide the argument for using them.
   b. No goals, benefits or rewards from management
   c. The users consider the trade off, the product platform provides unattractive.
   d. The platforms and their rules are difficult to understand and hence use.
   e. The platforms are not known.
   f. Platform development and use is an extra burden for the product developers.
2. Maintaining the platform and avoid undesired changes of the solution, that erodes the benefits.
3. The technical platform solution did not perform as expected.

4. Multiple errors due to reused new technological solution.
5. Market needs have changed, and the platform solution does not fulfil the needs anymore.

Two of the reasons are related to the technical aspects of the platform and one is related to market aspects. These have significant impact, when it comes to the consequences of not meeting the expectations. Like the platform maintenance issue, they are addressed in product platform assessment criteria in literature.

The most occurring reason for deviations is the lack of use, which covers a number of aspects. The issue concern platform use, maintenance and calculation, support and goal systems. These aspects impact effective platform-based product development, and resources must be spent on them and attention must be paid to them. Product platform literature on assessment criteria does not address the issue of lacking use of product platforms.

In the industrial study reported a number of reasons for deviation, both concerning lack of platform use, technical design problems, bottlenecks in production, platform erosion, long platform development time among others, which are addressed by platform literature. Hence the lack of platform use as a reason for deviations in platform performance is supported by the industrial study.

9.1.4 Recommendations and models

To address the lack of platform use, a user incentive criterion is introduced. Alongside with the recommendation of a platform user incentive criterion, recommendations are also made regarding focus on down-stream effects, modeling and viable estimation and quantification of effects, facilitation of performance tracking and goal-setting and finally to understand a product platform as an internal system in the company. The last recommendation is supported by the Platform System Model, which was introduced to illustrate platform-based product development more comprehensively.

The recommendations were fully supported in the industrial study, except for the recommendation about focus on data and effects estimations and the recommendation about having downstream focus in identifying potential effects, which received moderate support.

The above results represent new knowledge within the field of platform-based product development as

- the process of identifying and estimating internal platform effects has not previously been described
- actual achievement of platform effects id documented and verified in more thoroughly than in existing literature
- a new platform assessment criterion is introduced, the platform user incentive criterion, addressing the lack of platform use
- new models are introduced describing a product platform a system, the input to and output from the platform development team, along with a categorization of five different approaches to platform-based product development seen in the industrial study.

9.1.5 Limitations

The limitations of these findings are that the study focused on the achievement of internal platform effects (due to the characteristic of the LEGO cases). These internal effects must always be supplemented by external aspects, when discussing the overall performance of product platforms. Similarly there may be important internal effects that have not appeared in the existing cases, the study still being relatively small regarding the number of cases. Such unaddressed effects may be relevant for other companies. There are a number of special prerequisites for LEGO cases, which may have influenced the platform performance and make the results specific for LEGO. This is sought adressed via the industrial validation study.

9.1.6 Industrial and academic implications

The consequences of the research results are relevant for both industry and academia:

In the industrial context, the verified internal effects in a variety of product platforms show potential, which however must be supplemented by relevant external effects. It justifies attention to the multi-product development approach as a way of creating competitive advantage.

The problems of lack of use of platforms point to the fact that the conditions for the achievement of platform effects are not well understood and is underestimated in the platform development projects.

Not only alignment of product and life cycle system parameters, also alignment of activities is critical for achieving platform effects. Often extra resources are required for this aspect. It must be considered in the development of the platform and be part of the assessment, deciding if a platform is worth the effort.

Estimating and quantifying internal platform effects is a challenge and can be controversial and cumbersome, but examples in this thesis documented how it can be approached. Especially the identification and estimation of the effects in the downstream phases has shown the potential of product platforms. I recommend estimation and quantification of effects, because it helps describing the product platform and its effects. Considering the resources and risks platform development involves, it must be necessary to have arguments to justify these. Of course the estimates must always be evaluated as part of a scenario, describing the platform as a whole concept with products, sales estimates and production strategies.

In the academic context the findings show the need of focus on modeling of the platform effects (especially in the down- stream phases) in combination with the product oriented models, existing platform design methods describe. I advocate for facts-based and financial quantification in the methods compared to metric-based assessment methods, knowing that it has its limitations. Research in how the introduced platform user incentive criterion can be met is also needed, and the above research results should be confirmed by other independent studies.

Finally the suggestion of a system-oriented approach to platform-based product development may lead to an increased understanding and more comprehensive models of the phenomena.

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Appendix 1: Factors influencing platform performance

A thorough study on the literature on which factors that influence platform performance is described below.

A number of the existing studies and their findings are comprehensively analyzed. Many of the factors that are mentioned in literature are however not special to platform-based product, but are also relevant in general product development, like e.g. characteristics of the product development team members, and in general change management which is also applicable in this context, since both structures and the tasks change [Robbins, 2001]. To study these study success of teams, which are also influencing platform development, we suggest McDonough III, 2000, who finds the factors contributing to success of cross-functional teams.

- Team cooperation
- Appropriate project goals
- Team leadership
- Empowerment
- Commitment
- Ownership
- Senior management support

He also finds that use of cross-functional teams is related to higher project success. However, achieving cross-functional team success appears to be complicated, i.e. obtaining the team behavior of cooperation is the most mentioned factor. These factors, relating to the development team, belong to the group of factors in the platform development phase.

Other studies look too at product platforms at project level: The empirical study by Tatikonda [1999], referred to previously, describes that following factors influence success of platform development projects:

- The project task characteristics "high technological interdependence" and "objectives novelty" both have a negative effect
- "Market newness" characteristics has positive effect; namely newness of product to customer and newness of target market to industry
- "Contingency planning" and "project management involvement in setting project objectives" are both beneficial
- Finally "overlap of the engineering function (crossfunctional teams)" and "projectbased evaluation" are also regarded as beneficial.

These factors both belong to the existing context group, describing the market aspects, platform solution group, describing the characteristics of the platform itself, and the platform development phase group, describing characteristics of this phase.

Juuti et al,[2004] considers platforms the later phase where the platforms are utilized and find that

- Company maturity
- Capability of using the processes
- Lack of competencies
- Shortcomings of tools and IT systems used for supporting in efficient operational (execution) platform mode

enables the transition success. They also consider the critical mass of users as important for the level of information and process formality. Hence they identify factors that relate to the existing context (company maturity) and factors from the platform exploitation phase, describing challenges in this phase.

Nieuwland [1999] describes Phillip Consumer Electronics adaption of an architectural approach, and he describes the conditions for good performance of this architectural thinking:

- Process responsibilities are known and supported by all hierarchical layers
- Implementation needs people, time and money
- Top management are not allowed to return to the old way of working

- Successful results shall be shown
- Clear target and measures are set

As described in his text these factors relate to aspects that occur in the exploitation phase.

As mentioned before these conditions do not seem very specific for product platforms, but for many types of projects, and they have a resemblance to the conclusions from change management theory [Kotter, 2007].

Ulrich and Robertson (1998) observe the organizational risks related to platform development. They emphasize the importance of

- knowledge creation, sharing and utilization
- competencies for platform creation, utilization and maintenance

Sanchez [2000] also describes the impact the adoption of a modular product and process architectures can have on the organization of product creation processes and the interactions of individuals and work groups, and on requirements for effective management of product creation. He focuses on that there must be found new ways to assess individuals and team performances, new kinds of incentive systems and that the documentation is important. Baldwin and Clark, (1997) and Simpson [2004] also note the organizational aspects as a challenge and that visible information is key to integration. Being very broadly defined these factors belong in both the existing context and the platform development and exploitation phase.

Jiao et al, 2007 focus on the cross functional organizational aspects and state that "successful implementation of product families depends on the extension of concurrent engineering beyond the traditional boundary of design and manufacturing to include customer interaction, marketing, service and recovery", showing a focus on the platform exploitation phase.

Halman et al, 2003 reflect on lessons learned and find important process oriented aspects to be:

- Definition of platform requires choosing from alternatives
- Development of a product family needs a clear concept
- Development of a platform is a strategic decision
- Understanding of market requirements is necessary

The above describes aspects of the platform development phase.

The importance of modeling and creating scenarios in the development phase are described by [Mortensen, 2001], and similarly Andreasen et al, 2001 has experienced following successful guidelines

- Form a strict function modular architecture, so that transparency and simplicity of the modularization is obtained
- Modularity (functionality and interfaces) must be explained in coherent models, defined in the mechanical, electrical and software domains
- Use the scenario technique for obtaining insight into the proper utilization of the modular architecture in the company, before you conceptualize the architecture

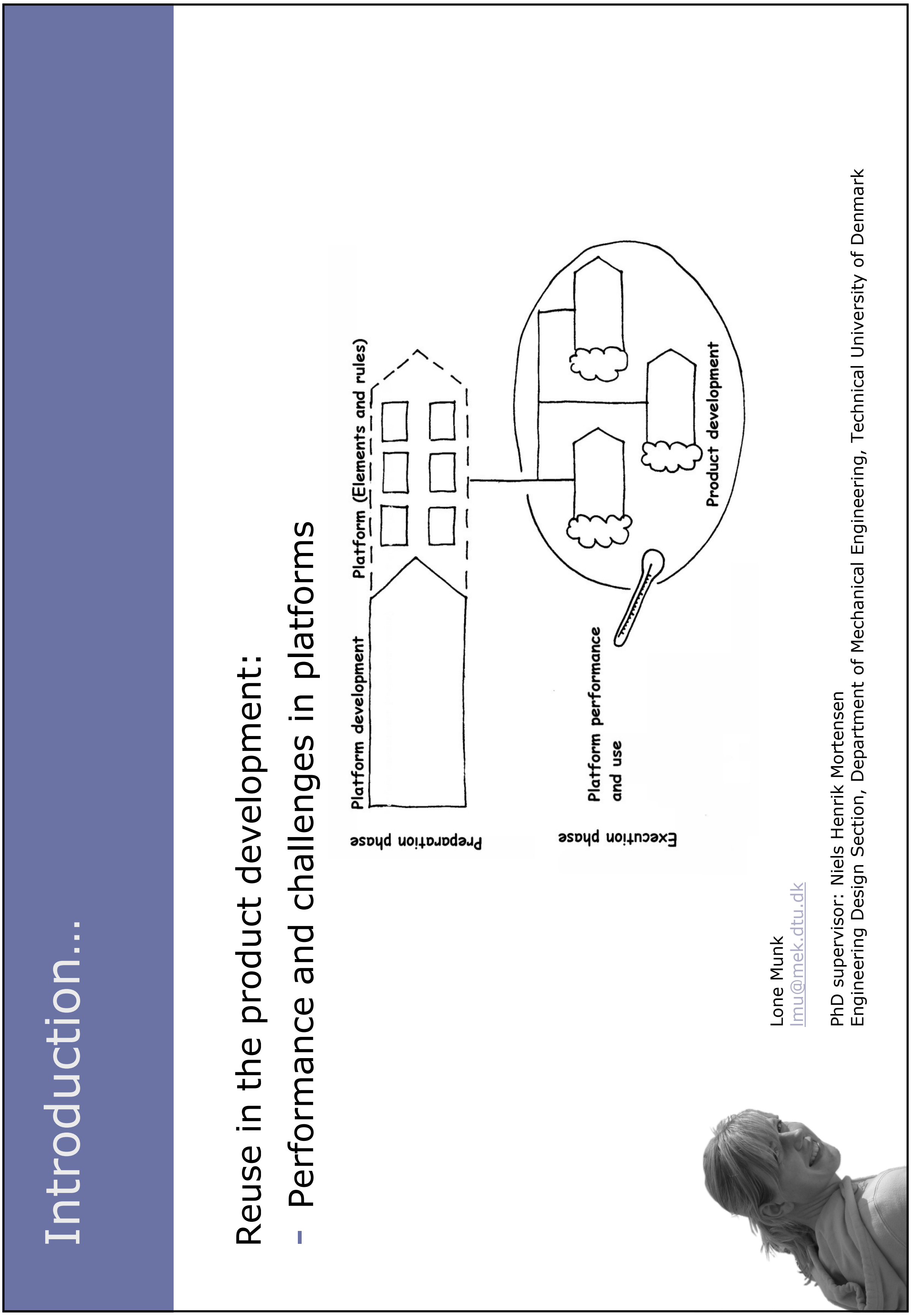
Miller [2001] takes a makro level point of view and list feasibility factors:

- Market conditions
- Stability of surroundings
- Design capabilities
- Mature architecture knowledge
- Technology maturity
- Initial investment of modularization

These aspects cover factors from both the existing context and the platform development phase.

Finally Andreasen et al, [2001] also postulate that the seemingly inherent reluctance to reuse, it is very important that companies build up a proper reuse mindset, meaning a proper understanding of the role and importance of reuse to the actual business, which is a task that stretches beyond the development of a platform. This must be considered as belonging in both the existing context as well as in the platform utilization phase.

Appendix 2: Material for industrial interviews



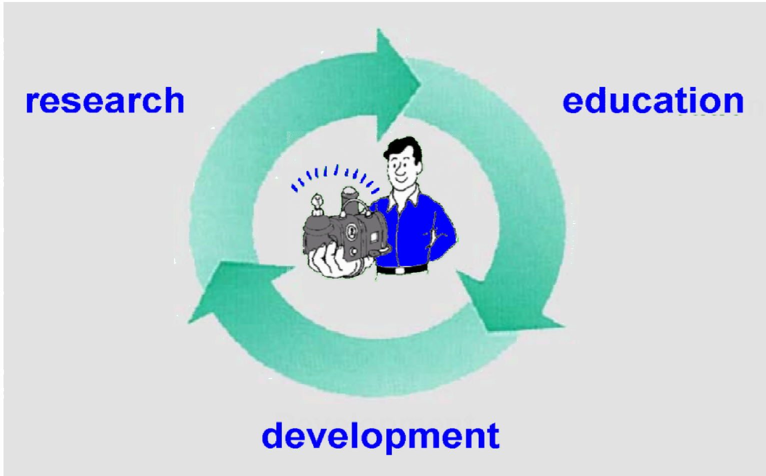
The Product Architecture Group

Focus area: *Architecture*

- Platform development
- Synthesis of architecture
- Modularisation
- Standardisation
- Configuration

Activities

- Research
  - Ph.D. projects
  - Industrial projects
- Consultancy
  - Development products
  - Courses & workshop
- Education
  - Master Thesis projects
  - Teaching



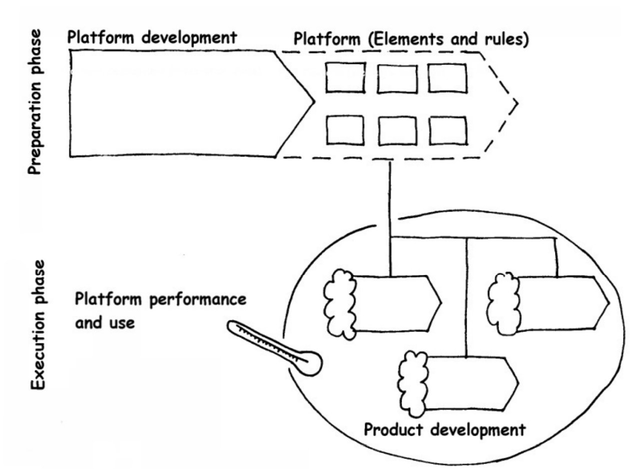
- Niels Henrik Mortensen
- Ulf Harlou
- Sten Augsburg
- Flemming Larsson
- Rasmus Pedersen
- Morten Kvist
- Ole Fiil-Nielsen
- Lone Munk

Co-operation with industry

- Close connection to LEGO
  - Closely following 9 platforms, from idea until part of the daily product development
- Connection to other companies:
  - Satellite following of platform projects

Background

- **Platform-based product development**



- **Benefits**
  - Cost reduction,
  - More product variants
  - Shorter development time

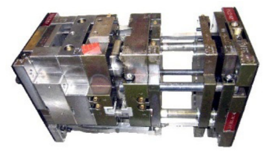
- **Focus on platform development methods in platform research**

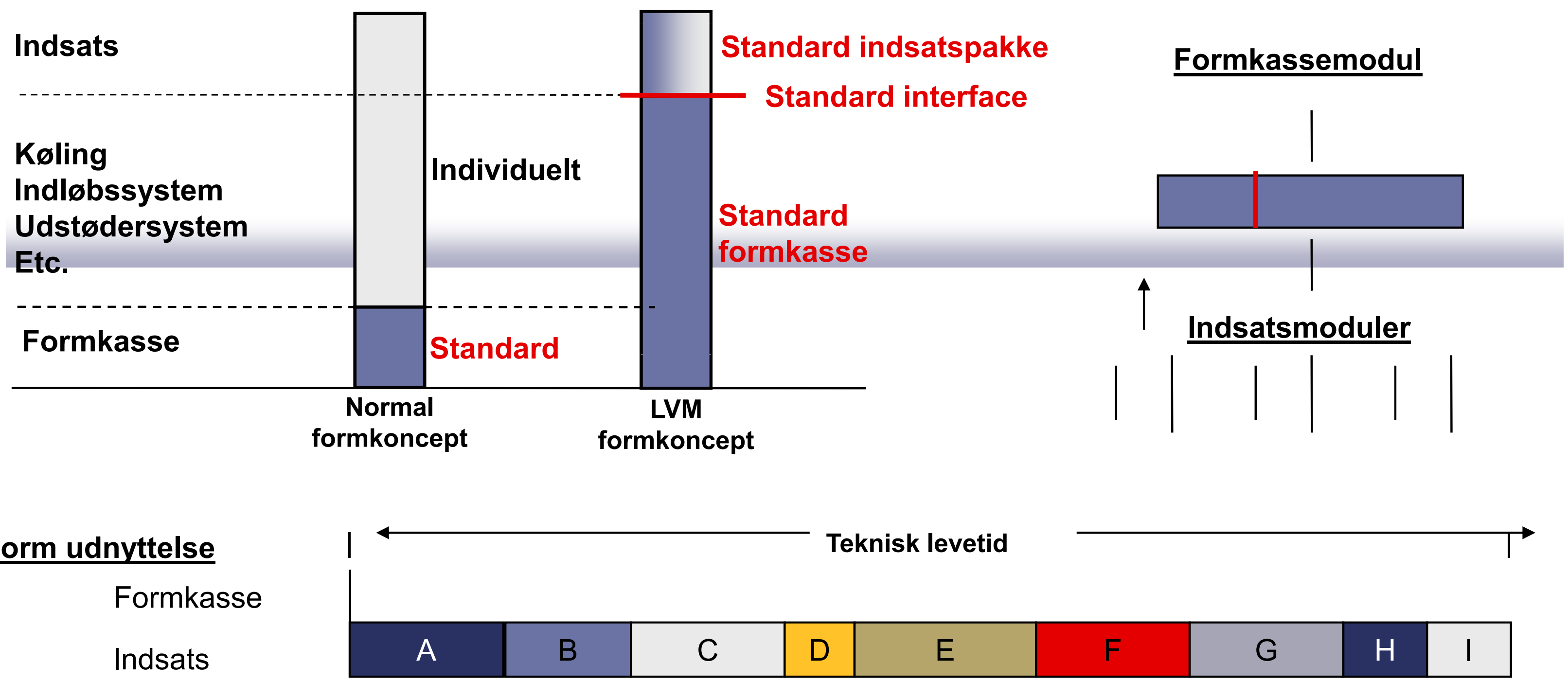
- **Little knowledge about platform performance and use**

  \- How well do they actually work?
  - Academia: Right focus in development methods?
  - Industry: Realistic expectation of impact?

Module Mould at LEGO

- **Mould platform**
  - Covers 80 % of LEGO’s elements
  - 25% reduction of mould investments –pay back: 1year
  - 30% reduction in development and lead time

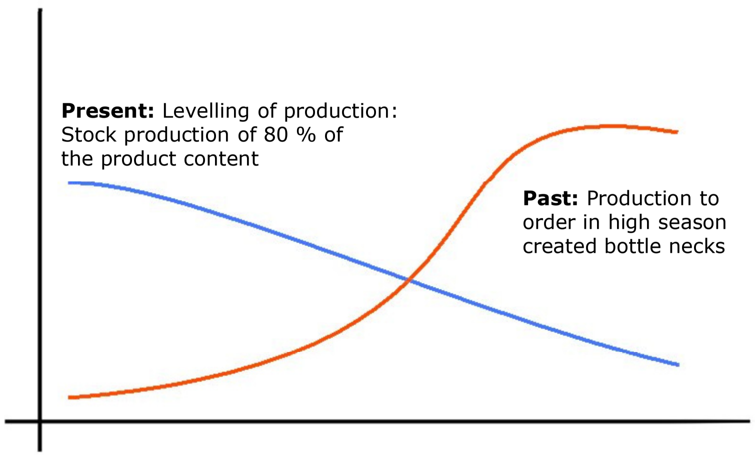




x

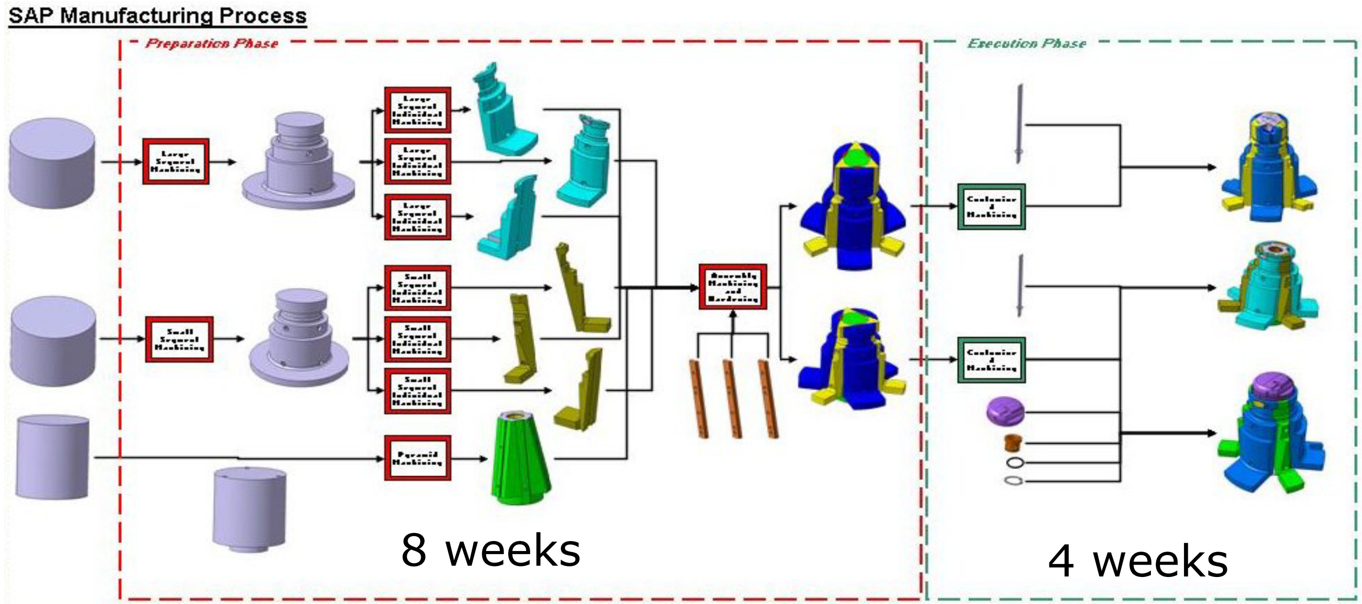
Prepack bag platform at LEGO

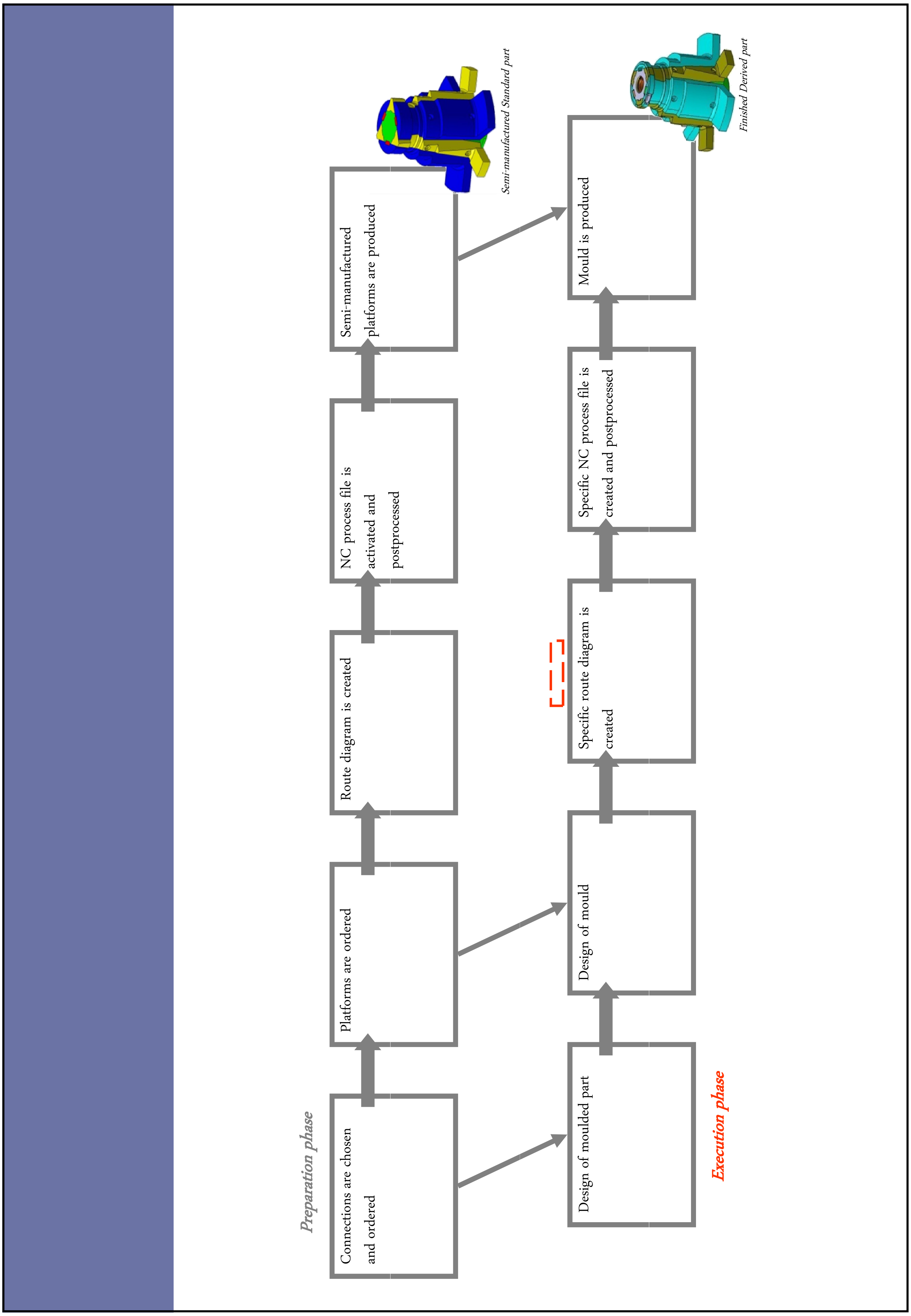
- **Prepacked bags with standard elements**
  - 60% reduction in development time
  - 20% reduction in packaging costs due to production leveling
  - No investments – only changed behaviour!



Collapsible core platform at Grundfos

- **Collapsible core for moulding of pump house**
  - Pre-manufactured core modules with platform dimensions
  - 2/3 reduction of leadtime
  - 15 % reduction of working hours




Preparation phase
Connections are chosen and ordered
Platforms are ordered
Route diagram is created
NC process file is activated and postprocessed
Semi-manufactured platforms are produced
Semi-manufactured Standard part
Execution phase
Design of moulded part
Design of mould
Specific route diagram is created
Specific NC process file is created and postprocessed
Mould is produced
Finished Derived part

Interview guide

- **Tell about the platform /modularisation system**
  - Platform description
  - Goals and performance
  - Initiating cause
  - Design phase
  - Decision base
  - Documentation and User incentive
  - Implementation
  - Challenges
  - Reasons for deviations
  - Maintainance

Platform name and implementation	
Reuse assets and the rules	
Goals (Reason) and expected effect money,time risk) and one time investments	
Performance	
Challenges (platform story)	
Reasons for deviations	
Assessment and design criteria	
Yearly Volumen & Products (evt. %f products	
Documentation and facillities and on-hand userlevel	
Owner/ controll	
Platform development process	
Level of intergration Unaware, Know, use, support	

Lessons learned from cases

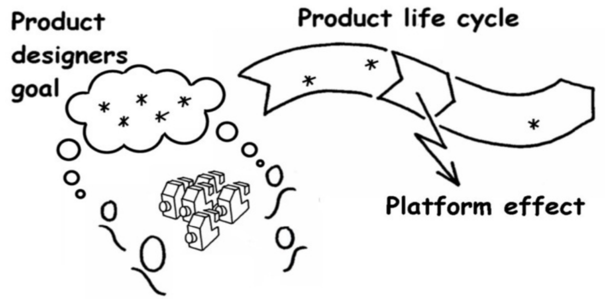
- **Platforms produce results**
  - Up to 50% reduction of component types
  - 1,5 to 3 weeks reduction of development time
  - Between 1-6 mill. Ddk cost/investment reductions
    - Ramp up
    - Production
    - Operations
- **But not as much as expected. Out of 9 platforms**
  - 1 does not perform satisfying
  - 5 performs somehow satisfying and don’t meet all goals
  - 3 performs satisfying
- **What are the challenges?**

Challenges

- The platforms are not used (as much) as intended (6)
- Maintaining the platform and avoid undesired changes of the solution, that erodes the benefits (2)
- Expanding existing solution (1)
- Multiple errors due to reused solutions(1)
- Market needs have changed, and the platform solution does not fulfil the needs anymore (1)

Platform use

- **The platforms are not used (as much) as intended (6)**
  - Design calculation models do not consider platform benefits and provide the argument for using them. (4)
  - No goals, benefits or rewards from management (3)
  - The users consider the trade off platform provides unattractive. (3)
  - The platforms and their rules are difficult to understand, hard to find and hence use (2).
  - The platforms are not known (2)
  - Platform use is an extra burden for the product developers (1)



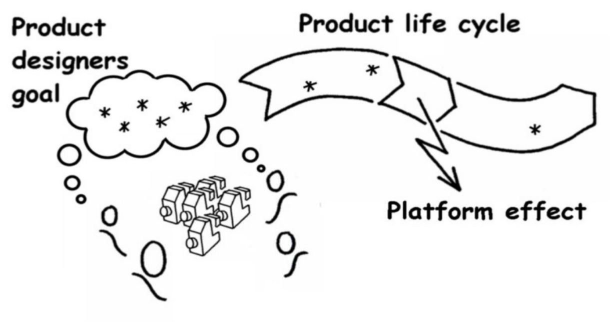
Platform incentive?

What differentiate the successful platforms?

- **Platforms must be considered as a system that needs to work continuously in the company!**
- **Prerequisites for the platforms:**
  - Clear concept for the technical solution,
    - meticulously checked before implementation
  - Platforms mainly based on rationalisation of existing products
    - Stabile area: Market and Technology
  - Decisions based on calculated and historic data:
    - Cost and time savings
  - Short payback time
  - Accept and proven usability
    - by products designers and other important product defining users

What differentiate the successful platforms?

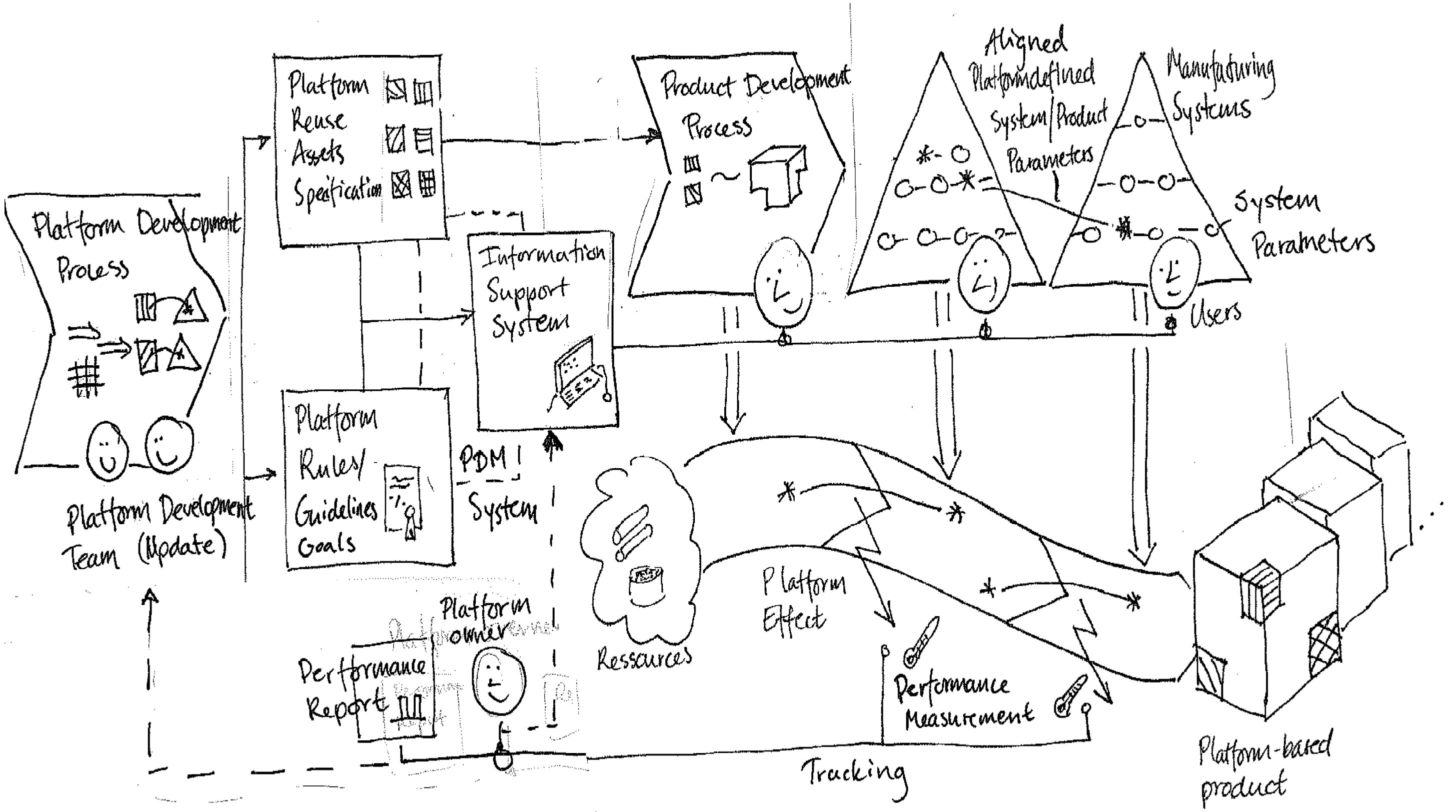
- **Determining efforts to ensure success**:
  - User incentive: cheaper parts, personal reward, only way
  - Supportive, integrated and updated user design system and documentation
  - OR simplicity of solution
  - Measuring system considering platform benefits
  - Platform owner: maintenance and further development
  - Number of users and how much of the product the platform constitutes



Recommendation

- **Platform user incentive criterion**
- **Focus on identifying down-stream effects**
- **Focus on data modeling and viable quantification of effects**
- **Facilitate platform performance tracking and goal-setting**
- **Understand a product platform as an in internal system in the company**

Platform system model



Conclusions from LEGO: RQ1:Identifying and estimating effects

First phase:

- *Concretizing the platform idea and analyzing effects of status quo*

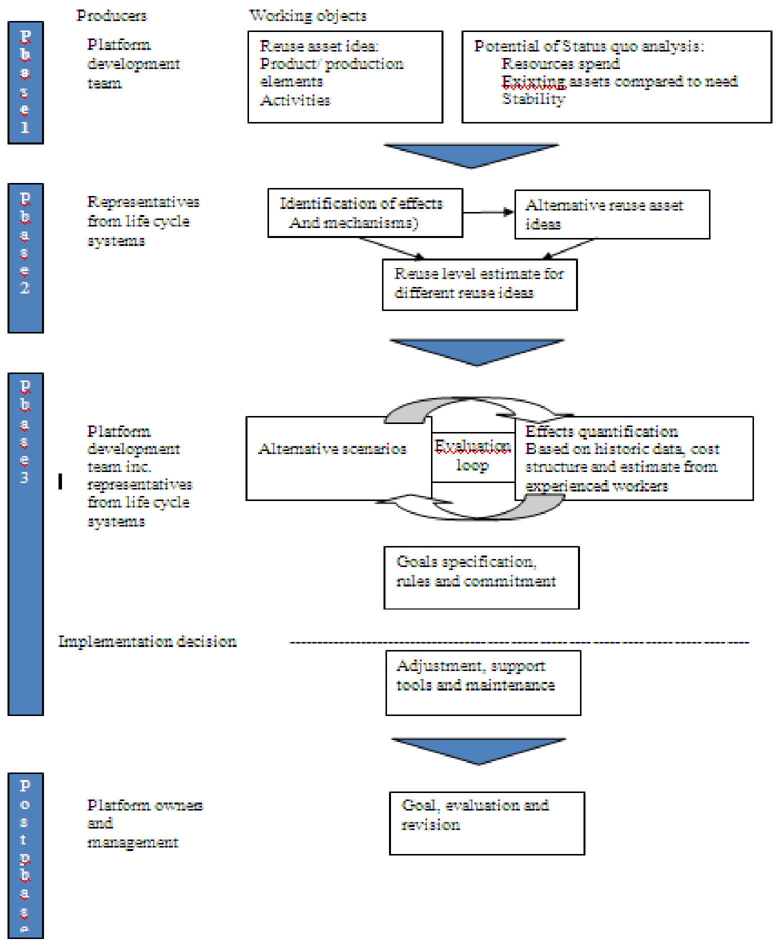
Second phase:

- *Identifying effects from life phase systems*

Third phase:

Quantifying effects from scenarios and specifying goals

Post-development phase: Goal evaluation and revision



Appendix 3: Data from industrial interview

Issue / Company	A	B	C	D	E
Part of subgroup, aiming at same effects as LEGO					
		x	x		x
Revenue 2007, (Mill.DKK)	3622	770	450	1409	382500
Industry	Production	Electronic	Electronic	Production	It, communication & tele
Market	Goverments, Institutions, Business	Business, Institutions	Business	Business, Institutions	consumer
Contacts	Head of R&D, Senior project manager	Head of R&D, Senior project manager	Head of R&D	Senior project manager	Senior project manager
Type of platform					
Random					
Overlap		x	x	x	
Rationalisation					
Strategy - prod. fam.					x
Strategy - func.	x				
Succes with platform- based product development (related to RQ2)					
	x	x	x	x	x
Measures platform effects (e.g. via goals) (related to RQ2 and REC 4)					
	1	x	x	x	x
Finds that it is important to set goals for, measure and track platform performance(related to REC4)					
	x	x	x	x	x
Platform performance (related to RQ2)					
The platform performs satisfying and meets its goals.	x	x		x	
The platform performs somehow satisfying and does not meet all goals.			x		
The platform does not perform satisfying.					x
Expected effects from platform-based product development (related to RQ2)					
Increased revenue (due to more product variants)		x		x	x
Reduced development time	x	x	x	x	x
Cost reductions (product or production aspects)		x	x		x
Production leadtime					
Reduced risk (mainly time and quality aspects)	x		x		
Improved product performance	x				
Reduced service costs					
Finds that it is important to have focus on down stream effects (related to REC 2)					
	yes	not so important	yes	Not been in focus	Mainly development time

F	G	H	I	J	K	L	Sum total	Sum sub
x						x		
15376	4376	36458	6042	2297	1367	24000		
Production	Electronic	Production	Production	Electronic	Electronic	Production		
Business	Consumer	Business, Consumer		consumer	Business	Goverments, Institutions, Business		
Senior Moulds Designer	Senior project manager	Manager for Technology R&D, Finance & Business Support	Technology manager, senior project manager	Senior project manager	Senior project manager, Modularisation manager	General modularisation manager		
			x				1	
	x				x		5	2
x		x					2	1
				x			2	1
						x	2	1
x (2 of 6)	x	x	x	x	x	x	12	
x	x			x		x	9	
x	x	x	x	x	x	x		
			x	x		x	6	2
x	x	x			x		5	2
							1	1
				x	x	x	6	3
x	x	x	x	x	x	x	12	5
x						x	5	4
x		x			x		3	1
x		x	x			x	6	3
	x						2	0
					x	x	2	1
yes	yes	yes	yes	not in focus	not in focus	yes	7	

Issue / Company	A	B	C	D	E
Challenges					
Specifying interfaces, making the right cut and technical solutions		x		x	
Cooperation between platform and product development organization (incl. work affiliation)					x
Getting data to calculate platform benefits			x		
Making benefits viable to management and other departments, e.g. sales organization			x		
Making the right fit between price and performance (avoiding overengineer and maintaining competitiveness)		x			x
Making supreme solutions (compared to product development organization and suppliers)				x	x
Organisational maturity: work organisation and affiliation					
Make mangement keep sticking to the platform					
Dealing and agreeing with steering committee with leaders from different departments (different interests and viewpoints)					
Making platform documentation					
Integrating the product platform in company IT systems					
Portfolio decisions and the overall scoping of products and their features				x	
Reasons for deviations (related to RQ 3)					
Platforms users don't use the platforms					x
Practical design problems: EMC og themical problems			x		x
Bottlenecks in supply of platform components					x
Platform errosion			x		
Platform development time is longer than expected				x	
Market conditions change					x
Production conditions change					x
Making too big and hence difficult platforms and modules					
Geographical distance between platform users and product developers					
Responding to LEGO deviations findings (related to RQ 3)					
1. The platforms are not used (as much) as intended (6)	not a problem	not a problem	to some extent	Not a problem here	Agree
a. Design calculation models do not consider platform benefits and provide the argument for using them. (4)			Agree	likely	Agree
b. No goals, benefits or rewards from management (3)			Agree	very likely	Agree
c. The users consider the trade off platform provides unattractive. (3)			Agree	very likely	Agree
d. The platforms and their rules are difficult to understand and hence use (2).			no	likely	likely
e. The platforms are not known (2)			no	likely	Agree
f. Platform development is an extra burden for the product developers (1)			Agree	Agree, but The only way	Agree, but The only way
2. Maintaining the platform and avoid undesired changes of the solution, that erodes the benefits (2)	may be a problem	may be a problem	Agree	Not a problem	Not relevant in Nokia, too short life
3. Expanding existing solution (1)			No	No	no
4. Multiple errors due to reused solutions(1)	Can be a problem	Relevant	Agree	Can be a problem	Agree
5. Market needs / technological solutions have changed, and the platform solution does not fulfil the needs anymore (1)	Not at problem	Not a problem	Agree	Can be a problem	Agree

F	G	H	I	J	K	L	Sum total	Sum sub
	x	x		x	x		6	1
		x		x	x		4	1
x		x					3	2
			x	x			3	1
				x			3	2
							2	1
		x			x		0	0
				x		x	2	1
					x		1	
		x					1	
x							1	
							1	
x		x					3	2
					x		0	2
		x					0	1
						x	2	2
					x		2	0
							1	1
							1	1
					x		1	0
					x		1	0
Agree	agree		To some extent, experiences not used in design of production equipment	not a problem	Not a problem	Not a problem		
		agree	agree	Not in this case	agree	Don't belive in such systems, a lot of work, seldom works, people just have to use the platform.		
		agree	agree	N/A	agree			
		agree	don't know	Not in this case	sometimes			
		agree	do not agree	Not in this case	do not agree			
Agree			agree	Not in this case	do not agree			
		The only way	do not agree		yes/no the only way			
Agree	Can be a problem		agree	Can be a problem	agree	yes		
				Yes	not expanding but making a bigger for the following	yes		
Likely	Can be a problem		N/A	Not in this case	N/A	no		
	Can be a problem		N/A	Not in this case	Not in this case	Stabile tech and Market		

Issue / Company	A	B	C	D	E
Responding to LEGO findings: Prerequisits for platforms (related to REC 5)					
Platforms must be considered as a system that needs to work inside the company	Agree	Agree	Agree	Not in radiometer but Agree to the extent that it is a different challenge with more organisational problems	Agree
	x	x	x		x
Clear concept for the technical solution,	Agree	Agree	Agree	Agree	Agree
Meticulously checked before implementation (technically, risks, supplier,)	Agree	Agree	Agree	Agree	Agree
Platforms mainly based on re design or update of existing products	NC	Not only - but there have always been something before	Not only - but there have always been something before	Not only - but there have always been something before	No
Stabile area: Market and Technology				Not only - but there have always been something before, more technology and known delkonstruktioner	Not in Nokia, but good idea
Decisions based on calculated data and quantification of effects	Agree	Agree	Agree	Agree, but sometimes not necessary if the demands are the same	Yes, but how realistic numbers
Cost and time savings -	Not only	Mainly	Mainly	Mainly	Yes, mainly time
Short payback time due to risk of locking decisions/ outdated marketssolutions or technological development.	Agree	Agree	Agree	Agree	Agree very much!
Accept and proven usability by products designers and other important product defining users	TO some extent	Not a problem	Agree	Not a problem	Agree, but no time
	x		x		x
Platform enablers (related to REC 1)					
User incentive (Rec.1)	Agrees	Agree	Agree	Agree or strong rolemodel	Agree
	x	x	x	x	x
-Supportive, integrated and updated user design system and documentation			not relevant		Agree
-OR simplicity of solution	Agrees	Agree		Agree	Agree
-Measuring system considering platform benefits	Agrees	Agree	Agree	Agree	Agree
-Platform owner: maintenance and further development	Agrees	Agrees	Agree	Agree	Agree
-Number of users and how much of the product the platform constitutes	Agrees	Agrees	Agree	Agree	Agree
Model of identifying and estimationg effects (related to RQ1)					
Reaction to model:					
No so relevant	1	1		1	
Proactive design optimized for one product, which determines everything					
Not so many stakeholders involved	1	1		1	
Relevant, but the company does not yet go through such a thorough process			1		1
Lack of data					
Relevant, similar process as in the company					

F	G	H	I	J	K	L	Sum total	Sum sub
Agree	Agree	Agree	Likely	agree	agree	agree		
x	x	x	x	x	x	x	11	
Agree	Agree	Agree	Agree	agree	agree	agree	12	
			Agree	agree	Likely	agree		
In this case	Not only - but there have always been something before	Not only	no	no	no	no		
						best if		
Agree	Agree, but sometimes not necessary if the demands are the same	To some degree	No	no	only in some cases	Agree		
Agree	Mainly	Agree	no	no	mainly time	Cost		
Agree	Agree	Agree	N/A	no	no	No, plants payback time		
Agree	Not a problem	Agree	N/A	yes	yes, decided whiich products it should be in.	No, just have to use it.		
x		x		x	x		7	3
Agree	Agree	Agree	Agree	Agree	goal and mangement support			
x	x	x	x	x	still a challenge	They have to use it!	11	5
Agree	Agree	Agree	Agree	Agree	Agree	Agree		
Agree	Agree	Agree	Agree	Agree	Agree, but not always possible	Agree		
Agree	Agree	Agree	Agree	Agree	Agree	Agree		
Agree	Agree	Agree	Agree	Agree	Agree	Agree		
			1	1			5	1
				1			1	0
			1				4	0
		1					3	2
1	1				1	1	4	2

Platform-based product development makes it possible to create product variety, enabled by reuse across multiple products and with potential to reduce the spent resources. The subject has gained increased attention in industry and academia the past decade, but the experiences are often based on single case studies, and it is sparsely verified if expected effects are achieved.

This thesis documents how the Danish toy manufacturer LEGO has achieved significant internal effects with product platforms, such as
- reduced development time (often around 25 %),
- reduced number of components (often around 50%) and
- reduced production cost and investments (often around 25%)

These results are supported by experiences from Danish industry and verify a general potential in platform-based product development.

The thesis identifies why platforms do not always achieve the expected effects, mainly because of 1) lack of use of the platform assets, 2) technical reasons and 3) changed market conditions. A new platform assessment criterion focusing on the platform users is introduced, and models for different platform approaches are presented together with models for identification and estimation of platform effects.

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