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A Modelling and Simulation Approach for Linking Design Activities to Business Decisions

Magnus Löfstrand

Luleå University of Technology
Division of Computer Aided Design

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Division of Computer Aided Design
Luleå University of Technology
SE-971 87 Luleå
SWEDEN

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Preface

The research reported here has been carried out at the Division of Computer Aided Design at Luleå University of Technology in Luleå, Sweden, during the period October 2002 to January 2007.

I would like to thank my supervisor, Associate Professor Tobias Larsson, my former supervisor Professor Graham Thompson, Professor Lennart Karlsson and my colleagues at Luleå University of Technology.

This work has been carried out within the Polhem Laboratory in cooperation with mainly two companies: Hägglunds Drives AB and Volvo Aero.

The cooperation with Volvo Aero was carried out through the Swedish National Aeronautics Research Programme (NFFP). At Volvo Aero, I would like to thank Thomas Gustafsson and Bengt-Olof Elfström for truly positive support and valuable feedback. In addition, I would like to thank all of my informants at Volvo Aero and Hägglunds Drives AB for their time and patience.

I started this project with studies at Hägglunds Drives AB. Bengt Liljedahl and recently also Mats Nytorp of Hägglunds Drives AB really deserve a special mention for their continuous interest in and support for my project. Additionally, I would like to thank all of my informants, including all partners in the creation of the Faste Laboratory for Functional Product Innovation.

Lastly, I would like to thank my family and friends for allowing me to be distracted for periods of time and for their help.

Abstract

The business environment of the manufacturing industry is changing from a hardware-based product focus to a process and function focus. A current industrial interest is the development and sale of functions. This function could be realised as a product based on hardware, software and services, and may be sold as a function rather than as hardware. This function view is referred to as Functional Products (FP).

The new focus for the customer is on value rather than hardware. This presents new challenges for how engineering hardware design may best be carried out. Sale of functional products requires a changed business model in which the price of the functional product is related to the functionality of the product itself; hence the name functional product. The supplier can in such a scenario no longer sell maintenance and spare parts. Instead, these activities become a cost, thus motivating the supplier to increase process efficiency, decrease internal production cost by using less energy per produced unit and increase knowledge about use-cases.

The researcher's challenge is how to create new knowledge regarding functional product development for academic as well as for industrial benefit. The research question was formulated as:

How should methods and tools for design process modelling and simulation be developed to support functional product development?

Four case studies were carried out in Swedish industry. Case study 1 was carried out in cooperation with Hägglunds Drives AB. Case study 2 was carried out in cooperation with Hägglunds Drives AB, Volvo Aero and Volvo Car Corporation. Case study 3 was carried out in cooperation Volvo Aero and Case study 4 was carried out in cooperation with nine industrial companies during the formation of the Faste Laboratory, Centre for Functional Product Innovation.

The main results include the development of a tool for work process simulation using an engineering perspective. The tool allows simulation of an engineering-based work process for traditionally speaking, non-engineering-related usage. The developed support tools relate to industrial business scenarios for functional development and sale, and to the development process. The research shows the possibility of evaluating cost and time of development before doing the actual product development work by modelling and simulating the design process. Thus, the knowledge that previously was implicit in the work process is made explicit and possible to reconfigure and manipulate for a desired outcome and purpose. Linking the future business cases to work processes by modelling and simulation enables knowledge reuse and work-process predictions concerning cost and delivery time. Hence, modelling and simulation of work processes results in better knowledge of company development capacity earlier than before, thus allowing shorter reaction time to changes in the business domain.

Keywords

Modelling and Simulation, Functional Product Development, Engineering Design, Product Development Process, Service Development Process.

Thesis

This thesis comprises an introductory part and the following appended papers:

Paper A
Löfstrand, M, López-Mesa, B., Thompson, G., (2003), **The use of Product Development Process as a means of Implementing Company Strategy**, International Product Development Management Conference, Brussels, Belgium, June 10-11.

Paper B
Karlsson, L., Löfstrand, M., Larsson, A., Larsson, T., Törlind, P., Elfström, BO., Isaksson, O., (2005), **Information Driven Collaborative Engineering: Enabling Functional Product Innovation**, The 3rd International Workshop on Challenges in Collaborative Engineering, CCE05, Sopron, Hungary, April 13-15.

Paper C
Törlind, P., Larsson, A., Löfstrand, M., Karlsson, L., (2005), **Towards True Collaboration in Global Design Teams?**, International Conference on Engineering Design, ICED 05, Melbourne, Australia, August 15-18.

Paper D
Löfstrand, M., Larsson, T., Karlsson, L., (2005), **Demands on Engineering Design Culture for Implementing Functional Products**, International Conference on Engineering Design, Melbourne, Australia, August 15-18.

Paper E
Löfstrand, M., **Functional Product Development Challenges Collaborative Working Environment Practices**, Accepted for publication in a Special Issue of the Journal: International Journal of e-Collaboration, State of the Art and Future Challenges on Collaborative Design.

Paper F
Löfstrand, M., **Linking Design Process Activities to the Business Decisions of the Firm – An example from the Aerospace Industry**, Submitted for Journal publication.

Paper G
Löfstrand, M., Isaksson, O., **A Process Modelling and Simulation Approach for Business Decision Support in Pre-Conceptual Product Design**, Submitted for Journal publication.

The following papers are related to, but not included in the thesis:

Löfstrand, M., Thompson, G., (2003), **Design Management Lessons Learned from two Studies in New Product Design**, International Conference on Engineering Design, ICED 03, Stockholm, Sweden, August 19-21.

Larsson, A., Törlind, P., Bergström, M., Löfstrand, M., Karlsson, L., (2005), **Design for Versatility: The Changing Face of Workspaces for Collaborative Design**, International Conference on Engineering Design, ICED 05, Melbourne, Australia, August 15-18.

Löfstrand, M., Larsson, T., (2006), **An Activity Based Simulation Approach to Functional Product Developmen**t, Challenges in Collaborative Engineering - State of the Art and Future Challenges on Collaborative Design, Prague, Czech Republic, 19th-20th April, http://cce.ecolleg.org/2006/.

Contents

Table of figures

1 Introduction: Functional Product Development

Chapter 1 concerns the aim and scope of the research. The chapter briefly describes the industrial context.

The engineering product development area has developed greatly over the past decade. The value content of the product is increasingly originating outside the physical artefact (the hardware). Alonso-Rasgado et al. [1] introduce functional products (FP) as integrated systems comprising hardware and support services. Early identification of a growing interest in value added products (of which functional products is one) has been noted by Gann and Salter [2].

Functional Products is an emerging area of interest related to engineering product development. Functional Products consist of Hardware (H), Software (S) and Services (Ss) and may be developed for the purpose of supplying a function while not necessarily passing ownership of the hardware to the customer. An initial motivation for this work is the indication that increasing the value content of the offer affects the best practices for how the hardware should be developed.

Hardware producers in business-to-business settings need to take extended responsibility for their customers' production or productivity in order to stay competitive. A way to do that is through Functional Products, which involves providing additional value content to the customer. Value may consist, for example, of material and immaterial components, hardware functionality as well as availability, increased knowledge or business security.

It has been previously shown that the competitive advantage on which advanced industrialised economies rely depends increasingly on their ability to reconfigure knowledge [3]. Increasing the value content of the offer is inherent in functional products. The functional product provider takes more responsibility by selling the additional value, which increases the provider's business risk. Further increasing the functional product provider's ability to reconfigure knowledge by modelling, simulating and optimising the value adding work process may be a way to alleviate that risk.

The main Case study on which this thesis is based was carried out in the aeronautics industry (Case study 3, Chapter 2.4.3). The most influential factor identified in the research presented is seen in new business drivers that imply interfirm alliances on changing markets. One example of interfirm alliances in the aeronautics industry is discussed by Gröbler et al. [4]. Gröbler et al. describe the long-term cyclic nature of the airline business. Strategic alliances, leasing and transfer of capacity are suggested as ways to counter the cyclic behaviour. Taking part in strategic alliances is part of the industrial context of the main case study included in this thesis. In the context of interfirm alliances in the aeronautics industry the business drivers are more service-oriented than product-oriented. Drivers include a life-cycle perspective, productivity, and eco-efficiency in addition to, as always, increasing requirements on shortened lead times, low cost and (sufficient) quality. Additionally, in this thesis the context is mainly business-to-business relations. These business drivers may be catered for by development and sale of functional products.

To know upfront if a certain functional sale or development of a functional product is of sufficient interest, modelling and simulation methods may be applied. Modelling and simulation provide a way to rapidly explore design space and desired outcome of a specific design choice or configuration. Thus, performance in terms of time, cost and revenue may be evaluated in addition to artefact performance.

Modelling and simulation have long been used to support artefact performance. Various support tools for engineering product development have been developed. For example, since the mid-1970s, 3D-based tools for Computer Aided Engineering [5] (CAE) have evolved, following the evolution of the microprocessor to create a genuinely useful support tool, which has significantly changed the way hardware products are created [6], [7]. Various other, non-hardware related simulation approaches are discussed by Szegheo & Andersen [8]. Simulation support for artefact performance has been one enabler for industrial products with a hardware core to be sold with the purpose of supplying a function. However, they have not yet been *developed* for that purpose.

In order to significantly cut lead times one may not only focus on individual support tools such as those mentioned above but also on the product development process, which extends from the customer need to the end of the life of the product. Hence, designers and design teams working with functional product development need other support tools.

In this thesis, the focus is on modelling and simulation of design and development processes in the early conceptual stages of design. In addition to existing simulation for artefact performance, the thesis introduces the possibility of simulating immaterial, business-related aspects in a product development and supply process for the purpose of demonstrating improvement in the development of the function.

This thesis displays a shift from a hardware-based product focus to a customer-value based focus where function delivery is central. New methods and tools to support designers and design teams engaged in functional product development activities are needed; such tools and methods are the focus of this thesis.

1.1 Aim and scope of research

The aim of the research is to show the possibility of evaluating immaterial, business-related requirements using modelling and simulation in the early conceptual design stage of functional product development. With this aim, the scope is to support designers and design teams that develop the functional product concepts.

1.2 Research question

The research process has been explorative and the guiding research question (RQ) is formulated as:

RQ: *How should methods and tools for design process modelling and simulation be developed to support functional product development?*

An additional interest has been the requirements that functional product development entail and how the current industrial product development processes may be affected by the introduction of functional product development.

1.3 Academic and industrial motivation

Many areas of business and product development could conceivably be affected by the development and delivery of functional products and many uncertainties therefore exist. The academic motivation lies in the fact that little theory currently exists regarding modelling and simulation support for early concept phases of hardware-based functional product *development* of hardware which is specifically developed for optimal functional sales. Hence, exploring the research question will create new knowledge regarding functional product development and in particular, modelling and simulation based support methods and tools for functional product development.

Given the industrial interest in reducing development cost and development time, any approach that facilitates doing “right first time” and minimising procedural trial and error for the purpose of increased value must be a worthwhile effort. Exploring the research question will create new knowledge regarding functional product development for industrial benefit; Modelling and simulation of work processes increases knowledge regarding company development capacity earlier than before, thus allowing shorter reaction time to changes in the business domain. Re-using knowledge through modelling and simulation is a way to increase efficiency and productivity and provide more time for innovation. As the current industrial product development processes have not been developed for functional product development, they may therefore need updating.

1.4 The industrial context

The main industrial context is that of the studied companies Volvo Aero and Hägglunds Drives AB. The nine partner companies of the Faste Laboratory discussed below provided a general industrial setting. In addition, the partner companies of a previous VINNOVA Competence Centre, The Polhem Laboratory – A Competence Centre for Integrated Product Development [9] provided the research project's initial industrial context. Both the main corporate data sources, Volvo Aero [10] and Hägglunds Drives AB [11] have experience as long-term suppliers in supplier-customer roles. Both companies sell hardware (units of machinery) as well as value-added offers. Volvo Aero sell thrust-on-wing / power-by-the-hour and Hägglunds Drives AB sell complete turn-key installations and productivity. They also both have experience of business partner relationships, especially in the case of Volvo Aero. The third corporate data source, Volvo Car Corporation does not have a stated interest in value-added offers on the scale of Hägglunds Drives AB and Volvo Aero. The corporate information regarding Hägglunds Drives AB and Volvo Aero is described below together with some brief historic notes.

Hägglunds Drives AB's drive systems contain a hydraulic motor, a power unit and a control system. The company has as of January 2007 sales of approximately SEK 1.5 billion and around 670 employees.

- The early 1960s saw HDAB evolve into a supplier of own end products.
- Between 1960 and 1970, Hägglunds drives AB produced hydraulic motors for marine and industrial applications, essentially as a part supplier.
- During the 1990s there has been increased interest in selling motors as well as complete drive systems (including power units and control systems).
- Turn-key supplies, including piping and installation.
- Increasing market share with respect to OEMs, using Compact motors.

Drive systems are used in a wide range of industries; for example, in mining, recycling, pulp and paper, rubber and plastics, offshore, fishing, building and construction. The group's operations are in three business areas: Industrial, Marine & Offshore and Mobile (Building & Construction). System sales account for around half of total sales, after-market services for just over one-third and component sales for the remainder.

Volvo Aero is a main contractor to the Swedish air force, both in the delivery of engines and service of them as well as related hardware services. Volvo Aero develop and manufacture high-technology components for aircraft-, rocket- and gas turbine engines, in cooperation with the world's leading engine manufacturers. Volvo Aero also offer extensive aviation services that help their partners increase profitability and focus on core business – including leasing, logistics, asset management, inventory sales, distribution and redistribution, as well as overhaul and repair of aircraft engines and industrial gas turbines.

In addition, the formation of the VINNOVA Excellence Centre "The Faste Laboratory – Centre for Functional Product Innovation" has provided input, and an industrial setting for the research. The Faste Laboratory includes participants from Luleå University of Technology and nine Swedish industrial companies. The Faste Laboratory was developed during the research process by the researcher's division, four other divisions and the industrial partner companies. The nine Faste Laboratory partner companies are:

- BAE Systems Hägglunds
- Gestamp HardTech
- Hägglunds Drives
- LKAB
- Metso Panelboard
- Sandvik Coromant
- Volvo Aero
- Volvo Car Corporation
- Volvo Truck Corporation

2 Research Approach

To show how the research has been designed and carried out, Chapter 2 deals with the research approach.

2.1 Design research

Cross [12] suggests three different classifications of design research based on the way the research is carried out:

1. *Research into Design*, Descriptive studies of development work by observations.
2. *Research for Design*, Creating methods and tools that support design.
3. *Research through Design*, Abstracting information from, for example, one's own experiences when designing.

*Hence, in the terminology of Cross, the research presented in this thesis has been **about research into design** in order to be able to do **research for design**.*

In addition to these three ways of viewing the design research process, the actual performance of the research process when generating new knowledge includes organising data into information, interpreting information to create personal or situated knowledge and drawing conclusions to create more generalised knowledge. How the research was carried out is described below.

2.2 Research Method

The research method presented in Figure 1 below describes the author's cyclic research method of Study, Observe, Analyse and Design. As a carrier of the research method, case studies have been carried out, also partly guided by concepts found in the field of action research. These issues are further discussed below. The research method is related to Kolb's [13] experimental learning model. Kolb introduces a cycle of Concrete experience, Observation and Reflections, Formation of abstract concepts and generalisations and Testing implications of concepts in new situations.

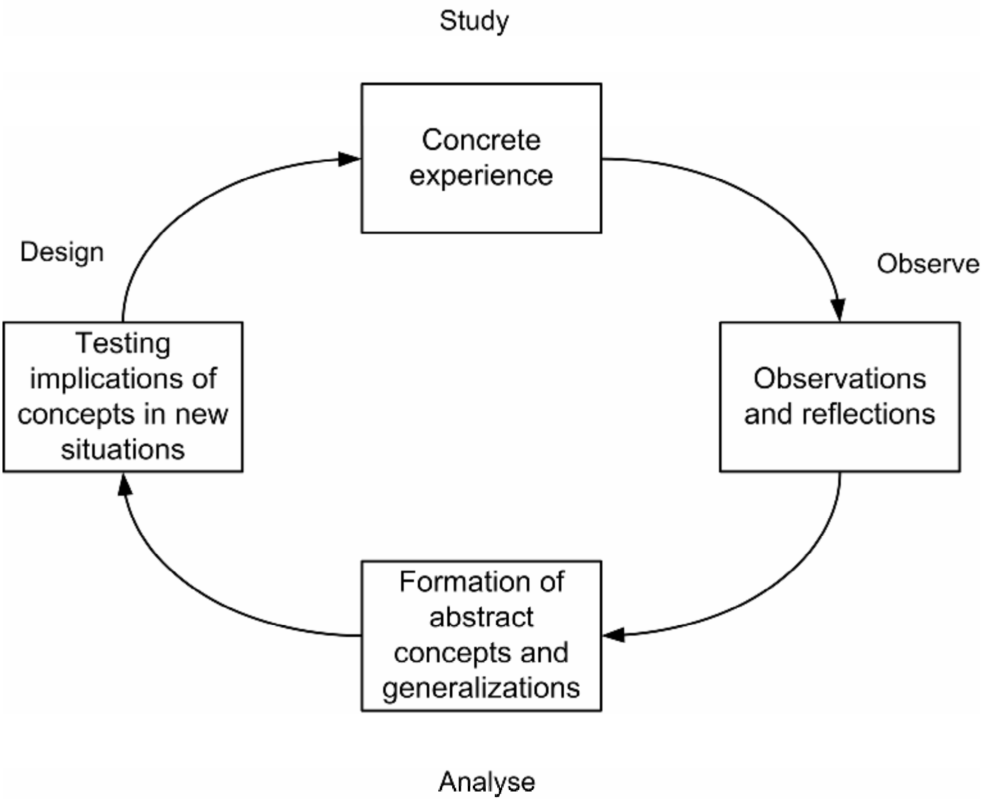

Figure 1: The researcher's cyclic, circular method in relation to Kolb's experimental learning model.

In Figure 1, *Study* refers to exploring existing *knowledge domains* for identification of related, existing academic contributions, based on concrete experience. *Observe* refers to carrying out *case studies* in industry and reflecting on what occurs. *Analyse* refers to analysing information from the case studies, creating personal knowledge and making *general conclusions*, which may involve forming abstract concepts. The *Design* phase refers to *creating models*, which in this thesis is based on information from the case studies. Models may be as-is models describing the current state of the studied process or to-be models, describing a desired state such as, for example, a future scenario. Designed models may be tested in new situations. The research method is described in a circular, cyclic way, since it has been repeated throughout the research process.

The research method is also partly based on Action Research [14]. However, basing this project only on action research would have required a deeper immersion in the studied organisation than what has been the case. Therefore, case-study research has been used as a research method, influenced by some aspects of action research in order to improve the validity of the case studies. These aspects include obtaining access and support for the research, asking questions with a view to improvement, a focus on critical reflection and feedback to informants and participants.

The purpose of the initial research iteration, as described in Figure 1, was to create researcher understanding of a situation (mainly business and hardware development challenges) and to form initial conclusions, assumptions or theories. The initial research iteration refers to the first two Case studies. Thereafter, intentional reflection by the researcher was necessary before carrying out a second iteration of research. The second research iteration refers to Case studies 3 and 4. Models created in the later iteration of the research process should ideally support conclusions or improve the conclusions or the model created in an earlier iteration with respect to stated industrial usefulness. If the updated model does that, the results are considered evaluated and found to be supporting earlier conclusions. Here, evaluated refers to the definition according to Duffy and O'Donnell [15] who differentiate between validation and evaluation, as stated below.

"*A distinction is made here between validation and evaluation. The former focuses upon ascertaining a degree of truth for a particular hypothesis or result. Thus, if a hypothesis or result is proven to be true then it is regarded as being validated. Evaluation, according to some criteria, measures the relation between a result, concept, method, tool, etc. against a datum of some kind such as a requirements specification, known practice, or performance targets.*"

Evaluation of the understanding as it had been developed after approximately the initial two Case studies was carried out through corroboration of information (i.e., interview statements and researcher interpretations) with interviewees, as well as with existing project documentation. Based on the researcher's understanding of the requirements of functional product development, Case study 3 was instigated. In Case study 3 a scenario (further discussed in Papers F and G) was developed which allowed the researcher to further evaluate and develop the understanding of the challenges inherent in industrial functional product development. As the scenario was developing, process modelling commenced. Evaluation of input data and the created work process models was planned to be carried out during and after development of the model in Figure 5 of Chapter 4.6.

2.3 Empirical data gathering methods

Especially in Case studies 1 and 2, the general main method of data gathering has been digitally recorded interviews, and interview notes based on open-ended, semi–structured interviews [16]. These interviews were in Case studies 1 and 2 less structured, allowing the researcher to gain an understanding of the interviewee and the subject matter chosen by the interviewee (often corresponding with the interviewees professional role in, for example, development, sale, repairs, etc.) Once this had been achieved, more direct questions were asked concerning the needs of the interviewee and the processes of his or her organisation. Interviews carried out during Case studies 3 and 4 were carried out for development of a scenario or in the context of a scenario with a closer focus on current and future development processes and the industrial need.

One advantage of the semi-structured interview is the flexibility to explore areas of questions as they arise during the interview process. The interviews were conducted thus to allow the interviewees to express themselves freely and to allow for questions and the creation of a shared understanding. The interview approach continued during Case study 3 to some degree and was supplemented by guiding principles from the area of participatory action research [17], further discussed below under the description of Case study 3. In Case study 3 especially, the data gathering also included observations of daily work, informal discussions at the workplace and various kinds of project meetings. As stated elsewhere, Case study 4 was not specifically planned as research by the researcher and is therefore not a Case study in the same sense as Case studies 1, 2 and 3. The data gathering in Case study 4 was by necessity based on the plan of work for the Faste Laboratory [18] and included academic strategy meetings and continuous discussions with nine industrial partner companies of the Faste Laboratory during its formation. The main data gathering method of interviewing has been supplemented by studies of secondary sources such as project notes, formal work process descriptions and retrospective project descriptions. Formal interviews were digitally recorded and evaluated after the interviews had occurred. Less formal interviews and interviews where informants felt uncomfortable being recorded was commonly noted in case notes on a laptop computer and discussed after the interview.

2.4 Case study approach

Case-study research is a way to explore the reality of the studied companies to gather data and has been used in concert with the comprehensive cyclic research method above. The research presented in this thesis has in general been explorative in nature; the data gathering has been done with the purpose of understanding a situation, most often a design process. The focus or initial intent in terms of the results of the individual papers has been prescriptive rather than explorative. That is, the intent has been to create prescriptive models based on conclusions from mainly descriptive studies. To do this, looking at the research process as a whole, a case-study approach to data gathering has mainly been used. In the cases the researcher studied the daily work on site, trying not to influence the natural state of work [19].

Case-study research has been the method for carrying out the observation and analysis in concert with action research [20]. This research does not claim to be fully based on action research, however. McNiff [14] states that: *Action research is open ended. It does not begin with a fixed hypothesis. It begins with an idea you develop.* Over time the idea to model, simulate and optimise work process flows developed. Prior to the development of that idea vague hypothesises existed within the whole PhD research project. In Case study 3 with Volvo Aero, especially (further discussed below) action research was used. In Case study 3, sets of action-oriented goals were developed by the researcher and the industrial informants over the course of the research project, these goals are elaborated on in the scenario discussion of Paper F. Discussions have been carried out in an informal manner with key informants concerning what information is being sought after and what interpretations and conclusions may be made. As Whyte [17] put it, key informants thus become active participants in the research. The research activities are discussed in more detail below. McNiff identifies that action research, among other things, is practitioner-based, focuses on learning and change and can lead to personal and societal improvement, an improvement of the situation. In the context of the author the improvement McNiff refer to corresponds with understanding the as-is situation and changing it with a specific goal to the desired to-be situation.

In comparison to Case study 3, Case studies 1 and 2 were about developing an understanding of the field of Functional Product Development including challenges and requirements. Consequently, few action-oriented goals were developed in Case studies 1 and 2.

The interpretation of information is based on triangulation of information from different interviewees and from different other sources which together form a coherent view of the results.

Case studies 1, 2 and 3 were designed and carried out by the researcher. Regarding Case study 4, the researcher participated in the planning and formation of the Faste Laboratory but did not specifically design it. Therefore, Case study 4 is treated differently than Case studies 1, 2 and 3. The most time and effort was spent on Case study 3 and Case study 3 is therefore most important for this work. Case study 3 was a two-year project carried out within the Swedish National Aeronautics Research Programme (NFFP) with Volvo Aero as the main industrial partner.

2.4.1 Case study 1 - Hägglunds Drives AB

For research carried out during 2003-2004, a number of people at three companies were interviewed, i.e. primarily Hägglunds Drives AB and Volvo Aero and secondarily Volvo Car [21]. Case study 1 is based on a number of interviews carried out during visits by the researcher at Hägglunds Drives AB. These interviews formed the basis of an explorative study to understand and describe the hardware development process of Hägglunds Drives AB and the strategic (business) positioning of Hägglunds Drives AB.

At the time, HDAB discussed creating a joint functional product with some of their customers. Paper A brings up the strategic gap between the current strategic position of the company and the aspired strategic position. In addition, design management lessons learned from case studies at Hägglunds Drives AB were presented in [22]. The purpose of Case study 1 was, in the context of this thesis, to create understanding concerning the challenges that faced the company when considering development and sale of a functional product.

Case study 1 included asking questions concerning current product development practices, future goals and extended product offers. Intents of questions were framed differently according to the interviewees' backgrounds. A company executive was asked:

Please describe your company strategy.

What, in terms of development process, project management or organisational structure supports that strategy?

An engineer was additionally, or instead, asked questions such as:

How do you do product development today?

Do you like the way it is done?

What improvement potentials exist given the current goals you develop or are asked to meet?

2.4.2 Case study 2 - Hägglunds Drives AB, Volvo Aero, Volvo Car Corporation

This case study is based on and is a continuation of Case 1, using open-ended interviews for data collection. It involved exploring the differences between the three companies strategic positioning and their considerations on functional product development.

Studies with and at Volvo Car Corporation (VCC) in Gothenburg were relatively minor compared to studies at Hägglunds Drives AB and Volvo Aero. They were facilitated by a colleague who had been situated for three years at VCC as a doctoral student.

The purpose of Case study 2 was, in the context of this thesis, to create understanding concerning the different ways the companies differentiate from their competitor. An additional purpose was to investigate their product development management practices. Case study 2 included asking questions concerning current product development related practices, future goals and extended product offers. Engineers at Volvo Car Corporation were for example asked:

How do you interact with management?

How does the management interact with you?

How do you get to know what the customer want?

Do you have any collaboration with Volvo finance?

2.4.3 Case study 3 - Volvo Aero

The research within which the case has been developed includes investigations together with 10 interviewees at Volvo Aero concerning their product development practices and goals. Additionally, less formal discussions have been held with seven other Volvo Aero employees. Case study 3 was based on the idea to predict the outcomes of products, service concepts and (functional product) business offers. The purpose of Case study 3 was therefore to gather sufficient information to model and simulate the studied process. The knowledge gathering activities and models of Case study 3 are reported in Paper F and the created simulation models are reported in Paper G. Within the project the current (as-is) Volvo Aero service development process has been studied with a focus on activities and information paths rather than on hardware function. The studies have aimed at creating an understanding of the information exchange process during the development of for example a repair description of work (DoW).

A scenario was developed for Case study 3 which is discussed further in Paper F. The scenario describes future business interests of and subsequent requirements of Volvo Aero. Using a scenario approach has been discussed by Caroll [23] in the context of design of information technology. Caroll notices that scenarios address five technical challenges, some of which are summarised below:

- Scenarios evoke reflection in the content of design work.
- Scenarios promote work-oriented communication among stakeholders.
- Scenarios afford multiple views of an interaction.

Much of the work was carried out during three week-long visits to Volvo Aero, where the researcher observed the daily work and was welcomed to develop a suggestion for improvement concerning how Volvo Aero responds to customers' requests for service provision. The project also included opened-ended interviews [16], document analysis of formal work-process descriptions, archival records, and subsets of what Volvo Aero calls their Global Development Process or GDP. This first led to the identification of the corresponding process in the Volvo Aero GDP, a hardware-based process for service provision. This work is further reported in paper E and F. The process, which supplies a service for a customer, mainly consists of engineering related activities. Therefore the process may be seen both as a service development process and as a product development process.

Due to the size and organisational structure of Volvo Aero, data gathering during Case study 3 included asking a number of Volvo Aero employees which company development process would be most suitable to study in relation to functional product development and existing knowledge in terms of process, product and customer needs. Identifying a relevant process was done in order to find a process to study in which people would be interested in the result, to create access and to create support for the research.

Once a suitable process had been identified, Case study 3 included asking questions concerning current product development related practices, and current service process practices in relation to extended product offers. These questions led to general understanding and the development of a process for services provision. The process includes a set of activities which are carried out by a set of internal Volvo Aero divisions. Questions also included with whom people from different departments cooperate (the most) when developing a service (which may be adding value to hardware). The process is described in Chapter 4.6, Figure 5 below.

After identifying a relevant process to study and a general understanding of the process had been formed by the researcher, specific interviews with key Volvo Aero personnel were held. Questions regarding the activities, variance in times to carry them out and cost were asked in order to gather information concerning the work process models which were to be created. For example:

How is this activity instigated?

Is it normally useful to add an extra person to this activity, and to what degree?
How long does this activity normally take?

What are the limits in terms of personnel?

Once the information exchanges in the studied process had been sufficiently understood, modelling commenced. When a larger change had been implemented in the model based on industrial requirements, the results and the layout were discussed by the researcher, the main industrial advisor and the primary intended industrial user. This process was iterated a total of five times towards the end of the research project.

2.4.4 Case study 4 – The Faste Laboratory

Case study 4 concerns the development, by the whole of the researcher's division and four other divisions at Luleå University of Technology, of a strategy for 10 years of research concerning functional product innovation. This is covered to some extent in Paper B, appended to this thesis. For this thesis, Case study 4 provided a wider knowledge base for evaluating needs of the participating companies. This gave the researcher input into what information should be used as output from the model developed in the context of Case study 3.

The research has included academic strategy meetings and continuous discussions with nine industrial partner companies during the formation of the Faste Laboratory – Centre for Functional Product Innovation, of which Hägglunds Drives AB and Volvo Aero are members. The context of the participating companies is Swedish industry and the member companies differ with respect to their specific interests within functional product development due to their customer needs. Some of the company representatives are more informed concerning functional product development than others and many use varying vocabulary to convey essentially the same meaning.

Case study 4 is a case of Research through Design. It is based on a two-day workshop and three one-day meetings with the partner companies. Almost all of the

Faste Laboratory partner companies took part, including representatives from Volvo Aero and Hägglunds Drives AB. As a whole, the researcher objectives were to gather information to compare to conclusions of Paper B and to gather requirements for functional product development. Notes were taken on a laptop computer when interesting issues arose in discussion. No formal interviews were held.

In addition, several internal meetings were held at the university regarding the Faste Laboratory strategy and future research projects. While the larger workshops mostly addressed issues of common industrial and academic interest regarding the future of the Faste Laboratory, the internal meetings focused more on specific research, new research projects which were likely to fulfil the goals and objectives of the Faste Laboratory.

3 Knowledge Domains

Chapter 3 introduces relevant literature fields in order to position the thesis in the literature.

3.1 The research area

A clarification of the research area is shown in Figure 2 below. The discussed literature indicates that research concerning conceptions related to functional products appear in several research fields. The main theoretical base of the research in the thesis is the engineering design literature, computational simulations and work process modelling.

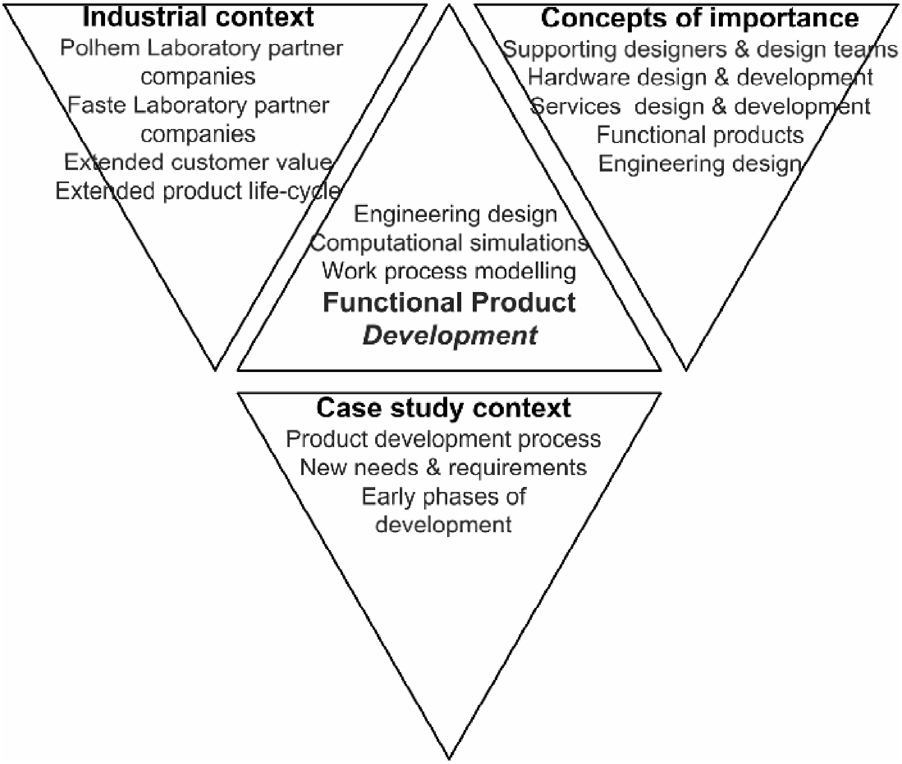

Figure 2: The research area.

Chapters 3.2 and 3.3 describe the researcher's starting point in literature. Chapter 3.4 introduces the background and the current streams of research in the area of functional products. Chapter 3.5 introduces the area of service development which has to some extent influenced the previous area through changing needs and requirements. Finally, Chapter 3.6 introduces simulations in product development as an area of interest once results concerning the research question had been developed. Chapter 3.7 introduces existing modelling and simulation support tools in product development. Based on the research area as described in Figure 2, related relevant literature fields are discussed below.

3.2 Engineering Design

The purpose of engineering design literature is to explain how to develop hardware to meet a requirement specification. Product development literature such as Womack & Jones [24], Otto & Wood [25], Wheelwright & Clark [26] and Roozenburg & Eekels [27] offers a broader view and generally aims to describe how to generate a product (hardware, service or whatever) to meet the customer needs. Product Development literature provides a rather wide picture of how to understand needs, and develop and sell products.

Ulrich & Eppinger [28] define product development as:

"*The set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product*".

The concepts of Integrated Product Development (IPD) and Concurrent Engineering (CE) focuses on concurrent rather than sequential activities, thus increasing the speed of product development. The concept of integrated product development was first described by Olsson [29], who describes an extensive IPD-process due to his inclusion of customer demands originating in market, design, production and business and finance. Olsson discuss product development as a process including both customer demands and the concurrent handling of the four activities Market, Design, Production and Business / Finance. Olsson treats these activities as parallel activities rather than integrated activities.

As a further example, Figure 3 below depicts the product development process according to Ulrich & Eppinger [28].

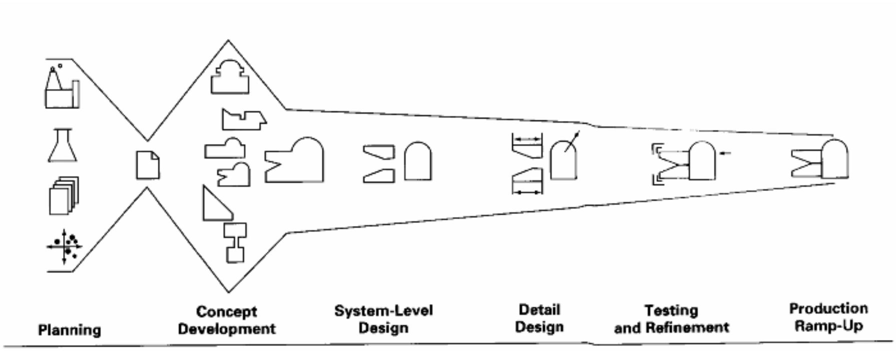

Figure 3: A schematic view if the Product Development Process according to Ulrich & Eppinger.

Related to the product development literature, engineering design is an area of work best described as the procedural and textual description of how to create a physical product from a technical requirement specification.

A modern classic in the area of engineering design that discusses the engineering design process is Pahl & Beitz [30], originally from 1984. Pahl & Beitz divide the development process into four stages: clarification of the task, conceptual design, embodiment design and detail design.

The original purpose of the work by Pahl & Beitz was to aid the creation of hardware. At the time of original publication and before, requirements were on creating hardware products which were to be made with the intent of hardware sale. At the time, no requirements for explicitly developing the hardware to be a part of a larger offer, with retained supplier hardware ownership, were expressed. Thus, Pahl & Beitz and many other related engineering design publications describe best practices for developing hardware, which is the essence of engineering design. Naturally, the practices discussed by Pahl & Beitz [30] may be applied to functional product development, especially to a possible hardware core. However, as discussed under the section Service Development below, these practices are not intended to capture and transform (added) customer value to hardware design requirements.

Integrated Product Development (IPD) [31] and Concurrent Engineering (CE) [32] are strands within the engineering design literature. According to Andreasen & Hein [31], integrated product development can be defined as:

"*the process of taking a product through the many interlinked stages of a company's business from concept to sales and installation.*"

By itself, this definition points out the need to interlink company activities, but lacks a focus on *customer need* and includes the assumption that *supplier responsibility ends* as the product has been sold and delivered.

By comparison, Roosenburg, & Eekels [27] describe the design process according to

Figure 4 below:

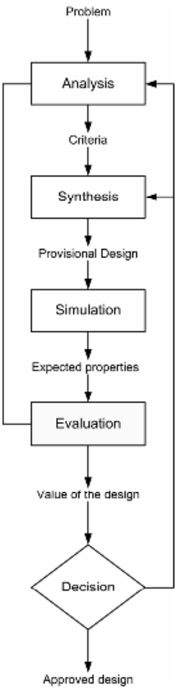

Figure 4: The design process according to Roosenburg & Eekels.

Roosenburg & Eekels [27] indicate the approach, commonly used in the engineering discipline, of using simulation to assess the value of a design and base engineering design decisions upon it. They further define products according to:

"*Products are artefacts conceived, produced, transacted and used by people because of their properties and the functions they may perform. Product design is the process of devising and laying down the plans that are needed for the manufacturing of a product.*"

Roosenburg & Eekels have a focus on fulfilling customer need through artefact function and make no reference to supplier responsibility in their definition.

3.3 Functional product development

Functional product development is a way to form what Nordström & Ridderstråle [33] call a total offer including both tangible and intangible assets, such as knowledge, financial offer, service deals, etc. Normann & Ramírez [34] argue that it is no longer possible to draw a distinct line between products and services, as all products include services vital for their value.

The general area of functional products is now being developed, for example by Alonso-Rasgado et al., [1], Löfstrand et al. [35], Ericson [36] and Sundin [37]. The area is being developed using varying nomenclature including Product-Service System [38], [39], Total Offers, [40] and Extended Products [41]. Managing development of a complete market offer has been discussed by Brännström [42]. However, development of extensively value-added products such as functional products has not been approached sufficiently from an *engineering development* perspective So far, the research concerning development and sale of functions has been done in the context of business-to-business relations. Now, research into functional sales for the context of business-to-consumer relations is starting to appear [43]. In this thesis, the context is development of functional products in an extended enterprise [44], business-to-business setting.

Mont [45] introduces a schematic representation of a Product Service System (PSS). Product Service Systems have also been discussed by Manzini et al. [46], who apply a sustainability perspective to the issues. In addition to the functional product related areas above, Functional Sales stands out as an area related to business success in functional product development.

3.4 Functional sales

The main difference between Functional Product Development and Functional Sales [47] is that the former conception include a strong development perspective while the latter is chiefly focused on sales. Functional sales are more dependant on contractual agreements than functional product development. Service development commonly has a business-to-consumer focus. Lindahl et al. [48] present a lifecycle-based interactive design model for Integrated Product and Service Engineering (IPSE) based on [49].

3.5 Service development

Service development is interesting for this thesis in that the concept of value is closely associated with service development. The change towards services-heavy products, where services are main selling points, is one of the business drivers of functional products. Hence, service development was identified as a potentially interesting area of reference. As added value is a main industrial interest in functional product development and functional sales, the service development area of research was identified as potentially useful in relation to functional product development and other related concepts where added value is associated with development.

Grönroos [50] presents a core product perspective and the service perspective. Ericson & Larsson [51] notice differences between product development literature and service literature; they notice that a majority of manufacturing companies have broadened the core product perspective to encompass services such as aftermarket activities.

Gadrey et al. [52] see services as the bundling of capabilities and competences to organise a solution for the customer. According to Cooper & Edgett [53], services have four main characteristics:

Intangibility
- Unlike [tangible] products, services have no physical form

Inseparability
- The act of supplying a service is virtually inseparable from the customer's act of consuming it.

Heterogeneity
- services on the other hand, generally are never delivered the same way twice…

Perishability
- Unlike tangible products, services are produced at the same time they are consumed.

Edvardsson et al. [54] draw similar conclusions. Cooper & Edgett [53] identify three cornerstones of performance for effective new service development: product development process, new service strategy and resource commitment.

Recent developments in the area of service development include contributions by Karandikari and Vollmar [55], who state that despite making service a central pillar of their growth strategy, very few companies have pushed to focus their R&D on service or to get their service organisations to engage more intensively with the R&D groups.

The area of service development is interesting for functional product development in that it focuses on intangible aspects of a product. Thus, the focus is shifted from the hardware functionality (which may remain the suppliers' responsibility) to other customer requirements. Correct design-criteria creation based on intangible customer requirements supplies added value to the customer, *assuming the hardware product core performs as agreed.*

3.6 Computer-aided tools and methods in product development

Methods for computational simulation are quite common and exist in a number of different related versions. In this thesis, computational methods are defined as methods for finding approximate solutions to mathematically described models of real systems. Neelamkavil [56] presents a useful definition of a model:

> "*A model is a simplified representation of a system (or a process or theory) intended to enhance our ability to understand, predict and possibly control the behaviour of the system.*"

Simulations in product development have traditionally been used for the purpose of evaluating the performance of a hardware artefact, to investigate if an artefact meets the standards described in the requirements. Roozenburg & Eekels [27] notice two uses for technical simulation:

1. Does the product perform as intended; will it fulfil its technical functions?
2. Can the product be manufactured in the planned quantity, and at an acceptable quality and price?

Another area in computational simulation is discrete event simulation. Pollacia [57] describes the historical development of discrete event languages.

Johansson et al. [58] identify through a survey that simulation has been ranked as a top-three tool in the area of management. The survey by Johansson et al. also identifies that information is not well structured in today's companies to support discrete event simulation in daily work. They further identify that moving discrete event simulation as a tool from physical and application integration to also support business and enterprise integration is a very hard task. Johansson et al. [58] notice that (industrial applications of) discrete event simulation is mainly integrated on a physical and application layer rather then in the business layer.

Johnsson et al. [59] conclude that working with complex collaboration, such as in a virtual enterprise, requires tools to support and secure decisions. Using discrete event simulation in the virtual enterprise is possible but a well organised working method has to be used.

Various types of Computer Aided Engineering (CAE) support have in recent decades developed and are used in product development. 3D part and assembly modelling is being used for increasing quality, reducing cost of building prototypes and has together with product data management (PDM) systems been used for storing and managing formal knowledge for engineers [5]. The computational support of geometry-based product information has been discussed by Fuxin [60] as positively affecting the lead time, quality and number of physical mock-ups. Further, Jeppsson [61] also discusses computer-integrated design systems in concurrent engineering.

In mechanical engineering, simulation results are often visualised graphically as stress, strain, temperature or as motions, depending on the problem at hand.

Every engineering or otherwise related discipline (such as mechanics, electronics, business & finance, etc.) commonly uses its own set of support tools. In general, advanced support tools suitable for use in the latter stages of the design process are more common than tools suitable for use in the early stages of the design process. In addition to the geometry-based product information tools discussed above, another CAE support tool in product development is computational simulation.

3.6.1 Computational simulations

The main point of creating computational simulations is that they allow optimisation for a certain desired outcome; therefore, anything that is possible to model mathematically is possible to optimise. Engineering functionality of hardware, economic properties and maintenance work processes, to name a few, may all be modelled and optimised.

Using discrete event simulation, a system and its operation is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system.

In the context of engineering simulations, Johansson [62] notes that up until 2001 most tools have been specialised in one specific area of the physical system and that modelling and simulation of coupled, multi-domain, physical systems therefore is quite demanding. Sinha et al. [63] presents an overview of the state-of-the art in modelling and simulation for the purpose of supporting the design process. They state that: *For instance, languages should allow models to be easily updated and extended to accommodate the various analyses performed throughout the design process. Furthermore, the simulation software should be well integrated with the design tools so that designers and analysts with expertise in different domains can effectively collaborate on the design of complex artefacts.*

Papalambros [64] suggests an enterprise context for design optimisation and concludes that target cascading and target setting were originally conceived as “business” processes. Papalambros [64] indicates that “business” processes can be formalised as quantitative design optimisation processes. Papalambros notices that in doing so, we are able to expand the context in which engineering design decisions are made to include the broader viewpoint of the enterprise within which designing takes place.

Wynn et al. [65] introduce a modelling framework which can support design process improvement activities ranging from process description to simulation and automation.

Another subgroup within computational simulations which may well make use of the aforementioned one is simulation-driven design (SDD). Sellgren [66] proposes a modular and object-oriented approach for a modelling framework that allows general numerical observations of the physical behaviour of technical systems. His proposed approach also should support verification and optimisation of the selected concepts.

Bylund [67] states that a simulation-driven rather than a simulation-verified approach will enable engineers to achieve simulation driven design by designers. Bylund as well as Sellgren focuses on traditional engineering hardware products. Larsson [68] and Larsson et al. [69] do as well, further proposing a modular process approach in product development, using a multibody system as the application.

A main advantage to the use of a modelling and simulation approach is that it may significantly improve the quality of the result because it allows both functional as well as predictive use.

4 A Modelling and Simulation Approach for Linking Design Activities to Business Decisions

Chapter 4 presents the research results from case studies and from process modelling and simulation.

Results from four Case studies are reported below. Case studies 1 and 2 were carried out with the purpose of creating a comprehensive researcher understanding. Case study 3 was the main study reported in this thesis. Unlike the other Case studies, Case study 4 was not designed and carried out solely by the researcher. After the Case studies the modelling and simulation efforts are presented.

4.1 Case study 1 – Hägglunds Drives AB

In general terms, results from Case study 1 included establishing an understanding of the importance of increasing knowledge in the conceptual stage about the products and future customer product use cases, before successfully entering a functional product sales agreement or a functional sale. Both interview material and conclusions indicate that Hägglunds Drives AB engineers know how to create their hardware and software: motor, pumps, controlling software, etc. However, creating functional products with hardware cores from their hardware and software was a challenge. During Case study 1, an engineer in a management role stated that:

High quality is for the most part the same as availability; to prevent production losses for the customer.
- The statement is an indication of climbing the value chain, offering a higher customer value product then previously.

With the 18 variants we can choose a better pump and pump cabinet. This is where we make our money.
- The statement is an indication of choosing an optimised pump system for a customer use case to minimise losses and thus increasing the gain.

When asked to summarise qualities the design department was focusing on during development of a motor which has since been sold as a part of a larger system the answer was:

Torque, life cycle, quality, good support to clients. More focus now on total systems.
-The statement is an indication of building on existing product knowledge and from there climbing the value chain, offering a higher customer value product than previously.

Fast service and support means that we react, care for and serve the customer as fast as humanly possible.

Another senior engineer stated that:

Service and support and long service life were rated the highest [of the design criteria]. *The relative importance of criteria was decided by consensus within the group.*

And:

Accessories are what is up and coming.

And:

We now get to develop [the client's] *applications more and more* [Design] *and then we have to be included to ….discuss the design.*

And:

We know a lot, but we need to test more, to simulate more, to field test more
[Creating more accurate knowledge is required]

Finally, another, less senior engineer stated:

We should have gone further with modularisation to get more motors, high power, less service life, etc.
- An effect of higher power is more wear and less service life.

And:

I don't think that we should sell reused motors, another firm might do it. One firm in the USA does it for the…
- Sale of refurbished motors could damage the Hägglunds brand.

I sometimes miss a group that develops component ideas so that we know in advance what works and what doesn't. It has started a little bit with…
- Expresses a need for design department to be ahead of the business schedule in product development to facilitate quicker responses and higher quality.

These statements show the focus to design a product to be used as a part of a more extensive product offer. The study showed the focus on total systems, value-adding accessories and availability. The study also led to the formal description of the HDAB product development process (reported in Paper A), which had not been formally described previously.

An engineer said:

Some of our customers want to buy functionality and we want to deliver. We are unsure if we know our product and the product use cases well enough to be able to take the risk of selling function.

Designers and design managers felt the need to increase the product's efficiency to minimise their losses and costs through a long-term research process. By doing that, they would be able to reduce the price for the customer and thus gain new markets and compete more successfully on markets where they are already established. Such long-term research programmes have been proven at Hägglunds Drives AB before and they will continue to carry them out.

However, for HDAB to go into business in a business-to-business, functional product setting, results indicated two main issues in addition to the hardware-based functional requirements being met. They chiefly were having a shared value and cost model and trusting one another well enough to start developing the project.

Results from Case study 1 are presented in more detail in Paper A and Paper D.

4.2 Case study 2 – Hägglunds Drives AB, Volvo Aero, Volvo Car Corporation

In general terms, results from Case study 2 included an understanding of the relative similarity of Hägglunds Drives and Volvo Aero, compared to Volvo Cars, in relation to their perceived ability to enter functional product agreements successfully. Case study 2 also highlighted the potential challenges with having highly geographically distributed partners and increasingly cross-functional project team members. Choosing or developing new product development methods in the context of increased complexity, in terms of the product as well as the business situation, was found challenging at Volvo Aero. This challenge developed the researcher's idea, together with Volvo Aero, to further predict the outcomes of products, services functional products and (functional product) business offers.

The study led to the publication of Paper D, which describes some of the challenges inherent in functional product development and prescribes a possible means of confronting some of these challenges by introducing a simulation support tool for functional product development. In the paper the authors discuss how customer requirements need to be handled when developing a total offer in the form of a functional product. Finally, the requisite traits of the engineer who is to develop it while being part of a multi-cultural team, possibly a geographically distributed team, are discussed. New and updated requirements to reach the possibility of developing functional products through the concept of Functional Product Innovation (FPI) were introduced in Paper B.

Interviewees at Volvo Cars had little interest in extensive product offerings of any kind, including functional products. Volvo Car Corporation at the time had a product development process which included a 5-year loop where future technologies were developed before they were considered for inclusion in vehicles. This is a feature which several HDAB engineers expressed interest in, according to Case study 2. It was felt that such a loop would enable faster market response and higher quality, i.e. longer service life.

The main points of HDAB's strategy in 2003 were: 1- System sales, 2 - Productivity for the customer in terms of economic gain and 3 - Function.

Concerning the main challenges to reaching the HDAB strategic goals (the to-be scenario) an informant in a leadership role at Hägglunds Drives AB said that:

In the concept generation phase of a project, the market division must be able to create better estimates in terms of volume of sales and marginal cost. The same should be done for competitors to the extent that this is possible.
- Asking for ways to create better estimates of business success.

One must also define [if a project's purpose] is to take market shares or to take part of a growing market.
-Deciding and communicating purpose to the development team is important.

The informant wants the company to improve in terms of: concept generation and selection, in close contact with the customer to [better] meet the customer's expectations.

Volvo Aero personnel expressed concerns with business risks and opportunities. Statements (regarding proprietary business information) included:

Our customers ask us to take more responsibility

We sold a product under, [a specific business contract] *and it did not work out…*
-This statement relates to the importance of contractual limitations on sale of value-added products. At the time, the contractual agreement allowed customers to make unforeseen decisions.

Results from Case study 2 are presented in more detail in Paper B and Paper D.

4.3 Case study 3 - Volvo Aero

In Case study 3, the researcher participated in and collaborated with personnel in the studied organisation. The scenario which was developed during case study 3 is based on a need for predictions concerning company performance that are much faster and more accurate than today's, because of the risk aspects and the strategic interest of Volvo Aero to be a best partner to their customers.

Volvo Aero now require service concept business decisions to be based on quantitative measures and useful predictions as well as on experience. The changing business demands require that a simulation which today takes two weeks will in the relatively near future have to be done in less than a day, indicating a need to further develop the company's existing simulation capabilities. Being able to supply a hardware-based service to a variety of customers is a driving force behind this development. These services include welding, milling, drilling, heat treatments and various types of written instructions, among others.

In interviews during the initial stages of Case study 3 several informants identified a strategic interest in decreasing testing of hardware components in favour of modelling and simulation. Requirement-related statements included that of a senior manager:

We have the strategy, extending our existing hardware functionality simulation ability and also creating new abilities in simulation.

A services development manager stated:

Is it worthwhile to make this offer?
- Expressing need for more knowledge regarding what parameters mainly affect a value added offer.

Faster offers to the customer!
- Which could be developed through modelling and simulation of design processes costs and times.

To move from the requirements (as-is) to the strategy (to-be) statements such as those below were made:

Simulation of the service process.

Concerning the usefulness of simulated work process predications, a junior level engineer stated that:

Well, it does not help me but it might help my manager, he has to prioritise jobs.
- The informant identifies a use of process modelling for the manager.

A senior market division employee discussed simulated work process predications and said:

If I have cost and time predictions, I can make an offer in hours rather than days.
- Simulating instead of manually gathering information would save time when putting together a tender.

Concerning contractual risks, a senior Volvo Aero research manager stated:

Contractual risks imply requirements on right simulation in the concept development stage, since the product is to a large extent defined there.

Contractual risks imply requirements on right handling of existing products, not developed for functional sale.

The informant suggests the use of process modelling:

Black box simulations in enterprise networks to create value in the customers' process.
[Black box refers to protecting company core knowledge while allowing access to simulation output.]

Simulating very large knowledge volumes is necessary
- Refers to modelling and simulating non-hardware, process-related material.

This process started with the researcher having lengthy discussions with a number of Volvo Aero personnel concerning identification of the most suitable process to study, identifying and understanding the design team. Grudin in Schuler & Namioka [70] calls this process "trying to find the design team". Initially, the hardware core of Volvo Aero's extensive product range and their organisational unit (civilian or military) was discussed. As understanding of Volvo Aero's practices grew, the work process activities themselves were identified as being more important.

Results from Case study 3 are presented in more detail in Paper F and Paper G.

4.4 Case study 4 - The Faste Laboratory

In Case study 4, as reported here, the author chooses not to include statements from other companies than Volvo Aero and Hägglunds Drives AB. Other data (statements/voices) are based on a research management and planning exercise with no previous background studies. They are therefore harder to interpret correctly and may be biased. Briefly, issues raised were reuse of knowledge, optimisation of the product in the customer's organisation or internal process and creating predictions for being able to even the workload.

Hägglunds Drives representatives stated that:

We need to show the customer value for the designer, a 1% cost cut may create a 20% value gain for the customer. When that understanding exists, the designer and the market personnel speak the same language.

Volvo Aero representatives expressed an interest in global aspects of functional development and delivery, knowledge engineering and simulation.

In general terms, results from Case study 4 support the need for integrating the domains of engineering and business further for future work in the field of functional product development and innovation. Case study 4 has to some extent been used as a way of evaluating the results created in Case study 3.Results from Case study 4 are not yet presented in the form of submitted or published papers.

4.5 Results from the case studies

Case studies 1-4 led to the general identification of a need for:

- Linking company engineering activities to customer needs and business processes further.
- A procedural loop, whereby future technologies could be developed for faster response to customer need, was expressed by informants from Hägglunds Drives AB, according to Case study 2.
- Evaluating cost/gain relations of future business offers before costs are incurred. (Case study 3, response to demonstrated model output)
- Evaluating company ability concerning product development and delivery before the concept stage in product development. (Case study 3, response to demonstrated model output)

These points may be summarised as an industrial need to reuse knowledge through the use of new support tools. Modelling and simulation-based tools may be used as a way to increase efficiency and productivity, providing more time for innovation, thus increasing industrial competitiveness.

Based on the above general requirements for functional product development as identified during the case studies, work process models have been developed which show the possibility of reusing knowledge in a (by the researcher) developed functional product provision process through further linking company development process to future business scenarios.

4.6 The developed work process models

A work process simulation modelling approach should allow simulation of cost, time and personnel distribution. For industrial benefit. The model, discussed below, were largely created based on the results from Case study 3. Case studies 1 and 2 mainly provided background understanding and Case study 4 provided additional motivation for the focus and to some extent the presentation of model output. The models relate to both industrial business scenarios for functional development and sale, and to the product development process.

4.6.1 Model specifics

The work process that is discussed in Paper F is schematically laid out in Figure 5 below. The process consists of a selection of blocks that correspond to sets of activities. Through modelling and simulation of the process, based on the available manpower and the cost of the manpower, the developed program delivers an indication of which business alternative is best for the company to suggest to the customer.

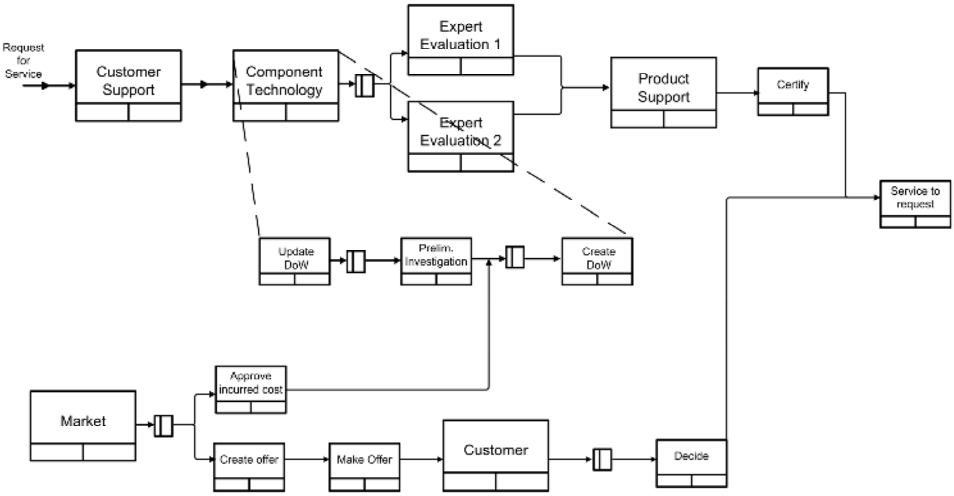

Figure 5: The work process that provides a service to an internal or external customer (public version).

Here, the process has been described for the purpose of portraying the interaction and communication that must take place internally, before delivery of the intended service. Starting in the upper left corner with a new order from a customer, the order goes though a set of either external activities or internal activities (with no direct feedback to the customer). The order is processed by the customer support department when it is received, the service description of work is updated, a price is set and finally the customer receives an offer. The offer may, for example, be to sell a component. The developed program is described in Figure 6 below.

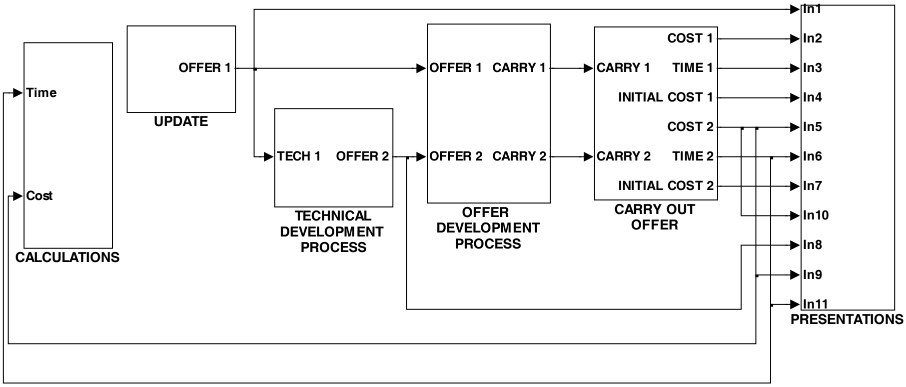

Figure 6: A public view of the developed to-be SIMULINK model consisting of six main blocks.

Figure 6 describes the top level of the developed SIMULINK program, based on the process described by Figure 5.

The SIMULINK program further presented in paper G is based on:

- Fifteen supplier-internal activities grouped in four activity-related processes presented in Figure 6 above. These processes are “Update”, “Technical Development Process”, “Offer Development Process” and “Carry Out Offer”. Two more boxes, “Calculations” and “Presentations” are required to create and to present results.
- One external activity (waiting for a customer decision)
- Four different execution paths may be evaluated by running the SIMULINK program.
- Similarities for each of the 15 activities are that the same mathematical work-related expression is used in each.
- Differences between the activities are controlled by settings in indata which differ in:
    - Maximum personnel
    - Start cost per division (A one-time cost when a division is first triggered.)
    - Cost per hour
    - The collaboration value (further discussed in Paper G).
- Outputs from two of the four execution paths may by the supplier or customer be evaluated against three other business choices. The other two main outputs are created for internal clarification of the development process, chiefly of interest for the supplier (Volvo Aero).

The SIMULINK model may be used to produce information according to Figure 7 below.

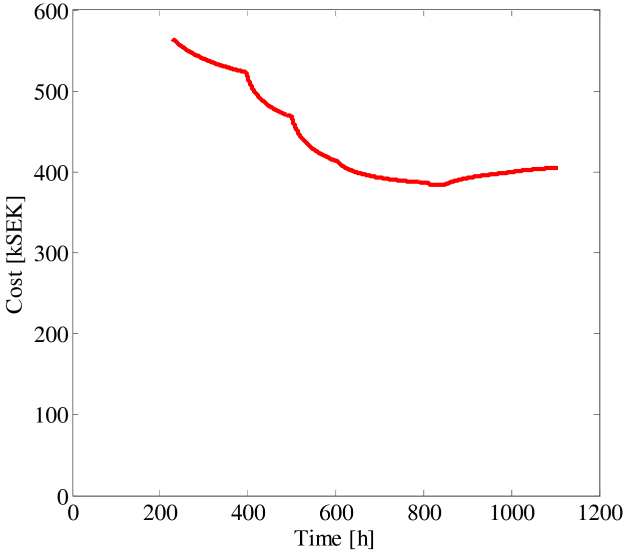

Figure 7: Simulated cost versus delivery time.

Figure 7 describes a part of the output from the developed SIMULINK program. Simulated cost versus delivery time indicates that prioritising-related decisions need to be made before and during development of products.

The process modelling and simulation approach presented in papers F and G is industrially useful in a number of ways. One example is that the developed program may be used as decision support tool for strategic choices and prioritising errands because of the model's ability to evaluate cost, personnel distribution and required profit margins for different cases. Another example is that the model may be used to evaluate customer demands. This is exemplified by the program's ability to respond to the common customer question as to whether a service could be done by Volvo Aero in a certain time and to a certain price. Additionally, the model's short execution time of normally not much more then a few minutes allows for repeated testing of many different scenarios, thus industrial users may evaluate the effects of a concern that they might have.

Thus, the modelling and simulation approach supports users in evaluating the cost of future business before costs are incurred, evaluates product development ability and links company technology and business processes further. It also increases user understanding and knowledge concerning the product development process and its limitations and allows for comparison of alternative versions of the same design process well before the actual development work has been carried out. Additionally, it allows knowledge reuse through process simulation of different outcomes.

The developed program is being applied by users in industry and academia. An evaluation has been started and initial industrial feedback has been positive. While the approach and results presented here are still under development, the current results described above are promising enough to conclude that the model, through the simulation-driven design approach, may become a useful industrial application

The approach introduces design process modelling and simulation as a tool which may be used in relation to the business and use case negotiations and development of the functional products. While the customer need is explored and business and use case negotiations commence, the design process modelling and optimisation approach creates knowledge for the supplier as to how quickly and to what cost a process may be carried out to create customer value. This information may be used in negotiation as well as requirements for the development of the functional product.

4.7 Summary of findings

For traditional services, production, distribution and consumption are simultaneous processes. For hardware artefacts, production and distribution are separated from consumption, as discussed in Chapter 3. A functional product is often unique for its specific application and will most often (depending on its composition of hardware, software and services) have both of these characteristics. Hence, functional products may have both material as well as immaterial properties. These differences have been described in Figure 8 and Figure 9. Functional products entail an increased focus on immaterial requirements from customers. No longer will measurable, technical requirements be the sole criteria for measuring the success of a product. Immaterial properties may include increased designer security, reduced risk, predefined cost per month, increased knowledge of use of own products, availability, etc.

Hubka & Eder’s technical system is presented by Roozenburg & Eekels [27] and is depicted in Figure 8 below.

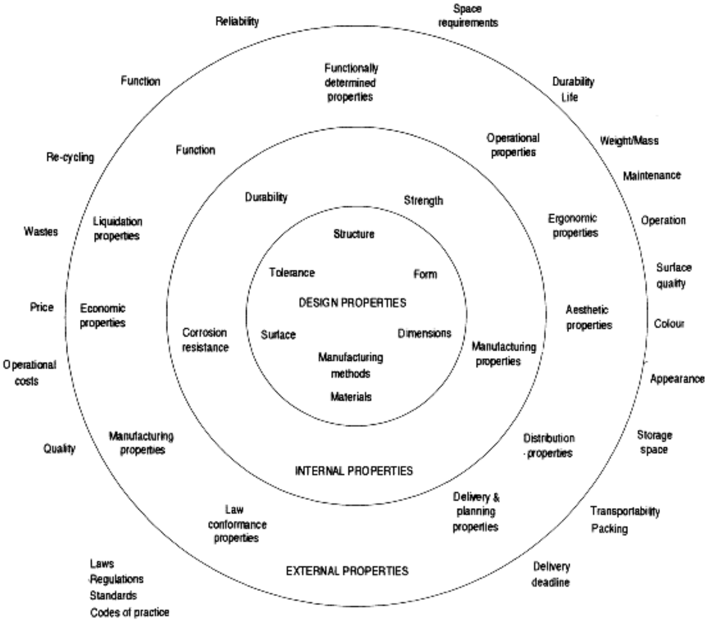

Figure 8: Properties of technical systems according to Hubka & Eder.

The properties of a functionality system are depicted in Figure 9.

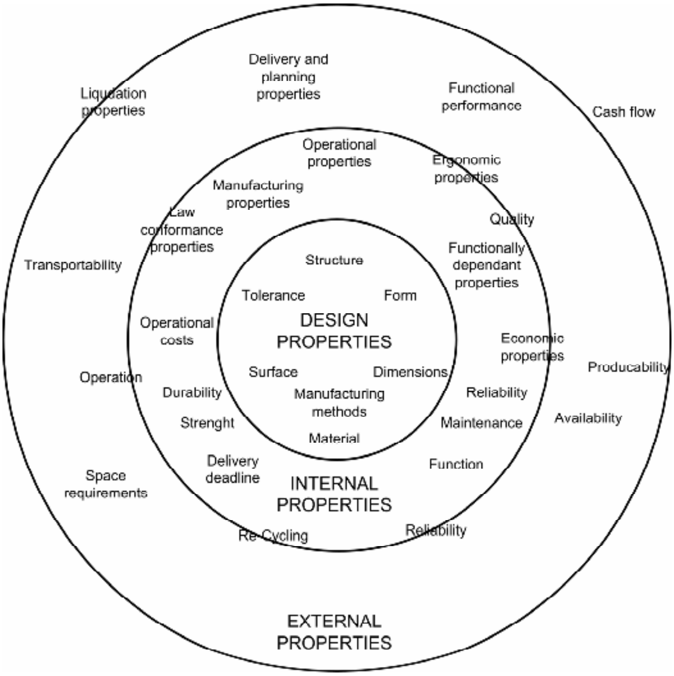

Figure 9: Properties of functionality systems.

Figure 9 is a summary of the researchers own results from Papers A, B, and D, presented in relation to Hubka & Eder's technical system of Figure 8. Figures 8 and 9 intend to depict how the responsibility of the product properties increases for the supplier. Together with a likely reprioritising of the properties of technical systems for creating design criteria of functionality systems, new requirements are in effect formed for the supplier. Affects of the extended responsibility taken by the functional product provider are described in Figure 9. For example, the responsibility for hardware functionality as well as hardware reliability and re-cycling is transferred from the buyer to the supplier. It is apparent that the number of design properties increase significantly in functional product development or the "functionality system" compared to integrated product development of hardware. These differences affect the development of functional products, as reported in Paper E. Functional product development differs from the current paradigm of integrated product development [1] in some important respects. The main differences are introduced in Table 1 below.

	Integrated Product Development	**Functional Product Development**
Product:	hardware	combo of hardware, software, services
	tangible	hardware core probable, not necessary
Ownership:	transferred	wholly or partly non-transferred
Design space:	experienced, defined, taught	experienced, not defined, not taught
Setting:	B2C, (B2B)	B2B, (B2C)
Value prod. by:	hardware, ownership	FP availability, knowledge, security
Value measured:	hardware performance	FP functionality
Responsibility:	company individual	shared in extended enterprise over life-cycle
Simulations:	verificational	predictive, optimising

Table 1: General differences between FPD and IPD that need to be taken into account when developing a functional product.

Based on the above differences, a definition of a functional product was developed and is in this thesis given as:

A product, not necessarily a physical artefact, consisting of any combination of hardware, software and services, being sold for the purpose of supplying a function, thereby meeting all agreed upon needs of the partner whose primary role is that of a customer.

This definition was first suggested in Paper D and seems to still be sufficient after having tested it through the research process.

The main result is the introduction of the developed work process simulation models. The model allows knowledge reuse and information restructuring through the ability to simulate different outcomes according to user need. The model show the possibility of obtaining the:

- Simulated minimised cost, related total delivery time and personnel distribution
- Simulated minimised delivery time, related total cost and personnel distribution
- Simulated minimal delivery time and cost and related personnel distribution

These simulated results support users in:

- Deciding if a customer request is viable or not.
- Deciding how much of the available workforce is affected by deciding to accept the particular customer request, this information may then be used to prioritise the ongoing and upcoming work.
- Deciding if the company process is cost efficient enough when comparing the optimum to an offer from a sub-contractor.
- Giving estimates of time of delivery and price to the customer within minutes rather than days.

Thus, the modelling and simulation approach (further presented in Papers F and G) supports users in evaluating the cost of future business before costs are incurred, evaluates product development ability and links company technology and business processes further. The approach also increases the user understanding and knowledge concerning the product development process and its limitations and allows for comparison of alternative versions of the same design process well before the actual development work has been carried out. Additionally, the modelling and simulation approach allows reuse of knowledge, since it enables simulation of different outcomes.

The herein presented focus on design process modelling and simulation is not intended to detract from the importance of the more traditional aspects of engineering product development. In fact, as long as there is a hardware core in the functional product it is becoming increasingly important for engineers to be skilled in handling new requirements on the hardware, in effect having to go through two loops of requirement definition before designing the hardware concept. The following are considered to be the most important contributions from the appended papers:

- Integrating product development process and company strategy is important for Functional Product Development. (As reported in Paper A)
- The Collaborative Working Environment (CWE) for functional product development needs to increase understanding between technology and business by a modelling and simulation approach. (As reported in Paper B). Further, Paper C highlights the challenges for these tools to support distributed work.
- New requirements appear in functional product development, such as trust and needs exploration as reported in Paper D, Figure 2.
- These requirements may be explored through a modelling and simulation approach. (As suggested in paper D, Figure 8.)
- The research reported in Paper E shows the possibility of evaluating development of cost and time before doing the actual product development work by modelling and simulating the design process in relation to a distributed design environment. (See Paper E.)
- The research presented in Paper F shows that by focusing on the information flows it is possible to map the knowledge exchanges in the studied service development process. The research indicates the need for, and motivates the development of, a computer-based development model that supports business

  decisions based on engineering activities.
- Paper G presents a process modelling and simulation approach for business decision support in pre-conceptual product design.

5 Discussion of the appended papers

Chapter 5 discusses the appended papers.

5.1 Relations of papers in thesis

Paper A	Identifying the product development process as a means for bottom-up implementation of change and identifying the importance of integrating product development process and company strategy for functional product development.
Paper B	Introducing an inclusive approach to functional product development research and development – Functional Product Innovation.
Paper C	Identifying challenges and opportunities for truly collaborative distributed work which is beneficial to functional product development in networks.
Paper D	Identifies challenges to the engineering design culture and proposes a simulation driven design approach to counter these challenges.
Paper E	Introducing modelling and simulation for work process predictions. A demonstrator model built using that approach is discussed as a suitable tool for use when developing functional products in a virtual distributed collaborative environment.
Paper F	Introducing knowledge capturing for service concept design modelling and simulation. Paper F indicates the need for, and motivates the development of, a computer-based simulation model that supports business decisions based on engineering activities.
Paper G	Introducing modelling, simulation and optimisation as suitable tools for reuse of information and knowledge in processual activities when creating conceptual functional products.

The logical couplings between the appended papers are described in Figure 10 below in relation to the research process over time and to one of three main areas to which the papers contribute: simulation, functional product and product development.

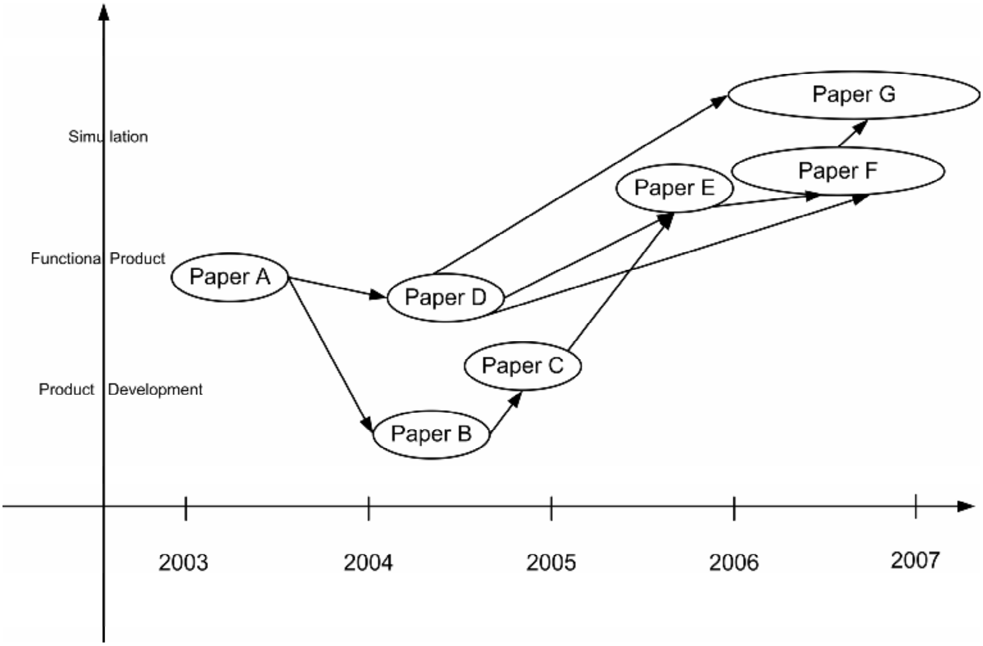

Figure 10: The logical coupling between the appended papers.

5.2 Paper A: The use of Product Development Process as a means of Implementing Company Strategy

Published at: International Product Development Management Conference 2003

Authors: Magnus Löfstrand
Belinda López-Mesa
Graham Thompson

Contribution to thesis:

In Paper A the authors suggest using the product development process as a means of implementing company strategy. It indicates the initial starting point of the researcher in the engineering design literature.

Author's contributions to Paper A:

B. López-Mesa and M. Löfstrand equally shared the work and G. Thompson commented on the later drafts.

Summary of Paper A contributions

The objective of the paper was to explore the strategic gap of Hägglunds Drives AB, comparing desired future business to the flexibility of the company's product development process. The main findings included business negotiation communication, human resource management and cooperative engineering design in the market-design relation, to name some the most important.

As the importance of nearly all of the points that arose in the development of Paper A will increase with the design of functional products, it is apparent that there is ample work yet to be done in the area of process integration for functional product development.

5.3 Paper B: Information Driven Collaborative Engineering: Enabling Functional Product Innovation

Published at: Proceedings of the 3rd International Workshop on Challenges in Collaborative Engineering, CCE05, April 13-15 2005, Sopron, Hungary.

Authors: Lennart Karlsson
Magnus Löfstrand
Andreas Larsson
Tobias Larsson
Peter Törlind
Bengt-Olof Elfström
Ola Isaksson

Contribution to thesis:

Paper B contributes a research strategy for functional product innovation based on the knowledge areas of the authors as well as on actual industrial needs.

Author's contributions to Paper B:

Magnus Löfstrand wrote the draft of the paper, rewrote after comments from co-authors and pushed for the paper's completion.

Summary of Paper B contributions

The objective of the paper was to form a starting point in terms of strategy and planning based on the author's then current research environment. The main findings were that Information Driven Collaborative Engineering (IDCE) is presented as an enabler of Functional Product Innovation – implying that the development of Functional Products will fundamentally change the ways in which global collaboration is carried out and thus also change the ways in which collaboration technologies and methods should be designed and applied in order to successfully support such collaboration.

Functional Products introduce new demands on work processes, tools and methods for collaboration between distributed as well as co-located teams. These new demands originate in five cornerstones: the extended product definition, the design team composition, the business organisation, the design process and new economic challenges.

5.4 Paper C: Towards True Collaboration in Global Design Teams?

Published at: International Conference on Engineering Design, Melbourne, Australia, 15-18 August, 2005.

Authors: Peter Törlind
Andreas Larsson
Magnus Löfstrand
Lennart Karlsson

Contribution to thesis:

Paper C contributes challenges for distributed teams for unrestricted, natural work in global design teams. It highlights challenges for tools and methods for distributed work, which is expected to increase in importance for functional product development.

Author's contributions to Paper C:

Peter Törlind and Andreas Larsson jointly wrote a large part of this paper, while Magnus Löfstrand wrote smaller sections and commented on structure and content.

Summary of Paper C contributions:

The objective of the paper was to summarise conclusions concerning a number of research projects concerned with distributed collaborative work. The main findings were the identified challenges based on the results reported from each individual research project.

Although advances in broadband videoconferencing systems show promising results in sending and receiving 'hi-fidelity' audio and video across continents, there is still an immense potential for improvement when it comes to designing virtual and physical places where global design teams can collaborate in more 'natural' ways than existing distributed environments allow. This has been found to be increasingly important to support distributed cross-functional design teams engaged in functional product development.

5.5 Paper D: Demands on Engineering Design Culture for Implementing Functional Products

Published at: International Conference on Engineering Design, Melbourne, Australia, 15-18 August, 2005.

Authors: Magnus Löfstrand
Tobias Larsson
Lennart Karlsson

Contribution to thesis:
Paper D introduces new challenges for engineers working with functional product development and suggests a simulation-driven, integrative approach to tool development in order to give access to a larger set of information than what has been the case in engineering teams previously.

Author's contributions to Paper D:
Magnus Löfstrand wrote the draft of the paper and finished it with feedback from the co-authors.

Summary of Paper D contributions
The objective of the paper was to evaluate the requirements on design teams working with functional product development, based on their design processes. A main contribution in this work is that engineers working on developing functional products must have knowledge to identify, value, and be skilled in handling a diversified group of project constraints and have knowledge of what constraints exist for a given project to a greater extent than today. Additionally, they must be able to handle these constraints in cooperation with business development personnel.

5.6 Paper E: Functional Product Development Challenges Collaborative Working Environment Practices

Published at: Accepted for publication in a Special Issue of the Journal: International Journal of e-Collaboration, State of the Art and Future Challenges on Collaborative Design, March 2007

Author: Magnus Löfstrand

Contribution to thesis:
Paper E introduces requirements on tools for distributed work in functional product development and introduces a demonstrator tool based on modelling and simulation for design process prediction.

Author's contributions to Paper E:
Magnus Löfstrand wrote all of Paper E.

Summary of Paper E contributions
The objective of the paper was to introduce functional product development challenges for collaborative working environment practices. The main findings were the differences between Functional Product Development (FPD) and Integrated Product Development (IPD)

This paper introduces the use of support tools in functional product development. Such tools may be used both to alleviate the workload for designers and design teams doing repetitive work and also work as constructs for increasing a cross-disciplinary communication and collaboration in distributed design teams. An activity-based modelling and simulation approach to functional product development is suggested as a possible support tool.

5.7 Paper F: Linking Design Process Activities to the Business Decisions of the Firm – An example from the Aerospace Industry

Published at: Submitted for journal publication

Authors: Magnus Löfstrand

Contribution to thesis:

Paper F introduces a work process model and indicates the need for, and motivates the development of, a computer-based simulation model that supports business decisions based on engineering activities.

Author's contributions to Paper F:

Magnus Löfstrand wrote all of Paper F.

Summary of Paper F contributions

Paper F indicates that developing a model which identifies costs, times, prices and personnel distributions that correspond to seven main customer and supplier considerations would significantly support the decision-making process and thus indirectly reduce business risks. This approach links business and technology and allows for faster access to better information than was the case previously. The process modelling and simulation approach also allows for knowledge reuse.

5.8 Paper G: A Process Modelling and Simulation Approach for Business Decision Support in Pre-Conceptual Product Design

Published at: Submitted for journal publication

Authors: Magnus Löfstrand
Ove Isaksson

Contribution to thesis:

Paper G contributes an approach to work process modelling, simulation and optimisation for conceptual design of functional products in furtherance of the suggested partial solution first introduced in Paper D. This approach links business and technology and allows for faster access to better information than was the case previously. It also allows for knowledge reuse through process simulation.

Author's contributions to Paper G:

Magnus Löfstrand gathered the necessary information for modelling and wrote the main parts of the paper, provided information for and partook in development of the simulation model. Ove Isaksson provided competence in the specifics of SIMULINK modelling and carried out main part of the simulation and optimisation.

Summary of Paper G contributions

The objective of the paper was to introduce an approach to work process modelling, simulstion and optimisation. The main findings were that it is indeed possible to model and simulate a design process in such a way that it is useful for the studied company process.

A case is made in support for the simulation-driven design approach as a useful tool for work process optimisation in functional product development. In addition, taking a starting point in the engineering design tradition has been found to be a plausible and fruitful way to approach research concerning functional product development.

In this paper functional products and other related conceptions where the function rather than the (hardware) product itself is being sold are discussed in relation to the approach of using the traditional engineering product development method of simulation. Results indicate that simulation-driven concept design of functional products may be established as a viable way to significantly alleviate the tedious and repetitive workload of a functional product development team. What is more, the approach has been discussed in relation to the industrial interest of developing functional products and has been shown to provide an optimised product development process in terms of workforce distribution in the services provision process of Volvo Aero. The approach support decision making for designers and design teams. It also allows knowledge reuse and reconfiguration of information for different purposes

6 Discussion and conclusions

Chapter 6 summarises and discusses the results presented in this thesis.

In the business environment of the manufacturing industry a shift is taking place from a hardware-based product focus to a value-based process and function focus. Therefore, interest arose in supporting designers and design teams by developing functional product concepts which may respond to that change. As a consequence, the research interest in modelling and simulation arose. After carrying out four case studies, results are both general with respect to functional product development and specific to the developed models.

Challenges in functional product development include being able to better predict the function and cost of one's business offers. Having identified a need for support tools and methods for functional product development, one such tool, based on internal company knowledge concerning cost and time of development, has been developed and is discussed here. The knowledge gathering activities and the development of the tool have been used to support Volvo Aero's service development process based on engineering activities using an engineering perspective.

Results indicate that modelling and simulation of concept design of functional products is a viable way for reducing the number of uncertainties designers and design teams have to deal with while at the same time cutting cost and time in development. Additionally, the approach allows for reuse of processual knowledge. Thereby, the designer will have more time and energy to spend on activities that require human creativity and innovation, thus creating more and better design concepts. Based on the developed scenario used in Case study 3, Papers F and G discuss an activity-based modelling and simulation approach to the FPD process where hardware development activities are combined with service activities in an FPD simulation system. A procedural view of the studied process is described in Papers E, F and G. It was developed through identification of the actual work activities carried out, with whom and how informants communicated and collaborated to develop a service.

Case study 3 and Papers D, E, F and G show that by using a modelling and simulation approach it is possible to predict the cost and time of carrying out a work process. Additionally, it is possible to simulate the personnel distribution for meeting the requirement of minimising process work cost. Modelling and simulation of the studied work process requires meeting some challenges including:

- Identifying and describing the main activities included in the process in a sequential order with respect to time.
- Identifying the main linked activities, as several activities may be carried out by the same unit or department.

An academic importance of this thesis includes the indication of how to build on the as-is framework of Integrated Product Development (IPD) [29] as a stepping stone to forming a procedural description of Functional Product Development (FPD) [1], [35] and describing in general terms how current engineering design is affected by functional product development. In effect, engineers need to go through two iterations of requirement definition before designing the hardware concept for functional sale: one iteration for understanding the business requirements – a study of market need by designers; and a second iteration, for creating hardware development requirements.

6.1 Conclusions

It has become clear that new and additional requirements appear in functional product development compared to the development of hardware as it is addressed in the current engineering design literature. Based on new customer needs, often including productivity and efficiency, the extended set of design criteria need new tools and methods for efficient concept development of hardware-based functional products.

A further conclusion is that development of modelling and simulation-based approaches for work process optimisation may significantly assist (industrial) users in making more informed business decisions. An approach to better predict the cost and time of an internal process, in order to decide if the process outcome is business-viable, is deemed to be an efficient way to address the business-related challenges in design and delivery of functional products.

6.1.1 Contributions

Affects of the extended responsibility taken by the functional product provider include that the number of design properties increases significantly compared to the set of design properties in hardware development (See Figure 8 and Figure 9). Therefore, integrating product development process and company strategy becomes important for functional product development. Process integration and a focus on added customer value in functional products give rise to new requirements in functional product development. These requirements may generally be explored through a modelling and simulation approach. The modelling and simulation approach used in this thesis, building on the area of computer aided design, shows the possibility of evaluating development of cost and time before doing the actual product development work by modelling and simulating the work process. Linking the future business cases to work processes by modelling and simulation enables knowledge reuse and work process predictions concerning cost and time. The main contributions are based upon the results presented in the “Summary of findings” and include:

- Integrating product development process and company strategy is important for Functional Product Development. (As reported in Paper A)

- New requirements appear in functional product development, such as trust and needs exploration as reported in Paper D, Figure 2.
- These requirements may be explored through a modelling and simulation approach. (As suggested in paper D, Figure 8.)
- The research reported in Papers E, F and G shows that by focusing on the information flows it is possible to map the knowledge exchanges in a work process. The possibility of evaluating development of cost and time before doing the actual product development work by modelling, simulating and optimising the design process.
- Industrial use of the proposed models enables users to make more informed decisions concerning their functional product development process as well as related business decisions.

Results presented in Chapter 4 indicate that a plausible answer to the research question is that making the modelling and simulation approach activity-based, based on future business scenarios, is a useful way to develop such an approach. Work process modelling and simulation approach ought to be applicable for other work processes as well provided that sufficient knowledge exists concerning the order of work activities and issues which affect the particular process cost and time. The knowledge gathering approach discussed in Paper F requires that activities as well as activity costs and times are identified. Thus, even if insufficient knowledge exists to directly create a simulation model of the studied work process, the approach should still be industrially useful in identifying process shortcomings and improvement potentials.

6.1.2 Reflections on the research process

The research question concerns how methods and tools for design process modelling and simulation may be developed to support functional product development.

As stated in Section 2.2, the purpose of the initial research iteration was to facilitate the researcher's understanding of a situation and to form initial conclusions, assumptions or theories. These are reported in Papers B, D, and E. Thereafter, reflection was carried out by the researcher before an additional iteration was performed in the research process reported in Figure 1.

The research process was carried out up until the publication of the researcher's licentiate thesis. In relation to the research process, the main conclusions reported in Papers B, D and to some extent E pertain to a wealth of information that poses uncertainties for the company providing a functional product and consequently for the development team. Therefore, an idea to create executable simulation models that support optimisation of the service development process, providing more information and thus alleviating much of the work of the design team was developed. This idea is explored in Paper F. The models created in the second cyclic research iteration support conclusions or improve the conclusions or the model created in an earlier loop with respect to stated industrial usefulness. (The conclusions of Paper G show that the developed model creates information upon which more informed decisions may be based.) Hence, the updated model is considered evaluated and found to support earlier conclusions. The second iteration of the research process is nearing completion as an executable model that allows optimisation of the modelled process is about to be tested in industry.

Evaluation of the input data has been carried out through first asking interviewees in the studied process the limits of personnel resources and times to carry out activities, compiling the results and cross-checking researcher interpretations with the interviewees. Evaluation of the created model has been carried out through researcher demonstrations at Volvo Aero and through trials and discussion with the industrial project manager and other key informants concerning the industrial usefulness of the model and the modelling and simulation approach. Accuracy is improved by interviewing different people and stringent interpretation. In addition, the semi-structured nature of the interviews allowed interviewees to express themselves freely.

Simulated results are reliable to the same extent as the indata. The developed work process model is applicable and valid for the studied process of that particular organisation. Possible sources of errors and limitations which affect the reliability of the developed work process model include the process model itself, the quality of the indata and interpretations of the results. These three issues have been improved and preliminarily evaluated through industrial participation in the research process as well as creation of industrial usefulness and acceptance of the results.

The validity is affected by conditions and limitations including the number of case studies and the number of studied companies. To increase validity of results, evaluation has been carried out through an iterative process of model evaluation by the researcher and key industrial informants. Key industrial informants have shortly tested the model using different indata and reacted favourably to the results. For example, process bottleneck may be identified. The validity of the general functional product related result as well as the model specific results have been supported by usage of the research approach discussed in Chapter 2, using an iterative research process and case studies. Case study 4 to some extent supports the industrial usefulness and increases the validity of the results.

6.2 Future work

The suggested and developed tool may be used both for design team collaboration and cooperation as well as for its direct application of modelling, simulation and optimisation of a work process.

Future work includes additional case studies in industry to be able to compare results presented here to a wider knowledge base, thus improving the practical usefulness of the simulation-driven modelling and optimisation approach as well as the generalisability of the results.

Future work also includes further identification of sub-tasks within activities and identification of rules concerning how much and when one activity affects a downstream activity. If that is realised, it may then be possible to simulate the process as a number of concurrent activities rather than, as indicated in Figure 2 of Paper G, as a number of sequential activities.

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Paper A

Löfstrand, M, López-Mesa, B., Thompson, G., (2003), **The use of Product Development Process as a means of Implementing Company Strategy**, International Product Development Management Conference, Brussels, Belgium, June 10-11.

THE USE OF PRODUCT DEVELOPMENT PROCESS AS A MEANS OF IMPLEMENTING COMPANY STRATEGY

Magnus **LÖFSTRAND** *
Belinda **LÓPEZ-MESA***
Graham **THOMPSON** * °

* Division of Computer Aided Design, The Polhem Laboratory, Luleå University of Technology, SE-97187 Luleå, Sweden
° Department of Mechanical, Aerospace and Manufacturing Engineering, UMIST, Manchester, UK

Magnus.Lofstrand@cad.luth.se
Belinda@cad.luth.se
Graham.Thompson@umist.ac.uk

ABSTRACT

This paper is concerned with the implementation of strategic change in industry. It contributes to the understanding of the role of the product development process in implementing a strategy. It also shows that when the desired strategic position of a company is chosen, management has choices to make on how to conduct product development. A management model to match the product development process of a company with its strategy is presented and evaluated. The paper reports on the usefulness of a management model in a medium sized industry.

INTRODUCTION

This paper concerns research carried out at a medium sized industrial company Hägglunds Drives AB (HDAB). HDAB is a supplier of hydraulic drive solutions. The company has about 500 employees worldwide and a turnover of 892 million SEK [4]. HDAB provides drive systems globally by means of Hägglunds sales companies, covering each part of the world: Nordic countries, Europe, the Americas and Asia. About 200 people are employed in sales companies totally and about 300 at the Head Office in Mellansel, Sweden. In the USA there are 50 people employed in sales and service, making it the largest Hägglunds sales company. The manufacturing and development activities are carried out at the Head Office in Mellansel. The development and manufacturing team is therefore relatively small and co-located. This constitutes one of Hägglunds' strengths since everybody knows one another and makes it possible for management to select the right people for the right job. Engineers have often worked their way up the company ranks giving them thorough knowledge about the company and its practices. HDAB has also been able to plan ahead, so as to replace competence lost due to retirement and other issues.

The two principal parts of the company are the Motor and System sections. The Motor section is concerned with developing motors. Besides defining specific solutions for specific clients, the System section is concerned with specifying and developing the other components of the complete drive solution, such as, pumps, pump cabinets, piping, control units, etc. The Motor section includes several departments: Motor Design, Product Care, Laboratory and Accessories MA/CA.

Hägglunds Drives AB has seven main products, listed below.

- Marathon
- Compact CA
- Compact CB
- Viking
- Hydrex
- Power Units
- Control systems

These products may be sold separately or in complete systems depending on the needs of the customers. HDAB is acknowledged as expert at hardware design by their customers and the market they are in. They have an excellent reputation for high quality products. Their aim is to be the "leading supplier of complete hydraulic systems" and are changing from being a supplier of hardware to being a supplier of complete power transmission systems, in some cases with certain additional services included. HDAB aims to identify the necessary improvements for their development process to suit its changing strategic position.

HDAB's desired strategic change has been used as the framework for the validation of a management model, named the 4P+N model [1]. This paper is to study the usefulness of the 4P+N model as a tool to explore the necessary changes a company should make in their development process due to a change in strategy. This study is based on 10 interviews with a focus on the current and future strategic position of Hägglunds Drives AB in relation to their product development process.

THEORETICAL BASE

The theoretical base of this work is described by López-Mesa & Thompson [1]. The 4P+N model is based on the 4Ps (Person Process Product Press) creativity model, and highlights the importance of matching the person, process and press variables of a company's resources with dynamic market needs to produce profitable products (Figure1). The person strand refers to the management of people within the company, the process strand represents the management of product development and the press strand comprises the management of the company culture and working atmosphere. These three variables will inevitably affect the resulting company's products. What the model basically says is that for a company to successfully implement a change of strategy it is required to define how the change will affect its resources, i.e. the implementation of a strategic change is achieved by implementing matching changes in the resources of the company. The changes in resources should be managed so that the resulting products match the identified needs.

At the needs stage of the model, it is important to identify the strategic gap, i.e. the difference between the current operation and the ideal state [6]. Market needs defines the strategic position that a company chooses by which to differentiate themselves from their competitors [7].

The model then suggests that a company counts on manageable resources (person, process and press) that enable it to deliver the new offer or product. These resources are variables that can be changed correspondingly with the desired strategic change. According to Porter, jumping from strategy to strategy does not render a competitive advantage [5], nor does radical discontinuous changes in a company's resources. Changes are required to be gradual to allow them to be implemented. An abrupt, imposed change is not desirable because it could, for instance, be perceived by employees as drastic and inappropriate, or because in case of errors it would cause management to loose credibility. Therefore, two actions are necessary at the resources stage: define the current state and to study the strategic flexibility of the resource. Weerd-Nederhof and Da Silva Gomes [8] defined strategic flexibility as the readiness of a resource to adapt to future performance requirements.

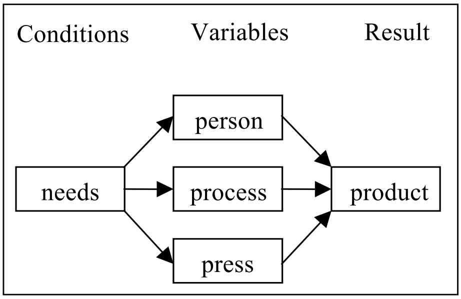

Figure . 1 The 4P+N model

The variable process is the main object of study in this research. To identify how HDAB's development process should change to adapt to the desired strategic position, the different steps suggested by the 4P+N model were carried out:

- Identify the strategic gap or need.
- Understand the actual development process.
- Analyse the strategic flexibility of the development process.

THE 4P+N FACTORS AT HDAB

As described in [1] HDAB relies heavily on selecting the correct personnel which corresponds with the person variable. This strenght in the person variable is a key factor in the creation of excellent products, especially those that build heavily on older generations of products. The freedom of expression with which meetings take place at HDAB and their relaxed atmosphere make the authors of the paper dare to say that the Press variable i.e. the environment where the employees work, has also a great contribution to the success of HDAB. The Needs identification as described in Figure 2 is related to the Process variable since it is the earliest stage of a product development process. The close contacts between HDAB and some of its biggest clients constitutes an important success factor for the company. The Process is the variable on which HDAB is focusing, in cooperation with the Polhem Laboratory, headed from Luleå, Sweden. This is why it is the variable studied in this paper.

OBJECTIVES

- The objective of this study is to validate the 4P+N model as a way to understand the necessary changes a company should make in their development process due to a change in strategy. The authors intend to validate the 4P+N model as a good and sufficient way to identify criteria for strategic change implementation.

- Explore how a strategic change can be implemented by modifying the product development process accordingly with the desired change.

- The strategic flexibility of HDAB's product development process is also studied i.e. the readiness of the current development process to adapt to future performance requirements.

METHOD

The case study was carried out through interviews, questionnaires and meetings with ten employees from HDAB. The interviewees represented the different Head Office departments (Motor design, System design, Sales, Marketing and Manufacturing). Seven were middle level engineers with management responsibility, two were from the company management group and one is an experienced design engineer with no formal management responsibility.

Hägglunds Drives AB has been a member company of the Polhem Laboratory for a number of years and is thereby associated with the division of CAD at Luleå University of Technology where the three authors are participating members. In addition, previous interview studies were conducted by two of the authors [2] concerning HDAB's product development. HDAB has also participated in a research project concerning distributed engineering instigated by Polhem Laboratory personnel [3]. This means that before the authors embarked upon the current case study, they already had knowledge about HDAB's activities while the interviewees knew about the research purposes. Therefore, the interviewers could omit some basic questions and focus on more specific ones.

Case study process

The case study began with the distribution of questionnaires, concerning HDAB's current strategic position. Interviews were then performed to understand what is the desired future strategic position and to explore how HDAB does product development. Approximately one month after the interviews were done, the results were presented to the interviewees and other managers from HDAB. A feedback questionnaire was distributed to the interviewees at the same session.

The questionnaires and interviews match the steps suggested in the theoretical base section:

1. **Identify the strategic gap**.

The strategic gap was identified by asking the interviewees about the current strategic position of the company and the aspired strategic position.

For the current strategic position identical introductory questionnaires were distributed to the interviewees before the interviews. The interviewees were asked to complete the questionnaires, for discussion at the beginning of the interviews. During the discussions it became apparent that the interviewees had misinterpreted certain questions compared to the intents of the authors. Therefore, some original questionnaire answers were modified or expanded upon or both throughout the interview. The questionnaires contained questions regarding many aspects; the percentage of product types they sell (e.g., motor, motor + service, system, etc.);, the advantages and disadvantages of their products and offer differentiation;, the product variants and market segments in which they are sold;, the workload of new product development and product redesign in terms of human resources consumed and time;, their relationship with suppliers, customers, consultants, etc.;, the HDAB organisation;, where they are involved in research; and how their strategic position had evolved until today.

To identify the aimed strategic position part of the interview was about how the interviewees expected/wanted the different aspects of the questionnaires to change. There were nine interviews, taped and semi-structured, and one phone interview. One interviewer took notes during the actual interview while another communicated with the interviewees more actively. A digital recorder was used to enable almost instant access to the data for the post interview studies. The interviews were transcribed and studied to identify the collective opinions of the interviewees.

2. **Identify current status of the resource object of study**, i.e**., the development process**.

During the interviews, questions were posed concerning HDAB’s development process. After the first two interviews the interviewers began mapping a model representing their development process. This model was shown to and discussed with the other interviewees and progressively modified according to their inputs.

3. **Identify the flexibility of HDAB’s development process**.

In order to identify it, the ALUO (Advantages Limitations Uniqueness Opportunities for change) technique was used during the interviews. The interviewees were asked to state the advantages and uniqueness of their current product development process, the limitations of the process to adapt to future performance requirements and the way they thought this could be overcome.

4. **Evaluate the 4P+N model as a way to implement change**.

The suitability of the 4P+N model cannot be measured in terms of business success. Actually “it is the very uncertainty of a given strategy or its implementation that makes it candidate for determining business success” [8]. Rather the suitability of the 4P+N model was measured by asking the interviewees about the usefulness of the whole experience. The interviews were carefully analysed and presented to the interviewees together with some other managers from HDAB one month after the interviews occurred. A discussion was held concerning the results obtained and a feedback questionnaire was distributed at the end. The questionnaire generated some results that will be discussed further (under section “Feedback from interviewees”) later in this article.

RESULTS

The remaining part of the article presents the results obtained during the interviews and general conclusions concerning the usefulness of the 4P+N model. The outline for the remaining part is as follows: Evolution of the Strategic Position, Offer Differentiation, Strategic Gap, PD process flexibility and feedback from the interviewees. Finally the paper concludes with some lessons learnt about implementation of change in the product development process and some general conclusions about the usefulness of the 4P+N model.

EVOLUTION OF THE STRATEGIC POSITION

It has been identified that the strategic positioning of HDAB has changed noticeably over the years. HDAB started out as a component supplier; today they focus on complete drive systems. Further information concerning the evolution of HDAB's strategic position can be found in table 1.

OFFER DIFFERENTIATION

The HDAB offers differentiate regarding the offers of competitors as described in the list below:

- High technical performance: superb drive control, high starting torque, responsive, fast start and stop, truly shock resistant, suitable for harsh environments, easy and adaptable installation, reliable with low maintenance, long service life.
- Unique product characteristics, e.g. complete drive system, unique features in some niche applications, turn key solutions, space saving compact motors.
- Unique relationship with customers: service and support availability, knowledge about customers' products, responsibility, focus and dedication.
- Know-how

- Early 1960's saw HDAB evolve into a supplier of own end products
- Between 1960-1970, they produced hydraulic motors to marine and industrial applications, essentially as a part supplier.
- During the 1990's there has been increased interest from management and owners to sell motors as well as complete drive systems (including power units and control systems)
- Turn key supplies, including piping and installation
- Win serial OEMs with Compact motors

Table 1. The evolution of HDAB's strategic position

STRATEGIC GAP

The current strategy includes selling high quality products to different markets and market segments. Today end users demand mainly individual drives, whilst big clients, especially OEM clients, have an increasing interest in complete drive systems in some cases includes services. HDAB believes that to meet the demands of tomorrow they should be able to offer complete drive systems that may be sold as supplying a function for the customer (such as torque/hour) under a negotiated responsibility between the client and HDAB.

CURRENT PRODUCT DEVELOPMENT (PD) PROCESS

Hägglunds Drives AB has a very long history in developing hydraulic motors. A result from this experience is the current product development process used at the motor department. The design process is not described fully in HDAB plans and was therefore mapped out by the authors. In Figure 2, the PD process as well as processes that act as inputs to the PD process (development of business idea, testing of motors, customers and sales studies) are represented.

The PD process starts with the detection of needs and ideas for new products. At some point a product idea is chosen to develop into a concept. Today, the idea creation and selection process is a very intuitive process carried out by management. The degree of holistic view that management has for this intuitive work is important since it is probably one of the key reasons why in previous products the quality of technological forecasting has been excellent. Managers count on high quality data from different sources that provide them with holistic information:

- An in-house produced remote monitoring system (RMS) monitors technical data from a number of motors tested by trusted customers in their actual applications. This system supplies performance measures of the motors that are used to evaluate which design solutions are working perfectly and which need further development. This information is used as input on how to allocate resources.
- Customer and sales studies provided by marketing department and sales companies.
- An agreed upon strategic plan that is continuously updated and undergoes a major revision every three years. . This document is commonly the basis for considered projects.

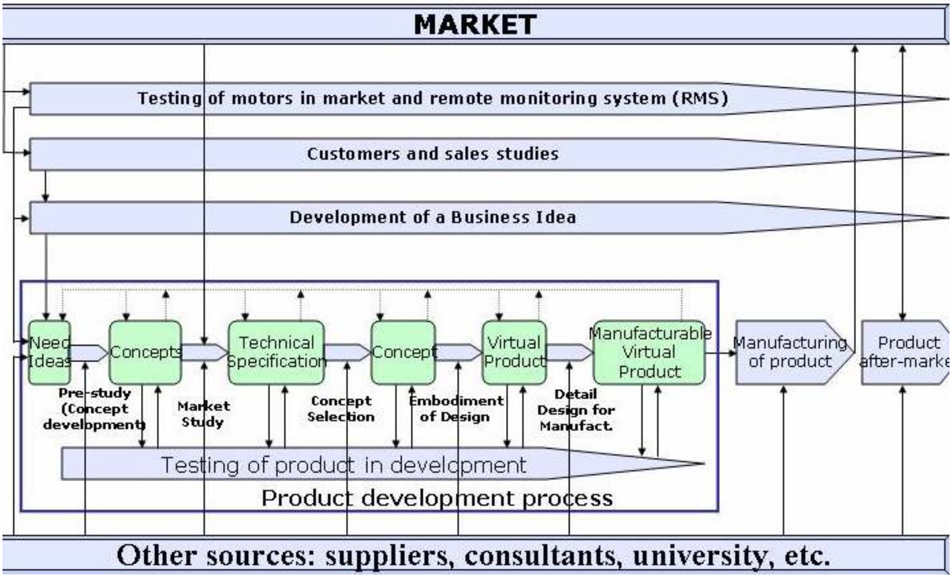

Figure 2. HDAB's product development process as understood by the authors.

When an idea is selected, a feasibility study consisting of exploring alternative concepts is performed.. The feasibility study consists of exploring alternative concepts to develop the idea, as well as preliminary feasibility studies of such concepts. This is done by a group of 3 or 4 engineers from between 6 to 12 months.

While the feasibility of 4 or 5 promising concepts is being proven, a detailed market study is made to identify the technical specifications that the clients demand. These technical specifications are used to select the best concept among the existing ones developed.

Once a concept is selected more design personnel become involved in the further development of the concept into a product. As far as prototypes can be physically or virtually represented; the manufacturability of the solutions is studied in detail.

After the interviews, during informal discussions with HDAB engineers it was pointed out that Figure 2 only represents the motor product development process and not the complete system development process. The consideration of systems comes after the motor concepts have been developed. This is a sign that HDAB has to work in a more system oriented way from early stages of design. Today's PD process is still somewhat component-based.

PD PROCESS FLEXIBILITY

Here, we will highlight in general terms the type of questions that arose as possible points of improvement. Even though the object of study was the PD process, other company factors such as organisation structure and habit were mentioned because modifications to some factors affect others. For confidentiality reasons the actual modifications suggested are not presented. Instead the nature of these modifications is explained. Issues that were mentioned during the interviews or meeting were:

- Product development management issues
  - Incorporation of certain methods and tools in different stages of the PD process.
  - Ways to reorder the different parts of the PD process.
  - How to make the PD process more system and service oriented.
  - Improvements on the type of involvement with the customers.
- Organisation management issues
  - Ways to organise departments in a more customer oriented way.
- Product management related issues:
  - Creation of more customer customised products without increasing the product variety unnecessarily.
- Change implementation issues:
  - How to work with university and other centres of knowledge.
  - Other issues that are presented below in section "Implementation of Change".

All the points discussed during the meeting had been brought up during the interviews by different interviewees. The interviewers' participation consisted simply of organising them in a structured way for their presentation in the meeting. This provided comfort within the group since the changes suggested had been born in-house and not imposed by external agents. Feasibility aspects for the changes were discussed in most of the cases. The discussion matters seemed to be familiar to the participants. This can be interpreted as a sign of high readiness to change.

The changes suggested are not of discontinuous nature. There is already at HDAB a trend to work in a customer and system oriented ways. Therefore it can be said that HDAB's current PD process presents flexibility for the desired strategic change. Its implementation will require time but it will not be of abrupt nature.

FEEDBACK FROM THE INTERVIEWEES

The interviewees were asked to fill out a feedback questionnaire after the conclusions from the study had been reported and discussed in a meeting. The purpose was to identify how the whole experience has contributed in the advancement of the implementation of their aimed strategic change. It was asked in terms of what had been learnt and of to what degree they had achieved a shared understanding of the changes required. The interviewees had very similar answers to the feedback questionnaire, as listed below:

- Many of them expressed their surprise to find diverging opinions concerning the future strategic position of the company. Even if they thought that it was something negative for the company, they expressed the importance of finding it out. They think that a shared opinion a must.
- Many of them expressed that the discussions concerning ways to improve the PD process were very enlightening.
- Other interviewees thought that they had the strategic position very clear already.
- The discussions about implementation of methods were appreciated by some of them.

IMPLEMENTATION OF CHANGE

Selecting a way to implement a strategic change is an arduous task. In the Hägglunds case abundant work still remains in defining with precision the whole implementation strategy. Throughout the case study with the Hägglunds personnel, different subjects of discussion concerning implementation issues have been brought up between the interviewers or between the interviewers and interviewees. These issues are summarised in the following lines.

The interviews identified that a change in strategy can be implemented through a change in product development, but only if the change solution is carefully company-customised and implemented gradually. A despotic decision by management to work in a certain prescribed way can hardly work. It would also be unlikely to implement long lasting, sustainable changes in by employing consultants with preconceived notions on the “correct” processes and engineering design tools. When describing a general way of work such as this it is important to remember to adapt the suggestions to the company in question. For example, Hägglunds Drives AB has a background of hardware component supplier and has during the last decade been expanding to being a system supplier. Their background almost certainly demand other tools than for example a significantly larger company with a background in system design, well versed in a number of management and product development tools which have been in use for a number of years.

The interviewees agreed that it is important to define and agree upon a common goal; to do so all team members need to understand the main points. Further, the goals definition should result from a process of combined top-down and bottom-up approach so that everybody feels a part of the process. That approach would facilitate changes in the way to implement the agreement since little loss of credibility would be incurred at the managerial level within the company.

Developing cooperation within the organization requires that upper managers use a “birds eye” view when considering projects. That means to look at a project as an entity within a system of related activities that combine to achieve a common goal. The common goal should be fulfilling the overall strategy of the company. Hence, all projects should be described in terms of how they contribute to the vision and the business idea.

Within the interview study all interviewees agreed that during the progressive definition of the implementation strategy it is essential to clarify all points of views, and to come to a consensus on what to do next. Specially important is to agree on a prioritisation of potential projects in order to decide on suitable changes to the product development process. The definition of a general vision for the company or the definition of the strategic gap is not enough to decide with precision how the development process should be changed. The selection of the percentage of resources to assign to each project should be made to fit the business strategy. Emphasis should be put in obtaining a suitable relation between the amount of resources assigned to different kinds of projects, such as, new generation of product, updated or derivative product, new innovative product and open ended speculative projects.

It is important to foresee when a product development process in a company is becoming progressively more complex. Even though in the case of HDAB the prioritisation of projects has been successfully handled until today without structured methods, the complexity that a customer and system oriented process will bring could demand the use of methods. The methods should incorporate criteria to judge how the alternative projects fit into the strategic plan, the market opportunity that have the potential to offer and the demand on resources and competence that they represent. Normally if changes to the product development process are carried out when the needs for them are obvious, it means that they are too late.

CONCLUSIONS

The 4P+N model has proven to be a helpful tool by which one may identify and organise changes to a product development process. It allows understanding changes that must be done in a variable because of changes in another as pointed out previously. The 4P+N model has also contributed in helping to identify the diverging opinions that different members had of the future strategy, creating a need for consensus.

It is important to define and agree upon a common goal; to do so all team members need to understand the others' points of view. It is advisable to work towards instilling the sense of agreement by structured methods. A top-down approach with a bottom-up implementation has been identified as necessary for a sustainable change. The interviews showed that focus by management on the strategic contribution of project prioritisation is becoming increasingly important.

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Paper B

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INFORMATION DRIVEN COLLABORATIVE ENGINEERING: ENABLING FUNCTIONAL PRODUCT INNOVATION

Karlsson, L., Löfstrand, M., Larsson, A., Törlind, P., Larsson, T.
Polhem Laboratory,
Luleå University of Technology
SE-971 87 SWEDEN
Lennart.Karlsson@ltu.se

Elfström, B-O., Isaksson, O.

Volvo Aero Corporation
SE-46181, Trollhättan, SWEDEN

Bengt-Olof.Elfstrom@volvo.com

Abstract. *This paper discusses Information Driven Collaborative Engineering (IDCE) as an enabler of Functional Product Innovation (FPI). It discusses challenges that arise in functional product development and how distributed collaborative work will be affected. Finally the paper proposes bringing the domains of Distributed Collaborative Engineering (DCE) and Knowledge Enabled Engineering (KEE) together to form IDCE, in order to meet these challenges.*

1 Introduction

This paper discusses the prospect of Information Driven Collaborative Engineering (IDCE) as an enabler of Functional Product Innovation – implying that the development of Functional Products will fundamentally change the ways in which global collaboration is carried out and thus also changes the ways in which collaboration technologies and methods should be designed and applied in order to successfully support such collaboration. A Functional Product (FP) is an offer developed by a network of companies and consisting of capital-intensive hardware integrated with accompanying services that are necessary for keeping it operational during the lifecycle [1]. Fundamentally, this means that globalization, in itself and as we know it today, is not the sole driver for change in terms of methods and technologies for global collaboration in engineering. On the contrary, it is the increasingly information-driven approach to engineering combined with the concept of Functional Products that sets the demands for what, how, when and with whom companies need to communicate.

Functional Product development, in general, puts new and extended demands on ways of cooperating and collaborating [2], and, in particular, it puts new demands on methods and technologies that support distributed collaborative engineering (DCE). For DCE to succeed there must be some assurance that the right information is available at the right time, to the right persons, regardless of the location of both the information and of the team in need of that information. In an engineering perspective, DCE methods and tools of today might no longer be sufficient to meet the demands of design teams working in cross-functional, cross-cultural, and cross-organizational settings.

The traditional approach to DCE has been based on ways of supporting distributed collaboration technically through video conferencing, online workspaces, and through the real-time transmission, storage and retrieval of data. Considerable attention has also been given to developing protocols and standards that enable easy integration of data and information. FP changes this into IDCE, where the prime focus is not on technical solutions (i.e., capacity or performance issues), but rather on enabling virtual enterprises to make use of the right information at the right time (i.e., usefulness issues), in spite of the rapidly growing volume of data and the increasing range of information sources that are available. The information-driven approach entails a contextual view of knowledge, meaning that the crucial transformation from information to knowledge is more likely to occur if the provided information matches what is requested (i.e., relevant information) and if it is made available just when it is needed (i.e., relevant timing). Also, in order for information to be an enabler and a true driver, this approach emphasizes the importance of capturing design rationale as well as tacit and local knowledge, to the greatest extent possible. Making sure that the information, or knowledge, is used in appropriate ways by users and organizations is thus a main driver, since the effectiveness of collaboration is highly dependent on how well the provided information fits the actual purpose. Realizing the impact of product performance failure or success, through simulation – early in the concept phase or even in the customer offering phase – creates the possibility to play “what-if scenarios” with the corporate know-how in terms of products and offers. In this paper, this area is described under the term Knowledge Enabled Engineering (KEE). Hence, the IDCE approach may be said to be a combination of technology (traditional DCE), work methods and procedures that support the highly heterogeneous environments that increasingly exist in industrial settings.

Current DCE practices and technologies must be adapted to the new drivers and the outcome will be new methods of work as well as new technologies that fall within the authors’ label of Information Driven Collaborative Engineering. Our approach of focusing on simulation-driven design, knowledge-enabled engineering, and distributed collaborative engineering in the support of functional product development is schematically introduced in Figure 1 below. The figure illustrates how our research areas (in red circles) contribute to Functional Product Innovation by means of an information-driven approach to collaborative engineering. Secondary, but highly relevant, knowledge domains are illustrated with grey circles.

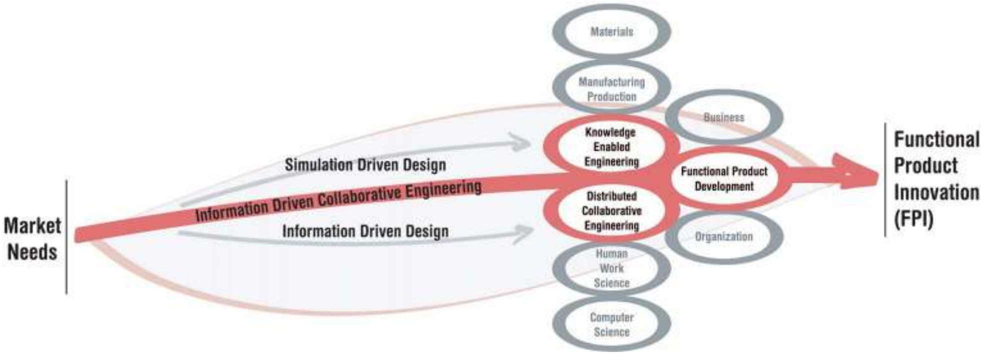

Figure 1: Functional Product Innovation – Going from market needs to Functional Products using Information Driven Collaborative Engineering.

2 Functional Product Challenges

Functional Products introduce new demands on work processes, tools and methods for collaboration between distributed as well as co-located teams. These new demands originate in five cornerstones: the *extended product definition*, the *design team composition*, the *business organization*, the *design process* and *new economical challenges*. Figure 2, below, introduces these cornerstones schematically, with Distributed Collaborative Engineering [3, 4] and Knowledge Enabled Engineering [5] as complementary and enabling methods and technologies.

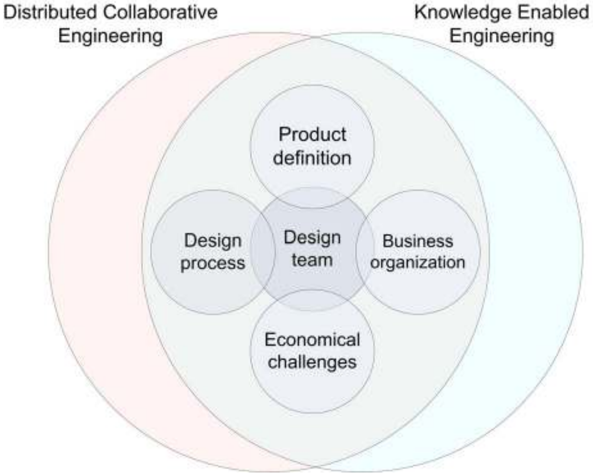

Figure 2: DCE and KEE relations to FP cornerstones.

Invariably, there will be several links and interrelationships between these cornerstones, which are mentioned below. This means that design of functional products is certainly a so-called wicked problem [6], as is often the case within Engineering Design and Product Development, in that no certain correct solution exists, that a sufficiently acceptable solution may still be found, and that that the solution differs over time and in different organizations. The research issues in this paper concern IDCE drivers for enabling FP innovation. Here, the main interest is the impact that these emerging issues have on design teams and their development activities.

2.1 The business organization: Extended enterprise

The extended enterprise consists of a network of companies that share risks, revenues and access to each others markets, and where, presumably, each partner has the goal of becoming best partner in a partnership, rather than the sole market leader. One of the reasons for such partnerships may be the increasing complexity of the hardware, software and services that make up the functional product in a business-to-business setting. Another reason might be the rate of technology change that must be managed in the FP design process.

2.2 The evolving product definition

One traditional engineering definition of product development is, for example, the one provided by Ulrich and Eppinger [7]:

> *"…the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product."*

By this definition, the product is finalized, sold and delivered to the customer and its use is, strictly speaking, not very interesting for the seller.

On the other hand, the ISO [8] definition of a product is:

> *"A product is an output that results from a process. Products can be tangible or intangible, a thing or an idea, hardware or software, information or knowledge, a process or procedure, a service or function, or a concept or creation."*

Based on the above definitions, in this paper, a functional product is considered to be:

> *A product, not necessarily a physical artifact, consisting of any combination of hardware, software and services, being sold for the purpose of supplying a function, thereby meeting all agreed-upon needs of the partner whose primary role is that of a customer.[2]*

The point here is that it would be more effective if people in a company talked about the same product perception, rather than engineers talking about the product as the hardware they are making and business people talking about the product as the offer they are making to the customers.

2.3 The design process

Current design, engineering design and engineering management literature describe how traditional engineering projects should be carried out and managed. However, team processes and best practices for FP development have not yet been described.

The important functionality for the end user has to be defined in each business case, which will probably lead companies in the extended enterprise to focus more and more on their own core knowledge and competence, while at the same time handling the increasingly complex business and product development relationships and strategies.

Some change to the design process will also occur because of the new demands on the hardware. Conceivably, this new business concept will include a stronger interest in upgradeability, configuration control, remanufacturing, modularization and customization.

The FP Design (FPD) process will be extended compared to the general hardware design process. In the FP design process, more emphasis is needed on needfinding in early stages and on the first offer to the customer, thereby extending the scope of the product development process, additionally this process will continuously evolve and adapt to the customer demands over the lifecycle of the FP [9].

2.4 New economic challenges

The development and sale of functional products also challenges current economic conditions and business models. Performance will not only be demanded in services and hardware but also in the surrounding economic system. For example, financing and insurance may be included in the functional product offer. As a company is selling functional products it is climbing the value chain and running the risk of "taking over" value from previous customers, which within the extended enterprise has the effect that the roles of the partners within it are no longer static, but dynamic and changing over time.

In these dynamic roles, trust between partner companies becomes more important as, for example, large supplies of spare parts are replaced with agreements on service availability.

One might say that the Functional Product is one of the drivers of globalization rather than the other way around and that globalization is no longer a choice but a reality.

2.5 The design team

Due to the FP design process within the extended enterprise and the new economic challenges at hand, the design team will include people from a variety of disciplines and functions. To name but a few team roles, the FP design team will include: engineers, lawyers, business developers, technical experts and finance specialists.

The FP team has (because of its cross-disciplinary character) different goals, purposes and motivations, and therefore includes different understandings, paradigms and world views, even though they may all be part of the same extended enterprise. Importantly, however, they still have to work with the same tools (at least to a limited degree) and with the same information (to a large degree).

Also, since actual functional products are assumed to be mostly of interest in the business-to-business (B2B) environment, and that FP drives globalization rather than the other way around, we are likely to see larger and more diverse (i.e., cross-functional and cross-cultural) design teams in the future.

New design team compositions raise the question "*What is a design team?*". As noted above, it is most likely that the design team no longer consists predominantly of engineers and other hardware related specialists. Few professionals have more than one academic degree and relatively few educational programs of today teach students to be knowledgeable in both, for example, design and business. Problems within the FP design team concerning professional vocabulary and understanding will arise more commonly than in a traditional, more homogenous team. The environment for distributed communication and collaboration must be able to support the whole team, which places new demands on the design and suggested usage.

To an increasing extent, information needs to be displayed differently to team members with different functions and purposes. *How* (in terms of layout) and *when* is a question for the definition of a FP design process, and *how* (technically) is more related to the DCE and KEE domains.

3 Information Driven Collaborative Engineering

The change from traditional hardware development to FP development implies a more integrated way of work between disciplines. Rather than having information spread out throughout the company and external enterprise and often a redundancy of information (i.e., the same information exists in duplicate in different standalone applications and at different parts of the extended enterprise), it is essential to make the information usable for all functions within the extended enterprise and available with the right level of transparency.

The heterogeneous FP design teams need to have access to all pertinent information regardless of devices, software and work procedures used. They should also be able to communicate any way they choose within the design team, handling changing product design and production methods, resources and facilities, product functionality, lifecycles, legal agreements, distances, time zones, given team members cultures, background, training, goals, purposes, etc.

As the domain of engineering design has evolved in order to better relate to the concepts of concurrent engineering (CE) and integrated product development (IPD), it must evolve to better address issues related to Functional Product Innovation. One way to more closely relate to the emerging needs of an FPI approach is to take an increasingly information-driven approach to collaborative engineering. This is not to say that CE and IPD are things of the past; it is just a way of highlighting that a changing business environment calls for changes in the way that we identify and deploy supporting technology and methods. Engineering Design characteristics in a functional product setting include multidisciplinary teams (which implies new challenges concerning culture, language and professional vocabulary), wicked design problems (which implies focus on argumentation, storytelling and discussion) and involves a iterative process including short as well as long design loops. All this, in addition to today's other issues related to design (such as ideation, concept design, detail design, production, documentation, etc.) fundamentally means that the complexity of information availability and use in global organizations will increase.

Our approach is to combine the concepts of integrated product development and distributed collaborative engineering, as we know them today, with our division's background in simulation of manufacturing processes, and evolving them into information-driven collaborative engineering in the support of Functional Product Innovation.

This approach involves the idea that decisions, at all times, should be based on the latest and most adequate information available at the time, and that these decisions and their rationale should be traceable throughout the design process. The information source should be the product model, so that decisions are made based upon verified information and simulation rather than rules of thumb, tradition and such.

In order to achieve Functional Product Innovation, the authors propose the application of a transparent view of the corporation, where business and technology functions are integrated through information-driven design. Current DCE practices and technologies must be adapted to the new drivers, mainly through design studies of product development teams both in academic settings and in actual industrial settings. Also, the approach would include a closer integration of the DCE domain and the KEE domain, thus allowing for a stronger connection between data, information and communication that is used throughout the product lifecycle, and the knowledge workers that locate, access and use this information.

3.1 Distributed Collaborative Engineering

The area of Distributed Collaborative Engineering can be divided into three levels: Integration (i.e., data management), Infrastructure (i.e., ICT tools that help create a shared workplace across locations) and Interaction level (i.e., interaction between people, and human-computer interaction). The different levels of collaborative engineering are shown in Figure 3, below. The figure also illustrates the communicative gap that occurs on different levels.

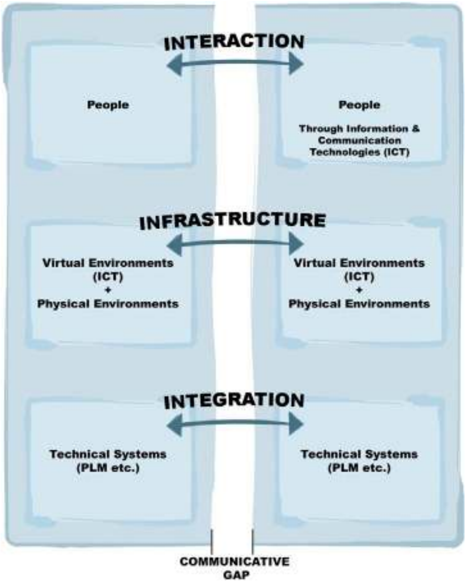

Figure 3: Three levels of collaborative engineering.

3.1.1 The Integration Level

The integration level is focused on the integration of the low-level communication structure, involving the exchange and synchronization of data and information between different software and partners within the extended enterprise. Here, one aim is to support the persistent storage of data, version control of design documents, and to show the current state of the design process.

The use of standards for information exchange is important. Tools should be based on, for example, Internet Protocol distribution such as IP multicast, Quality of Service, IPv6 and Peer-to-Peer technologies as well as communication standards from the International Telecom Union (ITU-T) and the Internet Engineering Taskforce (IETF).

Product modeling is important, since the product model provides a shared object for multiple participants to store all information about a product throughout its entire lifecycle, i.e., requirements, analyses and geometry.

Various techniques for exchanging design data between users exist today, but they are not satisfactory for use in distributed engineering because they are mainly designed for exchange of data and not interaction. Standards like STEP and CORBA provide useful exchange mechanisms for engineering data, but do not solve the problems of conversion. It is impossible to store all information in one place, so technologies for integration and sharing of information must be used. A requirement for collaborative engineering systems is that they must combine relevant data from many sources and present it in a form that is comprehensible to the users.

Another important issue is that of security. Information must be exchanged with partners, but not with others outside this partnership. Today, this means that company policies can hinder collaborative work (i.e., company firewalls secure the internal computer systems from threats from the internet while at the same time effectively stopping communication, using standard collaboration tools, from inside the firewall to a partner outside the firewall).

3.1.2 The Infrastructure Level

This infrastructure level includes the Information and Communication Technologies, ICT (a shared workplace with access to the relevant applications). This level includes collaboration tools for both synchronous and asynchronous activities, and today these modes are commonly separated. Due to the highly heterogeneous environments, the software needs to be highly scalable and adaptive in terms of bandwidth consumption and CPU utilization. It is important to support collaboration between distributed teams of engineers using highly heterogeneous environments, such as the internet and with mobile devices.

The infrastructure also includes the physical environments in which the collaboration takes place (i.e., meeting rooms, conferencing studios). The design of physical environments is also of great interest, since creative thinking and collaboration are largely dependent on the flexibility and usefulness of both physical spaces and the tools therein [10]. How do you create a project space that suits local creativity, but also opens up the possibilities for successful global collaboration?

3.1.3 The Interaction Level

On the interactional level, collaborative engineering is viewed from a *people* perspective. As such, it focuses on the interaction between individuals and groups using ICT (human-human interaction), and on the interaction between people and ICT (human-computer interaction). The former approach naturally has its base in the area of Computer Supported Cooperative

Work (CSCW), while the latter has its origins in Human-Computer Interaction (HCI). Both these approaches deal with the design of computer systems, and are thus closely related to both the *Integration* level and the *Infrastructure* level. The *Interaction* level, however, draws attention to the observation that although the other two levels might be functional from a technical perspective, they might not be usable (easy to use) or even useful (meeting a need) from an end-user perspective.

Thus, *Interaction* is about *Infrastructure* and *Integration* in use; observing how these technologies are used in everyday collaboration, and using this understanding as input to the process of designing new methods and technologies that are better tuned to the needs of global engineering design teams.

3.1.4 New Demands on Distributed Collaboration

The distribution of resources within the extended enterprise makes communication and collaboration over distances, which in many cases are very large, a real challenge. It puts additional requirements on the collaboration environment in terms of handling time zones and cultural issues even in a homogeneous engineering-based design team. Such challenges will be even more accentuated in a distributed FP development team where education, training and purposes also differ greatly, as well as languages, culture, religion, ethics and values. Collaboration within the distributed team should not be restricted to communication between project leaders in different teams. Such communication follows the structure of the hierarchical organization, where much information is filtered through the project leader, who may or may not be involved in the detailed design issues. Current DCE seldom supports detailed design in distributed FP development teams [11].

In an ideal world, it should be possible to support IDCE according to what has been described above. The support will consist of suggestions for methods of work and usage which should support all sizes of teams and team complexity. These new demands require research approaches that presuppose close collaboration between academia and industry.

Knowledge and different views on the same knowledge must have adequate forms of access control, so that, for example, private information remains private or information not intended for certain people do not reach them by mistake. On the other hand, for optimal product development, everybody needs access to their own relevant information. Here, there is a connection to the team members' own preferences, since many people produce at a much higher rate when they have a view of the whole rather than their own part only. The conclusion, here as well as for DCE environments, is that users must be allowed to customize their interfaces with the computer systems in ways that suit them.

The design rationale, i.e., why something turned out as it did [12], what motivated that particular design decision, what design possibilities were considered and rejected, etc., we acknowledge as being very important. Especially when it comes to facilitating traceability of decisions over time, methods of work and tools for capturing the design rationale are needed [11]. This area is a good example of challenges that arise from FP development and which affect both the FP design process as well as knowledge management on a technical level.

3.2 Knowledge Enabled Engineering

The functional product is knowledge-intensive in a high-risk and high-gain enterprise, which further increases the need for integration and synergy between teams and between computer tools through information modeling. The question, which varies from situation to situation, is: what information needs to be controlled in a knowledge management system?

Information needs to be structured and displayed according to the individual team members' goals, purposes and training. Knowledge Enabled Engineering (KEE), then, represents a methodology used to capture and reuse knowledge in computer aided design systems [5]. Specific knowledge capture and reuse, like traditional Knowledge Based Engineering (KBE) approaches, of computer simulations where knowledge of properties and behavior of forthcoming products may be predicted is of particular interest. KEE aims to support or perform engineering activities with the help of available and identified techniques and methods. The purpose of KEE is to allow automation of engineering work, as this creates an opportunity to extract knowledge normally found in later (downstream) phases and make this knowledge available already in the conceptual phase of the development process.

The emphasis in KBE is on providing informational complete product representations captured in a product model:

> *"The product model represents the engineering intent behind the product design, storing the how, why and what of a design." [13]*

KBE can be defined as:

> *"…The <u>use</u> of advanced software techniques to capture and re-use product and process knowledge in an integrated way."[14]*

Together with computerized engineering design tools, used to reduce technical risk and uncertainty along with the number of prototyping cycles needed, e.g., modeling and simulation tools, and the group of tools that enhances communication and facilitates the flow of partial information, e.g., tools based on shared databases, a simulation-driven approach can be taken where the knowledge assets can be used to model and simulate business processes, engineering design processes, products, and ultimately all lifecycle properties of a Functional Product.

Combining KEE methods and simulation technologies can improve the design evaluation process, no matter if it concerns the design of a product proposal or the design of the product itself. The knowledge assets can be cost models for business as well as performance models for engineering analysis. Positive effects are the possibility of early standard analysis of design concepts; shorter analysis cycles (i.e., creating the possibility for optimization and more iteration) and the fact that experienced simulation experts can spend less time on routine tasks that are done by the KEE system users instead. Ultimately, the information, or knowledge, can drive the design dynamically rather than being static objects. By having all processes, business and technology, in a company using, and updating, the same knowledge base it is possible to make sure that decisions, or simulations, made are done with the right knowledge asset. Lifecycle simulation of an offer or FP containing all valuable parameters is then possible.

4 Results

The research at the Polhem Laboratory have been performed using a three-layered approach [15] to the advancement of global collaboration, combining *product development, education* and *research platforms*.

4.1 Product Development Platform – Industrial Perspective

Due to the close collaboration between the researchers and the partner companies in the Polhem Laboratory [16], researchers can follow real design teams in action at partner companies. The design teams at the companies use a variety of different tools and methods to develop products between company sites in Sweden and in different countries as well as between different companies. Some of the studied companies are Hägglunds Drives AB, Volvo Car Corporation, Land Systems Hägglunds, Sandvik and Volvo Aero Corporation. During the past decade, there has been an intensive development of ICT tools and use of them in industry. First, these tools were used in the detail development phase, but now they are increasingly used together with advanced simulation and KEE tools in the concept development phase.

Ten years ago, Volvo Aero Corporation (VAC) joined the Polhem Laboratory and started to develop competencies in the DCE and KEE areas in several Polhem Laboratory projects. The company has successively incorporated the methods and tools in the development process. The most advanced technologies are not yet used, but combining video conferencing and online meetings with ordinary design and simulation tools has presented a new possibility for iterating many more design solutions than before. This enables optimization of the product solutions not only at the Volvo Aero level, but also at the customer and customer's-customer level. The product innovation environment has therefore been enhanced, and ultimately, a product with higher value is produced. This is the case for the Airbus A380 program, where Volvo Aero is partnering with Rolls-Royce to develop the Trent 900 aircraft engine, which provides thrust for the large double-decker.

The usage of the methods and tools are studied and further developed together with Volvo Aero and other aircraft industries in VIVACE [17], a 70 MEuro Integrated Project in the EU Sixth Framework Program (FP6). The acronym stands for "Value Improvement through a Virtual Aeronautical Collaborative Enterprise" and the main project goal is to support the design of a complete aircraft with engines by providing increased simulation capabilities throughout the product engineering lifecycle. The goal is to create a "virtual product" in a "virtual enterprise", thereby aiming to achieve a 5% cost reduction in aircraft development, a 30% lead-time reduction in engine development and a 50% cost reduction in engine development. One of Volvo Aero Corporation's goals in the Virtual Enterprise setting is to study barriers to collaboration in design and how to address them.

4.2 Education platform

To disseminate research in industry, a good way is to introduce the research tools and methods into engineering-design education, where new research ideas and technologies can be tested in design projects with industry. During the previous nine years, this approach has been tested in the SIRIUS program [18], a one-year student project, in which students and company development teams work together to develop new concepts for future products. These projects have provided a test platform for research in DCE, KEE and later for IDCE methods and tools. The projects have resulted in possibilities for developing product innovations, about 15 patents and many new products already in production. The students cooperate with the company engineers by using the collaborative systems and methods developed in the research platform at Luleå and communication studios located in Luleå, Gothenburg (Volvo Car Company), Örnsköldsvik (Hägglunds Drives AB) and in Trollhättan (Volvo Aero Corporation). Within these projects students from LTU have also cooperated with other student teams from the Royal Institute of Technology and Chalmers University of Technology.

4.3 Research platform

Some new ideas may not be possible to implement in industry; therefore, it is also important for the researchers to be able to test and evaluate these issues in experimental forms within academia.

The interdisciplinary work within the Polhem Laboratory inspired us to further explore the relationship between the social and technical aspects of collaborative work. By applying concepts from the ethnographic tradition to the context of our research center's understanding of engineering practices has increased, It is shown that the potential to create collaborative environments and technologies better suited to the needs of both co-located and distributed engineering communities has increased.

The research team has created several studios for collaboration [19]. The first studio was inaugurated in 2000, see Figure 4 below. Continued research has led to new ideas and concepts that are incorporated in the new experimental studio (see Figure 5), which is flexible enough to accommodate a wide range of co-located and distributed collaborative scenarios, while being rigid enough to also allow for realistic, everyday design-in-action and effortless research observation of those activities. The studio provides a rapid-response environment, in which the significance of issues raised through ethnographic observations of engineering work can be evaluated and solutions offered [20].

Figure 4: The original studio designed at the Polhem Laboratory.

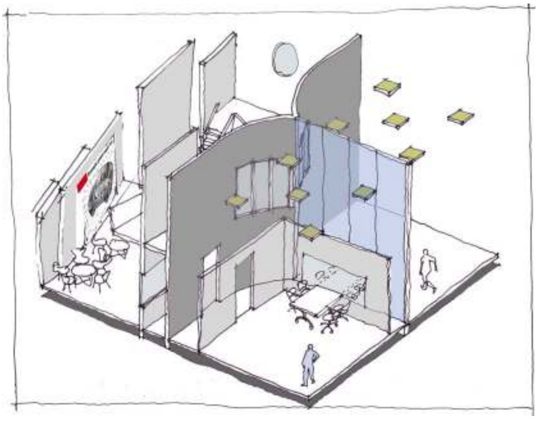

Figure 5: The new studio designed at the Polhem Laboratory.

It is likely that management and control of the evolution of product development for hardware to product development for Functional Product Innovation can be enabled in several ways. Our suggested way is to enable FPI through the realization of Information Driven Collaborative Engineering.

Given the Engineering Design characteristics in a functional product setting as discussed above, Distributed Engineering Design should ideally support all of this with a focus on information and knowledge. IDCE must support local as well as distributed teams with the help of our chosen tools: work methods, technology and demonstrators.

Work methods include such things as meeting facilitation, project work methods and distributed design methods. Technology on the other hand includes, for example, videoconferencing, audio conferencing, instant messaging, project portals and shared spaces to name but a few.

Whatever sub-solutions to problems (regardless if they are related to technology or work methods) are found in future research, the intention is to demonstrate them in industrial as well as academic settings as a way of spreading results.

To identify solutions we must first identify the knowledge gap, which is critical in order to perform relevant research. That includes identifying relevant FP cases and studying design practices at companies with focus on information and collaboration issues related to knowledge acquisition, knowledge retention, knowledge distribution, knowledge backup and knowledge availability. Also, a well grounded knowledge of engineering design and the best practice concerning how distributed engineering design is supported today is critical for reflection on the industrial studies in relation to the existing theoretical framework.

To develop more effective solutions (in terms of less time, lower cost, higher quality and higher efficiency), planning and deployment of demonstrators/pilots in industry situations similar to the studied situation is an important consideration. Pilots in an academic environment may then be developed, from which results may be compared to industrial-case results. These academic pilots are to be carried out as single "parameter" studies in an experimental setting using the new studio. The new studio will also be used to motivate efficiency in large scale by using results from small-scale experiments. After result reflections, new, multi-parameter pilots in industry may be developed, deployed and studied.

5 Discussion - Realization of IDCE

The purpose of this article has been to introduce some of the new challenges that arise when trying to develop information-driven collaborative engineering in a functional product innovation setting. The approach is to combine it with research, education and product development, which is expected to lead to functional product innovation. This belief is based on years of research in distributed engineering with several Swedish industrial companies (including Volvo Aero Corporation, Hägglunds Drives AB and Volvo Car Corporation [20]) as well as such research within the senior undergraduate course "SIRIUS" at Luleå University of Technology. This belief is also based on a genuine interest in research concerning engineering design and product development.

So why is it believed that that IDCE (based on DCE and KEE) will lead to functional product innovation? This belief is founded on the outcome of several studies of multi-cultural design teams [15,21], the results of which have been greatly improved and widely acknowledged, thanks to team diversity in terms of language and training. In Europe, VAC and the Division of Computer Aided Design at LTU are participating in the 6th Framework

Program VIVACE, where additional tools and methods for this kind of work are under development.

Many distributed design cases have been studied [11], including industrial cases with CONEX AB, Hägglunds Drives AB and winter testing of vehicles. These case studies have proven that using distributed design greatly speeds up the creative process. The discussed work concerning Knowledge Enabled Engineering aims at creating tools where routine jobs are automated and simulations speeded up for the benefit of the engineer. Both these activities give the designer more time to be creative and allow for a greater number of design loops with increased internal freedom. In short, this is conducive for creating innovative products. In the SIRIUS course, for example, over a period of nine years, about 15 designs have been patented by the involved companies, and interest from industry partners has never been greater, owing to their interest in innovative design solutions.

5.1 Challenges to reach Information Driven Collaborative Engineering

There are some fundamental challenges that relate to both the DCE and KEE aspects of Information Driven Collaborative Engineering.

First, there are technically oriented challenges. It is technically possible at an early stage of design to define product models with a high level of detail by making use of existing know-how. At the same time, it is challenging to gain that know-how at the right level of detail.

Secondly, there are methodological challenges. The main shift is that all logical product solutions and their combination must be defined upfront and coded into a computer application. This requires systems development and maintenance work, which is traditionally separated from interactive engineering work. Often, the knowledge models can be developed to be “good enough” for 80% of the expected preliminary work of a project. Upon entering the product-development phase, an additional 20% of systems development/updating is needed due to additional situation-dependent requirements. A challenge is to define and develop these engineering systems, so that users still have the necessary control and the systems do not become “black boxes”. It is then crucial to have an efficient updating and re-design methodology, since such work tends to be carried out in a severely restricted time frame. There is a need to develop simulation models adapted to the actual stage of design and available information. By doing this, the combined KEE and simulation environment will become a design support system that drives the design rather than a design verification system that verifies what is already decided.

Thirdly, there are cultural and social challenges [22]. The new generation of engineering support systems increasingly integrates techniques, methods and experiences from disciplines that are normally represented among different users, such as CAD, PDM and Simulation users, although it is a technical reality that the systems mergers, new roles and situations appear amongst the users. Challenges appear as new roles are defined, such as “Knowledge Engineers”. More effort is spent by users on actually defining the design systems than “simply” using a pre-existing tool from a vendor.

The new collaboration tools must be versatile, flexible and easy to use. In particular, in the early concept phase, they must be able to support different types of collaborative interactions: synchronous, asynchronous, point-to-point (engineer-to-engineer as well as between engineers and other company functions), many-to-many, small group interactions, group-to-group, etc. Collaboration tools should include support for session management and control, user presence and awareness, user mobility, and transparent storage of collaborative data and events to facilitate reuse and reprocessability. As examples, informal communication, brainstorming and prototyping are less common between distributed team members than co-located team members. These types of meetings seem much harder to support than meetings later in the design process, where formal product models, requirements, etc., exist and formal decisions are more likely to be documented.

Törlind and Larsson [23] showed that informal communication is an important part of the communication between team members. However, this type of communication is difficult to support in a distributed team. Solutions for informal communication, presence and awareness must support rapid communication [24]. The cycle of communication is short; problems are dealt with as they come up, and information is exchanged as a natural, effortless and integral part of everyday work. Therefore, it must be possible to initiate communication systems quickly, since relocating to specially designed conferencing rooms and starting complex systems for short meetings is inconvenient and time-consuming. The tools must be available from the desktop computer.

Many of today's tools are technology-focused and force the user to work in a specific way. The technology focus – the "what can" approach – becomes the basis of integration and communication technologies, whereas the user focus – the "what needs" approach – requires a deeper understanding and analysis of the information and communication processes. A typical example is video conferencing that supports communication between team members, but forces the user to work in a specific way (e.g., side conversation is not possible, eye contact is difficult to achieve, and users should preferably sit in one place and not walk around in the room).

New communication tools must support *effortless communication*, whereby the user can see if collaboration partners are available and initiate communication in a couple of seconds regardless of the partners' location. The communication is automatically adapted to the bandwidth of the connection and the hardware. The users have several communication modules that can be used if needed; e.g., start with instant messaging, then switch to video conferencing and use application sharing. All communication events can easily be stored and retrieved later on if necessary.

The challenge for global product development is to support true collaboration within global design teams, where the diversity and competencies of the whole team can be utilized and where team members can *think together* rather then merely exchange information, opinions and divide work [11].

Additionally, the collaboration environment should have the desired levels of security, availability and reliability over time. The challenge, as in the case with the knowledge management above, is to identify the process (using for example the design rationale) needed information and how it will be used and displayed in a system for distributed collaborative engineering of functional product innovation.

6 Conclusions

This paper discusses the challenge of designing intuitive and useful methods and technologies for a wide variety of contexts and needs, for an extremely heterogeneous and diverse user population. Also, this paper proposes that future research programs in collaborative engineering take an increased interest in understanding not only what can be communicated, but also what needs to be communicated. The former approach assumes its starting point in integration and communication technologies, whereas the latter approach requires a deeper understanding and analysis of the information processes needed to conduct global product development – essentially redefining the scope of supporting methods and technologies for collaborative engineering. First, we need to identify and thoroughly understand what information is needed for collaboration. Second, we need to understand how best to make this information available and useful for each partner and individual in the virtual enterprise.

Given that development of functional products affect many areas work in product development, many new demands are placed on today's methods and work environments for distributed product development. Methods of work, technology development, differing user needs because of different educational backgrounds, training, languages, culture, religion, ethics and values must all be considered.

Design of functional products certainly constitutes a wicked problem [6] and is as such possible to tackle in many different ways. Therefore, the solutions to whatever problem was originally identified will be context-dependant; that is as it should be, as one is aiming for a customized functional product for the customer, all within the limits of organizational flexibility in terms of design, production, assembly and so on.

The area of Information Driven Collaborative Engineering is based on the following argument:

1. Functional Product Innovation demands cross-cultural, cross-functional and cross-organizational collaboration in globally distributed teams.
2. As the organizational complexity increases, it is crucial to provide teams with methods and tools that enable them to effectively locate, access, understand, and make use of the information and knowledge that is now increasingly dispersed throughout often temporary organizations (i.e. Virtual Enterprises).
3. Research in the KEE domain is well equipped to handle issues of making explicit knowledge (i.e. "knowledge as content") available to members of an organization throughout the development process. For example, applications for Knowledge Based Engineering and Simulation Driven Design enables engineers to make well-informed decisions based on information derived from other domains in which they are not experts.
4. Research in the DCE domain has its primary benefits in promoting the sharing of tacit knowledge (i.e. "knowledge as process"). For instance, applications for Virtual Meetings make it possible to engage in a collective sense making process with other people (thinking together) something which is particularly useful when dealing with highly contextual information or ill-defined (i.e. wicked) problems.
5. Bringing the domains of KEE and DCE closer together will provide opportunities for cross-fertilization, for example by exploring how to better contextualize explicit knowledge, or how to better capture and codify tacit knowledge - issues which the separate research domains cannot adequately handle on independently.

By capturing and using the design rationale from previous projects it should be possible to decide what should be communicated through DCE practices and tools rather than what can be modeled, and by doing so, define both what is important and the order of importance.

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Paper C

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TOWARDS TRUE COLLABORATION IN GLOBAL DESIGN TEAMS?

Peter Törlind, Andreas Larsson, Magnus Löfstrand, Lennart Karlsson

Abstract

Today’s collaboration tools can support formal meetings to a certain extent, though there is still an immense potential for improvement when it comes to designing virtual and physical places where global design teams can collaborate in more ‘natural’ ways than existing distributed environments allow. One challenge for global product development is to support true collaboration within global design teams, where diversity and competences of the whole team can be utilized and where team members can *think together* rather then merely exchange information, opinions and divide work. This paper summarizes the results of several case studies and development projects performed within the Polhem Laboratory over the last four years and proposes challenges for future research. From our findings some of the most important challenges are how to support users with communication tools for more natural formal and informal communication (i.e. as a co-located team communicates), while automatically storing information and context from the distributed meetings.

Keywords: computer supported cooperative work, computer aided design, distributed product development, distributed engineering

1 Introduction

Demands on product development are ever increasing [1], and being able to develop radically shorter design cycles is of great interest: being able to build digital models, verify concept functionality and plausibility by relevant simulations, and finally, simulate production and sales of the product, all in a few days. To do this, the importance of design concepts to accurately predict outcomes increases to new levels.

Global collaboration in the design process is today a reality for many companies, often resulting from mergers between several companies. The use of distributed design teams is also common in Virtual Enterprises within complex systems engineering companies, such as those active in the aerospace sector. Virtual Enterprises consist of a temporary network of independent companies who share skills, costs and markets with neither central offices nor organization charts [2]. To cut costs and time, while meeting quality demands, these companies are forced to collaborate. Unfortunately, such global partnerships involve immense challenges regarding distributed work.

A new industrial demand has been recently identified - products capable of being sold as functions in addition to the parts of which they constitute (Hardware, Software and Services) – so called ‘Functional Products’. Due to the number of diverse disciplines that are affected by or involved in developing a Functional Product (these disciplines include, but are not limited to design, management, production, marketing and legal), additional demands on communication, collaboration and trust arise. A greater number of disciplines that are increasingly distributed geographically will need to work together to create Functional

Products. By considering these changes in product development, an increasing importance will be afforded to improving the performance of distributed teams.

In many distributed projects the collaboration between various distributed groups are often restricted to coordinating separate sequential tasks. Future challenges for distributed teams are to reach *true collaboration* – to utilize the diversity and competences of the whole team, and simultaneously bridge communication gaps between both technology and humans.

This paper summarizes the results of several case studies and development projects performed within the Polhem Laboratory over the last four years, as well as comparing the projects and proposing challenges for future research.

2 Background

Multidisciplinary work and concurrent engineering have been established methods in industry for many years. One main principle of concurrent engineering is multidisciplinary, or cross-functional, teams that collaborate across traditional, functional areas of expertise. One main concept is for designers to use their different backgrounds and professions to influence the final design. These teams should work together towards a common set of consistent goals, supported by an integrated computer environment where the information is shared between teams, machines and processes [3].

Fundamentally, development activities should preferably be carried out in parallel rather than in sequence, and if such collaboration is to be successful, it is very important to "*improve communication between the many involved people including management, designers, product support, vendors and customers.*" [4]. Because of globalization, the multidisciplinary team may be located in several sites around the world; collaboration between these dispersed groups often presents considerable challenges.

However, in addition to accessing defined data subsets in a suitable form, communication also concerns human to human communication, where a good design relies heavily upon the ability of a cross-functional team to create a shared understanding of the task, the process and the respective roles of its members [5, 6].

2.1 Functional Products

Behind the shifting industrial focus from hardware to functional products lies the fact of new business drivers which have been described by Brännström [7]. Interest in functional products has been expressed in a range of Swedish companies [7, 8]. According to Brännström, a Functional Product (FP) *"combines the lifecycle processes of hardware, software and services.".*

This need might be met by a total offer, sometimes in the form of functional sales. The effect of expanding this product definition is that it will be increasingly difficult to develop products in-house mainly because the concept implies an increased and stronger collaboration between engineering departments and departments with whom they have had no normal communication with in previous non-FP projects.

Due to the number of diverse disciplines affected by or involved in developing a Functional Product, new demands on communication, collaboration and trust between multi-disciplinary teams arise [9, 10]. The effect of Functional Product Development on today's engineers is suggested to be an increased contact area between traditional engineering design teams and other departments, customers, subcontractors, etc. The composition of these design teams should be reorganized to support multi-function design covering a wider range of company functions.

2.2 Distributed Work: The Problems of Globalization

Even a small distance greatly reduces daily contact and informal communication between collocated team members [18]. Allen [11] states the *"50 ft rule of collaboration - teams are essentially 'distributed' if they are more than 50 feet apart",* i.e. over this distance problems of being separated increase substantially. In this paper, the term distributed is used when teams are located in different geographic locations.

Many globalisation related problems introduced below are described in the literature, that occurs specifically for distributed teams:

- Team members working in a virtual, distributed environment have problems with carrying out information transfer and creating a common understanding [12, 13, 14].
- Other challenges for distributed teams include issues of proximity, awareness, communication latency [15, 16, 17].
- When product development is done in a global team participants are more likely to have different backgrounds and perspectives. The heterogeneity of culture, technical disciplines, language, etc., is commonly much more extensive in a distributed team than in a local team. These differences further complicate the collaboration [12, 18, 19], and if the teams are spread over different time zones, an additional problem arises since synchronous communication may be hindered due to limited overlap in work hours [12, 16, 29].

Collaboration problems often change during the design process. Kleinsmann and Valkenburg [20] categorized barriers in three different levels, and found that barriers at the *participant level* occur in the early design phases, barriers at the *project level* increase during the project and *organizational* barriers mostly occur at the start of the project.

Problems normally found within co-located teams, such as lack of information, problems with support tools, and conflicts between people, increase with distribution [21].

Distributed work also has several advantages. Larsson et. al. [16] has identified several opportunities with distributed teams compared to collocated teams, such as team diversity and market closeness.

Global design requires extensive communication between participants and several notations exist to categorize different levels of communication. MacGregor defines the difference between collaboration, cooperation and coordination [22] as:

- *Co-ordination is the organisation of resources or elements, usually within a complex body or activity, so as to enable effective collaborative work.*
- *Collaboration is the action of working with someone to produce or create something, usually where the parties involved have a common goal or interest.*

- *Co-operation, often used interchangeably with collaboration, is the process of working together to the same end. By definition, there is little to separate both terms other than collaboration represents the action and co-operation the process.*

The authors of this paper agree with Dillenbourg et. al. [23, p.189], who provide a functional difference between cooperation and collaboration: *"Cooperation and collaboration do not differ in terms of whether or not the task is distributed, but by virtue of the way in which it is divided; in cooperation the task is split (hierarchically) into independent subtasks; in collaboration cognitive processes may be (heterarchically) divided into intertwined layers. In cooperation, coordination is only required when assembling partial results, while collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem."*

The purpose of making this distinction is not to provide a rigorous definition of very closely related terms, it is to highlight that we see a potential for an even closer collaboration between remote partners.

2.3 Computer Tools for Design Collaboration

Computer Supported Cooperative Work is the scientific discipline that seeks to understand how people work together, how to design appropriate computer-based support and how these technologies affect group behavior [24, 25]. Bannon and Schmidt [24] describe CSCW as *"an endeavour to understand the nature and characteristics of cooperative work with the objective of designing adequate computer-based technologies."*

Today, a multitude of Internet-based collaboration tools exists for both asynchronous and synchronous collaborative work. However, most commercially available software tools focus on the later stages of the design process [26], where information is typically more structured, and information exchange processes can be more easily formalized. The early, creative, conceptual design phases are typically less structured, requiring a lot of ad hoc interactions and highly interactive meetings relying on swift and unrestricted information exchange. These types of interpersonal interactions are typically more cumbersome to support using computer-based support tools.

The EC funded *Future Workspaces* [27] presents a roadmap for future collaborative workspaces, where one of the research targets is*: "Establish network independent and scalable services to access audio-visual materials, 3D and mixed reality objects, distributed speech recognition over heterogeneous infrastructure with variable bandwidth and quality of service availability with a high trust level."*

Many research tools and commercial products claim to bridge distance and solve communication problems, though there is still a huge difference between distributed work and co-located collaboration. This statement from Olson & Olson [12] in 2000 is still valid: *"although we will be able to bridge some of the distance and make communication richer for remote work than it is today, distance still matters"*.

3 Methods

The input for the findings presented in this paper is based on a literature study and results from several case studies done by the Distributed Collaborative Engineering research group at the Polhem Laboratory, Luleå University of Technology over the last few years. These projects involved both distributed and co-located design teams, and included student projects in collaboration with companies as well as case studies in automotive companies, aerospace companies and component suppliers. Some of the major projects are listed below:

1. A 6-month case study where engineers from two Swedish industrial companies (Hägglunds Drives AB and the consultancy firm Conex AB) collaborated in a distributed setting [28].
2. A one-year student project where engineering students from LTU collaborated with students from Stanford University to develop a new type of pedal interface for Volvo Car Corporation [16, 29, 30, 31].
3. Studies at a component maker for trucks [32]
4. Two studies at BAE Land Systems Hägglunds; one focused on distributed and co-located collaboration, the other on interaction with physical objects in distributed meetings [33, 34, 35].
5. Studies at two different engineering departments of Volvo Car Corporation.
6. A one-year technology study where a prototype framework for winter car testing was designed by combining telemetric technologies, distributed Virtual Reality and broadband conferencing [36].

Other distributed projects observed include collaborative student projects between Luleå University of Technology, Chalmers University of Technology, the Royal Institute of Technology in Sweden and Stanford University, CA, USA. The research team has also been involved in the DITRA project, a development project created to utilize distributed collaboration technologies in industries in northern Sweden with the objective to increase their competitiveness [37].

4 Main Findings

In this section, we present some of the main findings from the above mentioned projects. The findings indicate that numerous challenges need to be addressed if ‘true’ collaboration in global teams is to be achieved. A summary of the projects can be found in Table 1.

4.1 Hägglunds Drives Study

The study at Hägglunds Drives indicated that computer tools simplified communication and enabled meetings several times a week instead of once every two weeks. The users experienced a clearer focus in the project when using distributed engineering technologies, and commented that the usage of competence and knowledge at both places improved because the communication tools simplified communication. Also, informal communication within the project was improved. For the consultant the project changed from an ordinary consulting assignment (with design goals, weekly progress reports and a final delivery of a design document) to a more flexible project where closer collaboration between the companies existed, where ideas were discussed daily, problems were rapidly solved and new directions for future work came up.

Summary of the projects followed

Study	Focus	Type of study	Size of group in collaboration	Main findings	New tools implemented	Challenges
Hägglunds	Introduction of distributed collaborative tools for synchronous communication	Ethnographic study, Interviews, empirical data collection	3+2	Limitations of whiteboard tools Steep learning curve for collaboration tools	Broadband conferencing tools	Steap lerning curve of tools, poorly designed tools
DTI	Informal communication.	Ethnographic study, empirical data collection	4+4 students 1+2 teaching ass (management)	Limited informal communication between remote team members Low awareness of what was going on at the remote site	Contact Portal [27]	Informal communication [27] Side conversation [28] Importance of shared objects in design [29]
Ferruform	Which tools are needed for collaboration	Ethnographic study, particaptory design, interviews	Varying 5-10 persons in several groups	Importance of physical prototypes, importance of low cost collaboration tools		How to interact with physical objects in distributed design.
Land Systems Hägglunds 1	Barriers for collaboration	Ethnographic study, interviews	Varying	Documentation burden Document flow		Automatic storage of information from meetings.
Volvo Cars Corporation	Social connectedness. Informal communication.	Ethnographic study	Varying	Social capital is important. Knowing-who-knows and knowing-who-to-trust is essential to successful decision-making.		Finding the person ‘behind’ documents. Locating expertise. Knowing what information and people to trust. Storage of design rational
Distributed Winter testing	Supporting remote monitoring of cars on proving ground	Evaluation of prototype systems	2 groups	Collaboration tools can streamline processes	Shared VR-application for remote monitoring of vheicles	Security issues,
Land Systems Hägglunds 2	Physical artefacts in distributed design	DRM research method	1-7 local 1-12 remote	Importance of physical prototypes	Mobile communication tool [32]	Interaction with remote physical objects
DITRA	Synchronous communication Distance education	Participatory design	Varying, 2-11 distributed groups with total of 2-60 participants	Difficult to perform large meetings, how shall many groups be represented	Tools for synchronous communication and physical environments for collaboration	Ease of use of communication systems, Large group meetings Floor control in meetings Storage of information from meetings

Table 1. Summary of the projects.

Some of the collaboration tools tested in this study, e.g. shared whiteboards, were found too cumbersome to work with. Instead, normal whiteboards were used and the camera was moved to allow for an unimpeded view. As well, the learning process for some of the collaborative tools was too long, and the setup of a conference was sometimes experienced as too cumbersome due to the technology in itself (such as audio, audio cancellation, cameras, etc.) requiring some time to learn how to use it fully. Coupled with misunderstandings of the interface, it was concluded that much work is yet to be done when it comes to user friendliness and stability of service.

In addition, this project revealed several technical and organisational issues such as network demands and meeting preparedness.

4.2 The DTI-project

The main findings indicate that the flow of informal information between remote team members was very low compared to that between local team members; team members also had a low awareness of what was going on at the remote site. To address these issues, some tools such as the Contact Portal [29] were developed, acting as a natural starting point for initiating and maintaining contact with remote team members.

The high-quality videoconferencing capability enhanced the ability to understand body language and other non-verbal information, making physical proximity less of a concern compared to telephone conferencing and low-quality videoconferencing.

However, several issues observed during co-located meetings were not observed in distributed meetings; i.e. *interaction with physical objects* and *side-conversation.*

Interaction with physical objects: team members could easily share the geometry of a concept (using shared applications and CAD-models), and discuss the physical object via videoconferencing. As well, they could successfully negotiate a shared understanding of how it ‘feels’ to drive with Virtual Pedals, or to shape consensus about concepts of ‘comfort’ and ‘ease of use’, when only one of the sites has access to a physical prototype.

Side-conversation: in the study, it was also noticed that one-on-one conversations held simultaneously with a main discussion were common in collocated teamwork, and they served as a natural part of creative teamwork [30]. Current systems for distributed collaboration cannot provide sufficient support to these subtle interactions, which has important implications for supporting and improving the performance of global teams by suggesting that the one-to-many channel of today’s videoconferencing is severely limiting, despite the current advantages of high-quality audio and video.

4.3 The Ferruform study

In this project slightly over 6-months, a design group at Ferruform was followed, and both co-located and distributed meetings were studied.

Interesting results were the comparison between the same type of meeting in a distributed and a co-located setting. In a distributed meeting (via telephone conference), much less interaction occurred between team members than in a co-located meeting. Obviously, the medium (telephone) prevents the user to explain difficult issues satisfactorily.

Another problem in distributed meetings was the interaction with physical objects. In local meetings the team often went out to the work shop to inspect a stamping tool or analyze problem areas in the production process. These issues could somewhat be solved in a distributed meeting by using a camera to document a specific issue and send the photo to all participants before the meeting, though the comprehension of the problem was much better when the team did a physical visit in the workshop.

4.4 Land Systems Hägglunds - Study 1

In this project a design group was followed over a period of six-months, with four weeks of site studies evenly distributed over the whole period. The project included a customer outside Sweden, several Swedish consultant companies and several divisions within Land System Hägglunds.

Among the findings from the project were the problem of *Document flow and Documentation burden,* i.e. optimizing the amount of documents sent to increase awareness and accessibility and keep all participants satisfied, without flooding them with unnecessary information. Users within the company could share documents readily; e-mail was used to share documents externally. In this process the final document was hard to find, and the review process was almost impossible to follow.

Another finding was the *Dependency on personnel:* This concerns the project's vulnerability, since in some cases key personnel such as the manager would have been difficult to replace due to his extensive knowledge of all aspects of the projects.

4.5 Land Systems Hägglunds - Study 2

This study focused on the importance of physical prototypes in distributed design, inspired by the findings from the DTI and Ferruform studies. In an attempt to realize this, a descriptive study observed co-located design reviews where a physical prototype was used. At Land Systems Hägglunds, a physical mock-ups was used to verify the design, to learn and to facilitate collaboration. The physical mock-up was often used to resolve design issues, to discuss system integration between different subsystems and as a physical embodiment of how the project was proceeding.

The study of co-located design reviews provided valuable input to the design of a wearable conferencing unit that was later used for distributed design reviews. The new system, tested and evaluated on distributed design reviews, allows remote users a first person view of the mock-up. With the new tools the remote engineers can share their *"virtual' CAD-data simultaneously as the mechanic situated at the prototype shares his "physical' data with the engineer*. The new tool also provided support in a co-located setting; users can look behind panels and view items normally hidden from the user's sight. This enables all members of the design team to have access to information regarding the project within minutes without relocating.

The project also highlighted the importance of physical prototypes. The new tool clearly enhanced remote work, though several issues still remained, e.g. problem to test and evaluate ergonomics and tactile properties such as weight of objects, friction in mechanical links, etc., from a remote location.

4.6 Volvo Car Corporation

Ethnographic work at two different engineering departments at Volvo Car Corporation revealed, among other things, current collaboration in co-located teams to be heavily influenced by the social interaction between team members. Since formal meetings mainly included project leaders of various kinds, it quickly became evident that the sharing of knowledge and expertise to other team members fundamentally happened through informal channels.

The work highlighted that “knowing who knows’ is crucial for engineers regardless of location, since many problems and activities require contributions from other people with previous experience. As well, “knowing who to trust’ is of great importance when trying to solve ambiguous and unclear design problems, since engineers are forced to trust the opinions of colleagues rather than blindly trusting facts or documents. The findings from the study not only point to the potential for companies engaging in global collaboration to leverage from a collective social capital, but also to the important challenge to improve how social capital is built and maintained in global collaboration.

In another study focused on design reviews at Volvo Cars Corporation, the storage of decisions in a distributed meeting used a primitive notation*, “it’s not sophisticated, but it’s easy to use”*. In the meeting, documentation from the final design solution was saved, though the design rational behind the decisions was difficult to find.

4.7 Distributed Winter Testing

In 2004, a framework for distributed winter testing was implemented, tested and evaluated under realistic conditions in cooperation with a winter test company in northern Sweden and a car manufacturer in southern Sweden. By introducing a framework for distributed winter testing (based on distributed engineering tools combined with telematics), temperature data from a test vehicle could be visualised at another location 1,500 km away. Despite the distance, the car manufacturer could follow the tests in real-time, communicate interactively with high quality and collaboratively interact with test engineers situated at the test facility. The presented system enables a new way of working with winter testing of vehicles, where companies can simplify the testing procedures and get a quick response and understanding of the process. It was concluded by the test car manufacturers that this type of system could save time and travel and will be essential in the future.

4.8 DITRA

The EC funded DITRA project introduces methods and tools for distributed engineering in industry. The DITRA framework consists of eleven studios for distributed collaboration, located in northern Sweden. All studios are connected via broadband network. Different types of communicating are done between them; education, distributed meetings, distributed collaboration projects, etc. Researchers from Luleå University of Technology have been involved, primarily as users and as technical support for other users. The DITRA project has contributed valuable experience in creating the required infrastructure, as well as testing communication technology on a daily use.

Findings from the projects include the problem of having large distributed meetings; normally, all eleven studios were connected simultaneously for project meetings. These meetings are much more formal and the requirements for floor control and a detailed meeting agenda is much higher than meetings with two or three sites.

The DITRA project has also focused of the technical problems of collaboration software today, e.g. even experienced users may have problems connecting to other users, the collaborative environment is dependent on infrastructure, computers and hardware that influence the quality of the communication, and if one part fails there is often no redundancy and the meeting must be postponed.

5 Summary of findings

From the different studies described in section 4, some general conclusions are presented:

Complexity of tools; a general problem found in almost all studies are the different tools needed for global collaboration, all with separate advantages, user interfaces and limitations. The success of using collaborative tools depends greatly if the users are familiar with the technology and if the equipment (e.g. lightning, microphones and cameras) is adjusted properly; if not, problems can be difficult to locate and eliminate. Even broadband conferencing systems capable of high resolution conferencing with CD-quality audio can be ruined by using the wrong types of microphones or by acoustic feedback.

Natural communication; informal communication, brainstorming and prototyping are less common between distributed team members than co-located teams. These types of meetings seems much harder to support than meetings later in the design process where computer models, requirements, etc., exist and the meetings are well documented. In the DTI study, a design team consisting of members located in the USA and Sweden sometimes brainstormed together for several hours. But when following the same type of meetings of a co-located team, the meetings were much less formal and side conversations between team members were more common. To reach common ground users involved the telling of stories and an extensive use of indexical representations. When verbal language was not enough, gestures, chairs, sketches, prototypes and all possible types of objects to visualize and describe what they wanted to 'say' were used. The overall structure of the meeting was more fluid, though there was no interruptions due to technical problems, etc.

Physical artefacts; in many projects the use of physical prototypes or other physical artefacts were an integral part of the design process. In design discussions within the DTI-project, members of the design team made use of just about anything that could help them communicate their ideas. Prototypes were often used as a proof of concept and to facilitate communication, and visits to the workshops were used to clarify design issues.

Lack of collaboration; In many of the studied distributed projects, the project teams have been rather small and the total group of collaborators is often less than 10 participants; therefore, the influence of managerial and organizational problems has not been studied. Building and maintaining trust between members is also easier in smaller groups. When following large distributed projects in industry, this type of close collaboration is rarely the case. Many distributed collaboration projects are reminiscent of parallel product developments that are divided into different tasks. In complex projects, these tasks are designated to specialists groups often located in different companies. The cooperation between the groups is commonly restricted to only a managerial level. Design influence between groups is rather small, often restricted to the interfaces between the groups' respective responsibilities (i.e. a specific hardware component), where the teams have to agree on the interface design. The information flow between the design teams will thus follow the structure of the hierarchical organization where much information is filtered through the project leader, who may or may not be involved in the detailed design issues, thereby the sharing of knowledge and expertise between other team members are based on informal communication.

Documentation has been found to be a problem in most of the studies, systems for sharing documents are used, but finding documents is still difficult. At the same time there is an information overload when users are flooded with e-mails and attached documents that may be unimportant to them. Synchronous meetings and design reviews are often poorly documented; usually a short note with the issues discussed and decisions taken are documented from a meeting. The design rationale is frequently not documented at all. Creating documentation within a design process is often a joint work claiming to be collaborative, in reality usually consists of a sequential view and mark-up review process with very little personal collaboration [38].

6 Challenges for future research

One challenge is the development of tools and methods that support *true collaboration* within global design teams, where diversity and competences of the whole team can be utilized and where team members can *think together* rather then merely exchange information, opinions and divide work. Team members must be supported by new innovative collaborative tools that allow users to communicate with both formal and informal communication in a more natural way (i.e. as a co-located team communicates).

Many of today's tools have the focus from the technology standpoint, and force the user to work in a specific way. The technology focus – 'what can' approach takes the basis in integration and communication technologies, whereas the user focus – 'what needs' approach requires a deeper understanding and analysis of the information and communication processes. A typical example is video conferencing that supports communication between team members, but forces the user to work in a specific way (e.g. side conversation is not possible, eye contact is difficult to archive, and users should sit in one place and not walk around in the room). Challenges for the future work must explore what needs to be communicated rather than what can be communicated.

6.1 Automatic storage of information

By creating distributed environments that allow for transparent storage of information and events in the distributed engineering environment, the documentation burden is lowered. The information could, for instance, be used to create a shared design document after a synchronous collaboration session has taken place. By using a common framework for collaborative environments, where all events made in the distributed environment (e.g. all visualizations of models, viewed movies, viewed documents, decisions, audio and video from the conferencing system) can be stored, we can extend the reprocessability.

These types of tools can also be used for dynamic documentation, turning the documentation task into a parallel activity within the process to increase agreement and thereby decrease revision and time-to-acceptance.

Challenges for storing and reusing information and knowledge, to mention a few:

- *Reuse*: support the reuse of documents and other information.
- *Design rationale:* why a decision was made, understanding why people rejected certain solutions, why it did work, why it did not work, etc.
- *Reasons for design*: increase awareness of what you have learned, not only what you have produced!
- *Reprocessability:* i.e. how much a message can be re-examined or processed again within the context of the communication event. This can also be used in a learning process, and to quickly bring new team members up to "speed'.

6.2 Social connectedness and informal communication

Findings from the followed project revealed that the collaboration tools of today - broadband conferencing, shared applications and whiteboards - can support formal meetings to a certain extent, though supporting informal meetings and distributed social activities is still a very challenging issue. One key to success might very well be the ability to adequately support social connectedness between remote team members and thereby facilitate the informal communication processes that often arise spontaneously in between the formal meetings.

Challenges include:

- Creating a social connectedness and awareness of other users and processes.
- Support of informal communication in between formal meetings.
- Support for creating the social capital (knowing who knows and knowing who to trust) and finding the person 'behind' the e-mails and documents.

7 Conclusions

Although advances in broadband videoconferencing systems show promising results in sending and receiving 'hi-fidelity' audio and video across continents, there is still an immense potential for improvement when it comes to designing virtual and physical places where global design teams can collaborate in more 'natural' ways than existing distributed environments allow. By following several distributed projects, it has been shown that some types of meetings, such as formal meetings, design reviews with digital information, etc., can successfully be supported to a certain extent using advanced computer based collaboration tools and broadband connections.

However, there are still many challenges for distributed collaboration; from our findings some of the most important challenges are how to support informal communication within distributed teams and automatic storage and retrieval of information in distributed meetings.

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Peter Törlind, Polhem Laboratory, Division of Computer Aided Design, Luleå University of Technology,
SE-971 87 Luleå, Sweden, Tel: +46 920 492412, Fax: +46 920 99692, E-mail: Peter.Torlind@ltu.se,
URL: *http://www.cad.ltu.se/*

Paper D

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DEMANDS ON ENGINEERING DESIGN CULTURE FOR IMPLEMENTING FUNCTIONAL PRODUCTS

M Löfstrand, T Larsson , L Karlsson

Abstract

Industrial product development focused companies, such as car manufacturers, have traditionally developed and sold hardware products. In professional business-to-business relations, the integration of hardware and software with services has been identified as a shift in focus in the seller-buyer relationship from hardware development to function development and the way a sustainable economic performance could be achieved. Therefore, the common perception today of where the product is mainly *hardware only,* needs to be expanded to include a definition where it does not even *have to* have any hardware at all. Expanding the product definition therefore places additional demands on the design and development of hardware, software and services that may all be part of the functional product. Further, this article discusses how customer requirements need to be handled when developing a total offer in the form of a functional product. Finally, the traits needed in the engineer who is to develop it while being part of a multi-cultural team are discussed, possibly a geographically distributed team.

Keywords: functional products, engineering design culture, profit model, design model, manufacturing industry

1. Introduction

Industrial product development focused companies, such as car manufacturers, have traditionally developed and sold hardware products. Consequently, much literature has been published on the design of hardware [1], [2], [3], [4], [5], [6], [7].Literature also exists on the design of services [8][26] and management of services [9], [10]. Today, there is an increasing occurrence of software, control systems and electronics in hardware-based products. In professional business-to-business relations, the integration of hardware and software with services has been identified as a shift of focus in the seller-buyer relationship from hardware to function and the way a sustainable economic performance could be achieved, Edvardsson et. al. [11]. Brännström [12], [13] calls this integration of services ‘Functional Products’ (FP). This paper focuses on whether or not developing functional products involves a shift in how traditional engineering design activity will be carried out, and on what aspects of the traditional engineering design culture should be modified due to FP thinking.

2. Background

As always, demands on product development are ever increasing [14], e.g. reducing lead-times, increasing quality and decreasing cost.

Until a few years ago, the industrial experience that shaped the inherited ideas, beliefs, values and knowledge of today's manufacturing companies has been characterised by the idea of selling a hardware product that should function past the guarantee date. By introducing functional products, the idea is to sell a product optimized for its use, so that in essence the product, from the customers' point of view, becomes the service itself. Therefore, the common perception today of where the product is mainly *hardware only,* needs to be expanded to include a definition where it does not even have to have any hardware at all. This expansion of the product definition therefore places additional demands on the design and development of hardware, software and services that may all be part of the functional product (See Figure 1).

Several Swedish companies have expressed an interest in functional products [15], among them Volvo Aero Corporation, Hägglunds Drives AB and AB Sandvik Coromant which are subjects in this research. These three companies are all part of the Polhem Laboratory. Additionally, Fransson [15] identifies two more Swedish industrial companies, SKF Service AB and Ovako Hofors, as being interested in functional products.

3. Methods

This paper concerns research carried out at three Swedish companies with global customers, including Volvo Car Corporation (VCC) and Volvo Aero Corporation (VAC). In 1999, Volvo AB was composed of numerous companies creating the Volvo Group, as in the spirit of corporate diversification [11]. Hägglunds Drives AB is a medium sized company that supplies complete hydraulic drive systems and a long time partner company at the Polhem Laboratory, as well as having been involved in several research projects and interested in the idea of functional products for some time.

The differences between the current R&D management of the three companies are explored by means of some 40 interviews [16] averaging 1.5h each. The interviews included questions concerning previous, current and potential future engineering design practices, products, and processes and the different ways the companies create their competitiveness. The interviews took place over several years, and were printed and fed back to the interviewees within two months after being taped to verify the accuracy of the authors' interpretations.

Other methods used were document search, literature studies, continuous dialogue with the engineers, notes from project meetings, project meetings, dinner discussions, etcetera [17].

The authors are members of the Polhem Laboratory [18], a competence centre together with 14 companies including VCC and VAC, i.e. the knowledge of these companies is the result of numerous years of cooperative research. The objective with exploring the differences in R&D management is to identify aspects of engineering design culture that are or should be modified to implement a functional product philosophy.

4. Functional Products

Results indicate that the reasons for a company to be considering development of fuctional products are resources and not being the sole market leader. If not all rescores are available to do it alone the need arises to become the best partner in a partnership and therefore to optimise the available resources to the benefit of the partnership. In that partnership risk and profit sharing will be concepts of importance.

The development of a total offer currently thought to be a functional product, overlaps a number of research areas, including Integrated Product Development, Engineering design, Modelling and Simulation, collaborative work, Industrial Organisation, Business Management and Law. The term "Functional Products" refers to a product that might be sold as a function instead of simply hardware, software or services. This is one of several possible ways to sell what Nordström & Ridderstråle [19] term a total offer, including both tangible and intangible assets such as knowledge, financial offer, service deals, etc.

Brännström et.al. [12] defines functional products as hardware plus software plus services. In this paper we choose to define Functional Products as: *A product, not necessarily a physical artefact, consisting of any combination of hardware, software and services, being sold for the purpose of supplying a function. Thereby meeting all agreed upon needs of the partner whose primary role is that of a customer.* (Graphic description in Figure 1)

In our opinion the added value in this definition is that it is flexible in terms of composition of hardware, software and services. It indicates a partnership between seller and customer and it focuses on the sale of the product as important for the product to be experienced by the customer as a *functional product*. Finally it focuses on customer satisfaction according to agreement.

Meeting the individual need of the customer whenever needed is an underlying idea of design for functional products. Providing a certain function is a way to meet that need, such as "*torque per hour*", "*power by the hour*", "*365 days a year*" or "*distributed collaborative work environment at need*". In many current discussions the least common denominator for the definition of a functional product is "*improved performance through available ability*". Fundamentally, it all comes down to describing functions instead of solutions. Looking at the hardware domain only, the function torque can be realized by several solutions such as hydraulic or electric motor, human power, etc. In the FP domain a functional demand can be realised by a combination of hardware, software and services rather than only by hardware. Additional constraints outside the functional description or demands on the solution space from the buyer have to be explicitly stated.

Functional Products consist of hardware, software and services, where the software is possibly integrated with the hardware when appropriate, as defined by Alonso-Rasgado et. al. [20]. Hardware includes, for example, a motor, a truck or a computer, all of which have been traditionally sold for years. Due to the developments of recent decades, hardware itself often includes software to a certain and varying degree, e.g. a modern truck. In this discussion we shall continue to call this hardware. However, software has also been sold "as hardware" for years and is included in a growing number of products. Services, (one of which is the "traditional" service) can include service, condition monitoring etc. Only then is a Functional Product being offered.

Such an offer may consist of:

- Variable rotation
- Transportability (Air, rail, sea, road…)
- Distributed interaction ability (Communication, work, experience, care…)

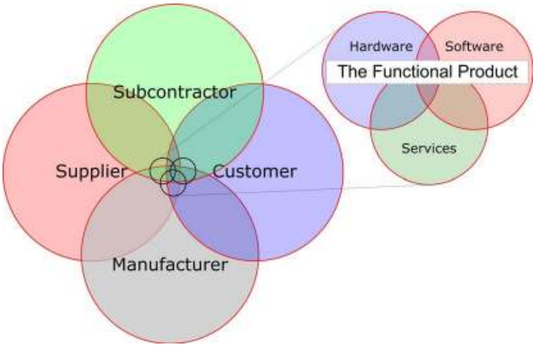

Figure 1: Two views of the functional product, business or communication view (left) and product view (right). Cooperation concerning functional products creates a wider partner network than what was in use previously.

The literature lacks any description of how to handle hardware development for functional products from the engineer's perspective. The assumption (as described in Figure 2) is that the service intensive nature of functional products will create new inputs (needs) into the IPD process, which should somehow be transformed into a requirements specification to be dealt with in the engineering design process.

These demands originate from the fact that a Functional Product strategy in an engineering design culture requires an increased recognition of the hardware as a contributor to the offered functionality and a decreased importance given to the hardware as the unique externalisation of the offered product.

4.1 New inputs for the hardware IPD process

Many new inputs for the hardware IPD process may be created. Some of them may be ownership, education, intellectual property rights, etcetera. Those discussed in this article are the concept of services, customer requirements and the continued industrial focus on reducing lead-times, increasing quality and decreasing cost. Based on the interviews in this study a model of assumptions for functional product success in industry was developed, see Figure 2.

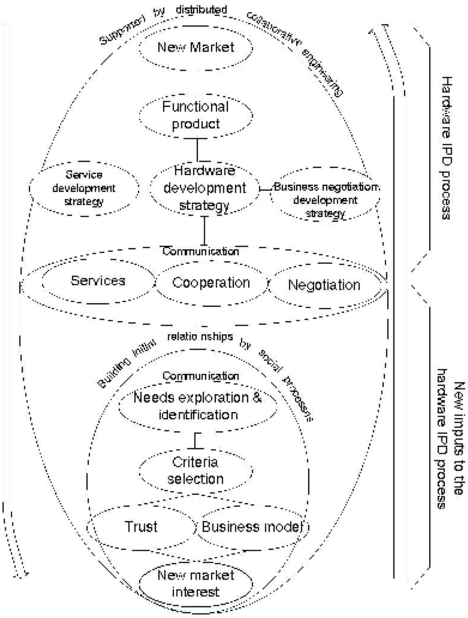

Figure 2: A model of assumptions for functional products success in industry.

Starting from the bottom of the figure with a new business interest, which of course is the basis for any interest in functional products for the designing company or companies. When attempting to set up a case study involving a number of companies, it became apparent that a business model needed to be developed to cover the cost of development, The issue of trust was apparent since both companies were reluctant to open up when it was evident that to get to the positive effects of a functional product, one needed to reveal some sensitive internal material. Criteria selection for selecting what product is possible to develop was next, followed by needs exploration and identification together. This process will probably be rather long before simulation methodologies have been developed, which may create increased accuracy of predicted outcomes of design concepts.

Next, there is the need to understand that communicating needs in terms of services requires cooperation, an understanding of each company’s goals and a possibility to negotiate these goals at a managerial level. However, even as early in the development process as here, it would be useful to integrate several company functions (Market, Design, Production) when negotiating to an even larger degree than what is suggested in previous literature.

One issue of the concept of functional products is that most industrial companies have existed for a relatively long time and therefore have a long tradition in developing products; this gives rise to both a useful practice and a potentially restricting Product Development (PD) tradition. Changing from hardware to functional sale requires a culture change in a multi-cultural environment of functional product development.

A starting point for discussion concerning functional products as a whole is: hardware development becomes more important in terms of the functionality of the product (which absolutely *must* be according to agreement) and decreases in importance in terms of perceived product value. Behind this lies the fact of new business drivers described in Figure 3 below. Figure 3 also tries to show how we might expect to see other business drivers in the future. A suggestion is that the business environment will continue to change with functional products being the current, but not the final business interest. Just as companies still develop and sell hardware, functional products are one of the ways to develop and sell something. Hence, we are likely to see a continued evolution of the product offer. For example, Swedish technology foresight [21] discuss societal change leading to such changes. As suggested from Figure 3, the next phase might be the “Lean Society”. Womack, Jones & Roos [22] discusses elements of lean production, possibly supporting the “Lean society” [23]. The possibility of a future in a lean society, where instead of working as much as possible for the customer, companies work as little as possible, using as few resources as possible, to supply the required value for the customer. In this study the lean society was identified by some interviewees at Volvo Aero Corporation.

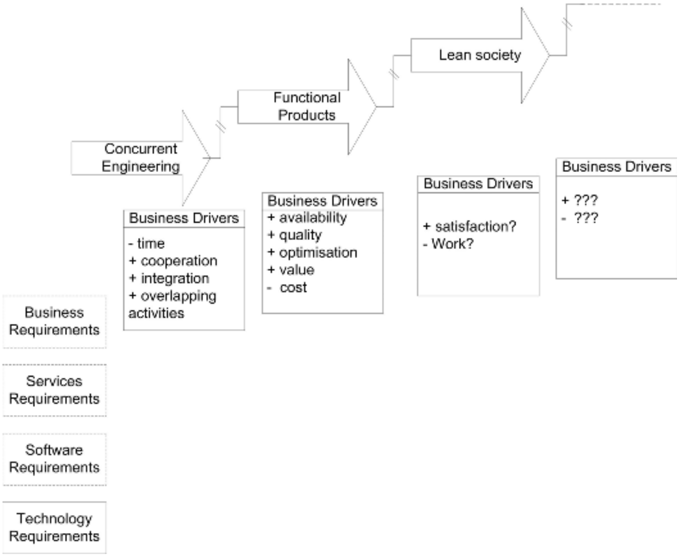

Figure 3: The changing nature of the business environment

In addition, if the offer is developed in cooperation between a number of companies in a network of interdependencies working in a ”virtual enterprise”, a situation that is becoming more and more common, this increased external collaboration will increase accordingly. Figure 4 below attempts to describe how process integration in networks will be more and more common as we move towards the development and sale of function based products.

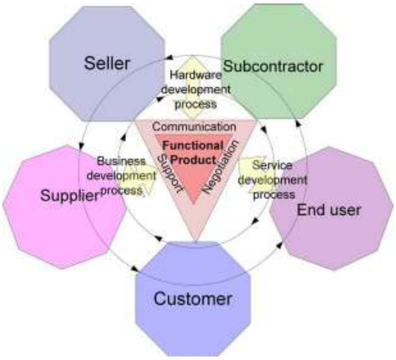

Figure 4: Process integration in networks for functional product development

4.2 Implications of services for hardware development

Gadrey [24] sees services as the bundling of capabilities and competences (human, technological and organisational) to organise a solution for the customer. The concept of Functional Products indicates risk and profit sharing rather than regular sales to be the basis for the total offer or new business deal. Therefore, a Risk Diagnosing Methodology such as that proposed by Keitzer et.al. [25] will become increasingly important.

According to Cooper & Edgett [26] four main characteristics of services exist:

- Intangibility
  "*Unlike [tangible] products, services have no physical form*"
- Inseparability
  "*The act of supplying a service is virtually inseparable from the customer´s act of consuming it.*"
- Heterogeneity

  …"Services on the other hand, generally are never delivered the same way twice. … "

- Perishability

  "Unlike tangible products, services are produced at the same time they are consumed."

Edvardsson et.al. [27] draw similar conclusions.

Cooper & Edgett [26] identify three cornerstones of performance for effective new service development: product development process, new service strategy and resource commitment, as described in Figure 5 below.

Figure 5: Cornerstones of performance for effective new service development

Abrahamsson & Eriksson [28] offer a comparison between sales offers of goods and functions (See Figure 4 below).

	Goods	Functions
Ownership	Buy	Rent
Responsibility	Short term	Long term
Structure	Informal	Formal
Price setting	Cost based	Value based

Figure 6: A comparison between sales offers of goods and functions

Since the total offer (using Brännströms [29] nomenclature) is value based according to Abrahamsson & Eriksson [28], investigating which product is going to supply the value and what kind of customer requirements are typically applied in the product development of today is necessary.

The importance of listening to the customer has been identified by many engineering design researchers, including Clausing [30] in his discussion "voice of the customer". The voice of the customer is described by Ullman with seven types of customer requirements [31]:

- Functional performance (flow of energy, flow of information, flow of materials, operational steps, operation sequence)
- Human factors (appearance, force and motion control, ease of controlling and sensing state)
- Physical requirements (available spatial envelope, physical properties)
- Manufacturing requirements (materials, quantity, company capabilities)
- Life-cycle concerns (diagnosability, testability, reparability, cleanability, installability, retirement)
- Resource concerns (Time, cost, capital, unit, equipment, standards, environment)
- Reliability (MTTF, reliability)

What new inputs does the service perspective create for engineering activities?

4.3 Ownership of customer requirements

The sale of a total offer is hypothesized to be based on some type of hardware for the foreseeable future. Supplier and customer need to develop a way of negotiating, what Ullman calls customer requirements. However, either partner must take additional responsibility for his subset of the requirements. Any kind of offer is value based, though a total offer being primarily value based rather than secondarily (as a traditional hardware offer where the customer buys a hardware and thereby value) will affect what type of customer requirements are needed for the customer to specify; those being suggested are functional performance, reliability and some human factors and physical requirements. The other requirements should be (mainly) the responsibility of the supplier to handle.

Morelli [32] discusses related questions concerning product/service systems and raises the question of 32 methodological implications for designers, such as *"What are the tools available to designers for the purpose of analysing PSS as a social construction?", "How can designers manage the different phases of design and planning activities?", "How can designers represent material and immaterial components of PSS?"*.

The formal nature of function sales creates the need for the supplier and customer to have some degree of insight into each other’s value creating process, without getting information about the others core knowledge. This may be handled differently. One could for example:

- Build personal trusting relationships on and between each level of communication
- Create written legal agreements for every conceivable situation
- Create a common understanding between all necessary people through common communication channels only, e.g. taking, e-mail and written project descriptions and project briefs.

4.4 Industrial focus

The continuing industrial focus on decreased lead times creates a situation where industrial long-term goals are sometimes set six months rather than six years in advance. Such a focus is suggested to not always be beneficial given the long term nature of functional product development. Figure 7 below describes the effect on the individual engineer of the increasing production and lead time focus.

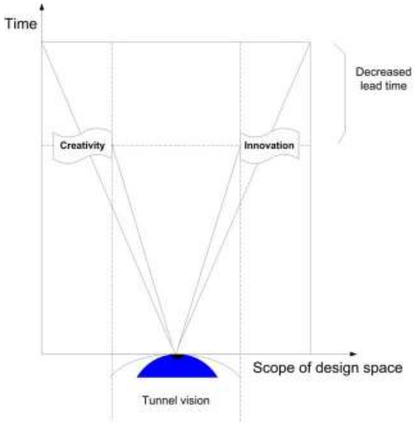

Figure 7 Increasing time and production demands tunnel vision

When increased production at a higher rate is a goal, one experiences an increased degree of stress which at some point becomes severe enough to hinder people from everything but producing against the clock. At some time in this process the ability to be creative and innovative diminishes. To keep long term goals in mind is also problematic when stress levels are high regarding meeting short term goals. The long-term nature of function sales creates reasons to actively work and keep partner relationships and on the technical side, points to the importance of creating flexible technical solutions, maybe for the next 30 years in some cases. To build the best socket one can afford so that the product may be easily updated in the future.

Abrahamsson & Eriksson [28] raise the question of how the customer defines value. The term “customer requirements” indicates an obvious definition of the customer. These discussions become more complicated considering that the customer and suppliers might very well have co-dependencies between one another so that it becomes difficult to identify where one partner is the customer or the supplier.

These issues point to the increased importance of customers focusing on function requirements (at least in the initial specification), for example: “we need a specific amount of

Nm/(h, rotation)" or "we need a specific amount of Ton/km". Ton/Km is a term sometimes used in logistics, but during the sale of a hardware product the most common way for a customer to specify their needs is to specify the technical solution. For example, "We would like to buy your motor including a brake and it should be capable of … "

Functional Products is a large, encompassing area and the authors do not claim to handle all parts of it. Our starting point is engineering design theory for hardware development and modelling and simulation within this domain which are broad areas in themselves. The decision forward for engineering design and modelling and simulation with respect to functional products is to create different aspects of a knowledge management system that can handle simulating an increased number of business processes, design iterations in CAD programs, as well as low level simulations supported by simulation development projects. Figure 8 schematically describes such a system.

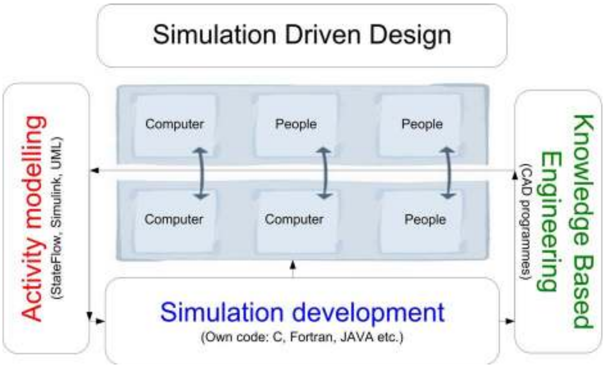

Figure 8: A schematic representation of a simulation support tool for functional product development

Because of long traditions in industry as well as academia there are systems in place to develop hardware. A simulation support tool is one of the ways a system for development of functional products could be designed. This simulation support tool may be used to create a negotiation platform within the extended enterprise along with a common understanding between the people in question. The simulation support tool would consist of three layers, each communicating different types of data in three layers (computer-computer, computer-people, people-people) from essentially the same source. At the top level (Activity modeling) business decisions and design process occurrences as well as services would be modeled. At the second level (Knowledge Based Engineering) hardware design decisions and economic effects would be modeled. At the lowest level (Simulation Development), simulation of mechanical processes would be carried out. This system would be supported with work concerning new improved ways to do simulation.

All of these system layers would communicate and relevant information would be presented to each company function when needed, for example: A barrister, a business manager and an engineer would have access to effects of presidential decisions concerning redesign of a product in the line-up. The barrister would see suggested needed changes to the standard sales contract, the business manager would see effects on needed sales volumes and the engineer would see effects on geometry and other physical properties.

5. Cultural change

Some of the many definitions of Culture are introduced below [33]:

- Culture is symbolic communication. Some of its symbols include a group's skills, knowledge, attitudes, values and motives. The meanings of the symbols are learned and deliberately perpetuated in a society through its institutions.
- Culture is communication, communication is culture.
- Culture is a collective programming of the mind that distinguishes the members of one group or category of people from another.

Hence, defining how to change the engineering design culture at hardware producing industrial companies or elsewhere is not easy. We choose to use a combination: *communicating changes to collective skills, knowledge, attitudes, values and motives of a group of people.*

The traditional culture of engineering and engineering design in the three studied companies (Volvo Cars Corporation, Volvo Aero Corporation and Hägglunds Drives) is to a varying degree, still traditional. In the case of Volvo Cars the interviewed engineers still do not operationally cooperate over any more departmental borders than necessary, engineers from one department cooperate with engineers from other departments mostly when the need to share a volume or design space in the car arises. Other interdepartmental cooperation is carried out by groups of department managers and their support staff. Not surprisingly they have had little thought on designing functional products. Hägglunds Drives, a long standing, well-appreciated member of the Polhem Laboratory, sells total drive solutions somewhat alike to functional products. Hägglunds Drives were informed of the work concerning functional products almost since its inception in 2000. The engineering department at Hägglunds Drives is small compared to Volvo Car Corporation and Volvo Aero Corporation, and is therefore easier to get an overview of the corresponding departments at Volvo Cars and Volvo Aero. Hägglunds Drives do all of their product development in-house or in some cases in close cooperation with some trusted consultancy firms. Volvo Aero Corporation supply jet engines to the Swedish Air Force and civilian aircraft manufacturers. They have a significant interest in the development of functional products as requirements on their increasing ability to take system and life-cycle responsibility. They are currently working towards becoming a service provider as well as a hardware developing company.

Values and attitudes

Delimitations on an engineering project occur due to a wide range of related domains or company functions, e.g. Economics, Marketing, Support, Production, etc. These constraints have always been partly invisible to the individual engineer. Commonly, most engineers are not as interested in the non-technical constraints as they are in those purely technical, though non-technical constraints (such as material and production costs, volume, etc.) often have a greater effect on the project. It seems as if the non-technical constraints are experienced as newly imposed or additional, though they have always existed. Being aware of and being able to handle these other constraints will be the way forward. Engineers may no longer be hampered by monetary constraints, but should be able to use them to their own advantage. Only when handling all pertinent constraints will an engineer have created the largest design space possible for himself in a development project. He will have a chance to decide what to do within a known frame. If not, somebody else will tell him what to do or even suggest technical solutions based on invisible constraints and this while probably not having the right education to do so.

Figure 4 puts additional focus on the importance of customer/partner relationships, Communication in general, and especially between service development, business development and hardware development strategies.

Engineers working on developing functional products must also learn to value the limitations originating in non-technical domains. The only way to maximise your design freedom as an engineer is to be aware of all limitations; if not, the existing hidden ones will make maximising the project output harder. Hence, engineers being aware of economical, law and other issues not commonly associated with today's engineering will be in higher demand for total offer development. Other issues that arise will be how to handle the expanding professional vocabulary and creating ways of producing and managing the information flow.

Knowledge and skills
A conclusion from this work is that engineers working on developing functional products must have knowledge to identify, value, and be skilled in handling a diversified group of project constraints and have knowledge of what constraints exist for a given project to a greater extent than today. Additionally, they must be able to handle these constraints in cooperation with business development personnel.

5.1 Challenges for future research

Companies interested in adopting a functional product strategy require a profit model to understand the processes by which this type of product concept can actually guarantee sustainable economic performance. Paradoxically, this profit model is hard to create without knowing how engineering design is affected. For this reason, we believe that the way to approach the problem is by verifying the design and profit models in several loops.

One way is to create several levels of simulation tools, by simulating the information exchange between people involved in the business negotiation process and hereby map the "business negotiation flow", allowing for the possibility to find parameters that affect a deal. One level is where one simulates changes to the hardware design by a rule based knowledge management system. The third level may be where one simulates lower level operations such as welding with the help of the Finite Element Method or optimization of flow by deploying methods for Computational Fluid Dynamics.

The development of functional products increases globalization because resources in terms of personnel and company functions are distributed in the business-to-business environment that is the main arena for functional products. Additionally, these personnel have a diverse professional vocabulary and different, varying needs that need to be communicated over large distances, preferably in real time. Hence, improved methods for distributed communication to support these issues need to be developed, to a degree where they are user friendly and as functional as a normal telephone. Additionally, these needs will need to be filtered and presented to different personnel so that they support the multi-facetted approaches to work of many different company functions.

6. Conclusions

This paper started out by challenging the engineering design activities we take for granted today. Certainly, the formal and the long term nature of total offer development create a number of new inputs for the product development process. The current focus in industry of faster, better, cheaper has been brought forward as a reason to increase the predictability of future design concepts and do it much faster than today, for successful functional product development. *New integrated tools* for three levels of simulation have been suggested as a way to solve these issues. The effect for today's functional product development engineer is that there is an *increased contact area* between the traditional engineering design teams towards other departments, customers, subcontractors, etc. Therefore, *the composition of the design team should be updated to multi function design teams to cover a wider range of company functions*. Being aware of and able to *handle technical and non-technical constraints* will be the way forward. Only when handling all pertinent constraints the engineer will have created the largest design space possible for himself in a development project.

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Magnus Löfstrand, The Polhem Laboratory, Division of Computer Aided Design, Luleå University of Technology, SE-971 87 Luleå, Sweden, Tel: +46 920 493874, Fax: +46 920 99692, E-mail: Magnus.Lofstrand@ltu.se, URL: http://www.cad.ltu.se/.

Paper E

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Functional Product Development Challenges Collaborative Working Environment Practices

Magnus Löfstrand
Division of Computer Aided Design
Luleå University of Technology
SE-97187 University Campus, Luleå, Sweden
Tel.: +46-920-493874
Fax: +46-920-491399
E-mail: Magnus.Lofstrand@ltu.se
Web page: www.cad.ltu.se

Abstract. *Developing service-laden products in a virtual extended enterprise implies a wider distribution of resources and product development (PD) team members than what is the case today. In this setting, the challenge is getting a cross-disciplinary distributed team to collaborate effectively over distance using not only the tools available today, but also new tools and approaches. One such activity-based approach, based on an actual Volvo Aero service-provision process, is presented in this article. Supplying a physical product as part of a service contract within an extended enterprise demands increased speed and quality of the predictions the supplier wants to make in order to keep track of the product functionality, its cost effectiveness and lifecycle cost. One approach that has been proven in engineering is modeling and simulation, here implemented as activity-based simulation of an actual industrial work process that provides a maintenance service. The activity-based simulation approach is realized in the industry standard simulation environment MATLAB. It is created as a demonstrator of one of several future tools that may help a virtual extended enterprise to face the challenge of supplying function or services to the customer more effectively. Conclusions regarding Collaborative Working Environments include new requirements on quality of tools for supporting functional product development regarding knowledge availability, usability, security and interoperability. Conclusions also support the suggested approach concerning development of distributed, modular activity-based process simulation models as a suitable approach for supporting functional product development.*

Keywords: *Globalization, Strategic Alliances, Cross-functional Teams, Optimization Methods, Collaborative Work*

Functional Product Development Challenges Today’s Collaborative Work Practice

This paper discusses demands on Collaborative Working Environments (EC, 2005) (CWE) originating in companies’ transformation from hardware providers to function providers. An activity-based modeling and simulation approach to Functional Product Development (FPD) is suggested as part of a simulation-driven CWE approach to meet the new demands that are placed on tools and methods used in industrial product development due to this transformation.

A shift in view, captured in the concept of functional products, is found within the manufacturing industry. Traditionally, the manufacturing industry has focused on providing excellent goods, i.e., hardware. Services occur on an aftermarket, as add-ons to the developed hardware, and much of the profit is made on activities such as maintenance and spare parts. Nergård (2006) indicates that competition has increased in the manufacturing industries’ aftermarket activities; one trigger for the concept of functional products according to information from the case discussed below is seen in the interest to control aftermarket activities associated with the developed hardware. By supplying functions, with hardware components as the core product, instead of merely selling the hardware, companies can control the aftermarket. The responsibility and availability of the functions provided by hardware remains with the service provider, as does the responsibility for maintenance and spare parts. This approach is a response to a necessity for business-to-business collaborators to gain economy-of-scale partnerships in the extended enterprise and ultimately to be able to develop competitive offers, as discussed by Löfstrand, Larsson & Karlsson (2005) and Alonso-Rasgado, Thompson & Elfström (2004) Hence, the shift in view is a move towards providing services while taking a lifecycle commitment for the hardware as well as optimizing the availability of its function in the customer’s system. The redirection from hardware development to a process where the development of functions, comprised of hardware, software and services, or total offers is in focus is hereafter referred to as Functional Product Development (FPD), an area in which technology processes (hardware) and business processes (service add-ons) merge. The function provider needs some partners to act as sub-function suppliers in an extended enterprise fashion. Based on information from the workshops discussed below, this calls for closer collaboration than what is normally the case in a project aimed at hardware development only. Different team members with different functions (e.g., engineering design, production, management, finance and marketing) must be able to share relevant function-specific information while doing distributed collaborative work. O’Donnell (2005) suggests using an approach based on systems thinking for handling business models. This might be carried out by team members in management or economy-related roles.

Product development literature provides a broad view of how to understand customer needs, develop and sell products and includes discussions concerning best practices, (Ulrich & Eppinger, 1995; Wheelwright & Clark, 1992; Cross, 2000) For example, Smith & Reinertsen (1997) offer a general view and aim to describe methods for generating a product (hardware or service) to meet customer needs. Within the hardware product development domain numerous tools have been developed to support the creation of excellent goods; Computer Aided Engineering for geometric representation (LaCourse, 1996) and Finite Element Method for stress calculation. Typically, this work has been about making knowledge explicit and expressible and support tools have over time been developed to aid the creation of the hardware.

On the business side, tools and methods exist for managing the kind of knowledge that is typical for this domain (Porter, 1998; Shostack, 1987; http://www.valuebasedmanagement.net/). Related tools sometimes include functions for project planning and project coordination. Some consist mainly of document templates (http://www.envision-sbs.com/business/index.html). Business-related methods include Total Quality Management, Business Process Reengineering and Process Management. These methods, according to Nilsson (1999) correspond to the second level of development work – organizational development.

It becomes necessary to develop tools and methods for effective and efficient optimization and simulation of future hardware-based services, one way of minimizing the functional product's total lifecycle cost (Boart, 2005).

This paper discusses an activity-based modeling and simulation approach to the FPD process where hardware development activities are combined with service activities in an FPD simulation system. The simulation system is realized in the industry standard simulation environment MATLAB (http://www.mathworks.com/products/matlab/). The approach both challenges and provides new opportunities for distributed collaborative work. A wider distribution of resources and people constitutes the main challenge. This requires an increased need for communication and collaboration between participants. No discipline has a single best tool, which complicates distance collaboration where many tools must be distributed, some of which are not known to all participants. The opportunities include being able to better predict the function and cost of one's development process, which is a prerequisite for daring to enter into business deals where supplying function is a main ingredient. Many approaches may be used to meet the challenge of functional products. They include business process re-engineering (BPR), customer relationship management, marketing, etc. Tinnilä (1995) has reviewed some of the literature concerned with business process re-engineering. He notes that Davidson (1993) sees that the objective of BPR is usually the optimization of a single process rather than transformation of the enterprise itself. Modeling a single process is the approach has been used for this article. Danesh & Kock (2005) discuss the benefits of using models, as described by Sharp and MacDermott (2001). Modeling is used here, since models are relatively quickly created, safe to manipulate and may allow clarification of non-physical activities of the actual process. Modeling and simulation have long been used in product development research to *verify* a hardware design and are here suggested for the company internal purpose of clarification and optimization of process activities. Since the MATLAB models introduced here are executable and create simulation results, they also allow for work process *predictions* and process *optimization* which may be used externally, for example in business-to-business negotiation. Additionally, models are suitable for remote collaboration, more so because of the modular structure approach used during development. Hence, while modeling in general is not a new approach, to apply it in order to optimize a work process is novel in the field of engineering design and an attempt to allow distributed collaboration through models with a simulation driven approach.

The purposes of the research presented in this article are:

- To identify challenges for distributed collaborative work practices when working with FPD.
- To demonstrate the potential of event-driven simulations of work processes, for supporting distributed collaborative work in functional product development. The demonstrator is based on a case from the aerospace industry.

Based on the need to increase the predictability of design process outcomes, the research question was formulated thus:

“How is distributed collaborative work affected by functional product development?”

The Rationale for a Simulation Approach

Many variables affect the effectiveness and efficiency of the design process (Löfstrand, Larsson & Karlsson, 2005) Identifying how these variables interrelate is crucial for developing adequate models. By applying a simulation rationale in a lifecycle manner and with the idea of simulating not only the hardware but also the service components, the FPD simulation system is achieved, based on the notion that almost anything that can be described can be modeled, simulated and optimized with respect to a desired state. Since the right choices, depending on cost, profit, etc, are desired before any investments in manufacturing and production are actually made, a primary concern is to predict any lifecycle commitment as early as in the concept phase of the development process.

Functional product development may be seen as a response to needs arising in an increasingly globalized market. Here, business-to-business collaboration to gain economy-of-scale partnerships in the extended enterprise is necessary. This has led to an identification of the need to increase the predictability of design in relation to business scenarios.

Given the right variables, activity-based process models may be used to:

- Identify process bottlenecks in collaborative work processes.
- Create material for go/no-go business decisions and causal development decisions.
- Support decision-making by improving the capacity to predict if and by how much a suggested business offer is lucrative.
- Create structures and interfaces which may serve as tools upon which to base discussions in an increasingly cross-functional design team.

These tasks are especially important in the extended enterprise during FPD and must be possible to perform effectively and efficiently over distance in a distributed collaborative environment. This approach is an attempt to identify the design space for the functional product development team member and to alleviate the need for communication, thereby freeing time for more design iterations, producing more concepts and creating better results.

DATA GATHERING AND ANALYSIS

The research within which this article has been developed includes ongoing investigations with about 10 interviewees at Volvo Aero Corporation concerning their product development practices and goals. Much of the work was carried out during three week-long visits to Volvo Aero, where the researcher observed the daily work and was welcomed to develop a suggestion for improvement concerning how Volvo Aero responds to customers' requests for service provision. The project also included opened-ended interviews (Yin, 1994), document analysis of formal work-process descriptions, archival records, and subsets of what Volvo Aero Corporation calls their Global Development Process or GDP. This first led to the identification of the corresponding process in the Volvo Aero GDP, a hardware-based process for service provision. The information was collected through field notes on a laptop computer when the researcher more or less participated in daily work or interrupted daily work to ask questions. In some cases, formal interviews were recorded. Between visits to Volvo Aero the data was interpreted and modeling was carried out. The information given by interviewees and the researcher's interpretations thereof were then discussed with other Volvo Aero personnel (aside from the interviewees themselves) regularly during the week-long visits, during quarterly project meetings at the university and at Volvo Aero.

In parallel, during the course of 18 months, the researcher's division and Volvo Aero were heavily involved, with other industrial and academic partners, in the planning and formulation of the strategy of the Faste Laboratory – Centre for Functional Product Innovation. During the course of the work, several meetings were held; during these meetings, future challenges concerning Functional Product Development, Simulation Driven Design and Distributed Collaborative Work were discussed; since they are the cornerstones of the Faste Laboratory.

Results from Interviews and Workshops

The information given by interviewees and researcher interpretations thereof were verified through taped interviews with the five most important informants, including the main industrial advisor.

Results indicate that collaborative work will continue to be increasingly distributed. As a consequence, doing research here will require identification of new user needs, evaluation of existing tools and development of new approaches and tools rather than developing technologies for supporting current practices only. The main results from the interviews and workshops follow.

- New distributed tools for CWE are needed to merge the business simulations and hardware-based functional simulations to create a simulation-driven holistic approach to FPD.
- These new tools must be used in an increasingly distributed fashion.
- Tools for distributed work must be simple enough that anybody with little computer skill can use them for communication and collaboration.
- Feedback from the tools needs to be appropriate for the user needs in the specific scenario and may therefore be varied. Different settings would be preferable: fast

and relatively inexact (a minute), yet useful; or slower (20 minutes) but more exact simulation results in terms of data maturity or degree of probability.

- One cannot assume that current CWE practices will suffice to support distributed cross-functional teams developing functional products.
- Effects of distribution of the simulation model and results include need for:
    - Managing intellectual property rights
    - Development of access control technologies to enable black-box simulations and preventing reverse engineering.
- Drivers for industrial FPD interests include: decreasing the competition on the aftermarket, sharing risks and therefore also profits within the extended enterprise.
- Functional Product Development requires closer collaboration, between more disciplines, than what is mostly the case today.

Danesh and Kock (2005) make a case for the importance of placing focus on communication flows rather than on activity-based flows only. In the work leading up to this article it was always necessary to monitor dialogues and to do retrospective studies of communication paths in order to find out what activities people carried out. This is schematically described in Figure 2, below. A main result is the development of a scenario for service provision, which the activity-based simulation models are supporting. The final main result is the developed process for service provision based on an actual hardware-based industrial process. This process is schematically described in Figure 1 and Figure 2 and is included as a component of the scenario.

THE SCENARIO

In order to show the benefits of the simulation-driven CWE approach a business scenario is created, anchored in the company needs. The scenario is based on a need for predictions concerning company performance that are much faster and more accurate than today's. The changing business demands require that a simulation which today takes two weeks will in the relatively near future have to be done in less than a day. Being able to supply a hardware-based service to a variety of customers is a driving force behind this development. These services include welding, milling, drilling, heat treatments and various types of written instructions, among others.

The work process that is discussed in this article is schematically laid out in Figure 1, below. The process consists of a selection of blocks that correspond to sets of related activities. Through modeling and optimization of the process, based on the available manpower and the cost of this manpower, the corresponding model delivers an indication of which business alternative is best for the company to suggest to the customer; to carry out line one, line two or line three. The approach suggested herein also allows for optimization of the selected line.

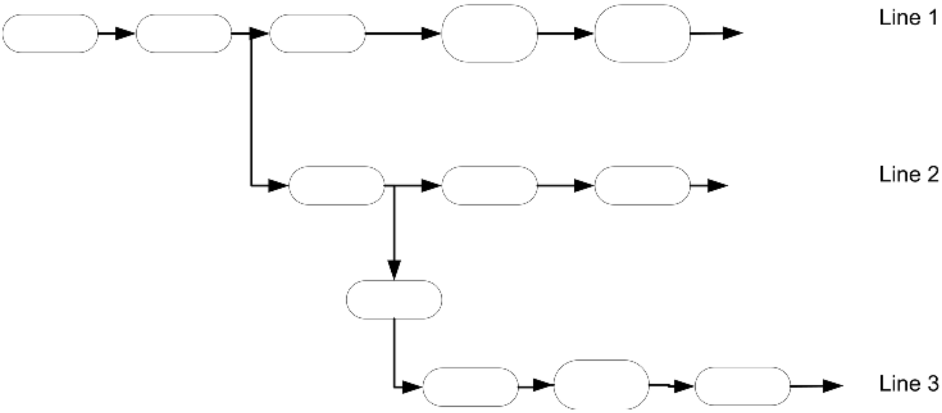

Figure 1: A schematic layout of the studied process.

Activity-based discrete event simulations as well as dynamic, deterministic simulations are built on sets of rules. The rules used for developing the event-based model discussed here are mainly based on the necessary activities for performing the service. Creating a first version, the demonstrator model requires knowledge of internal aspects such as which capacity, when, for how long and to which cost. Finally, one must have some idea of external aspects such as what customer value is achieved and the risks involved. This becomes important when negotiating issues concerning, for example, profit margin.

A procedural view of the studied process is described below in Figure 2:

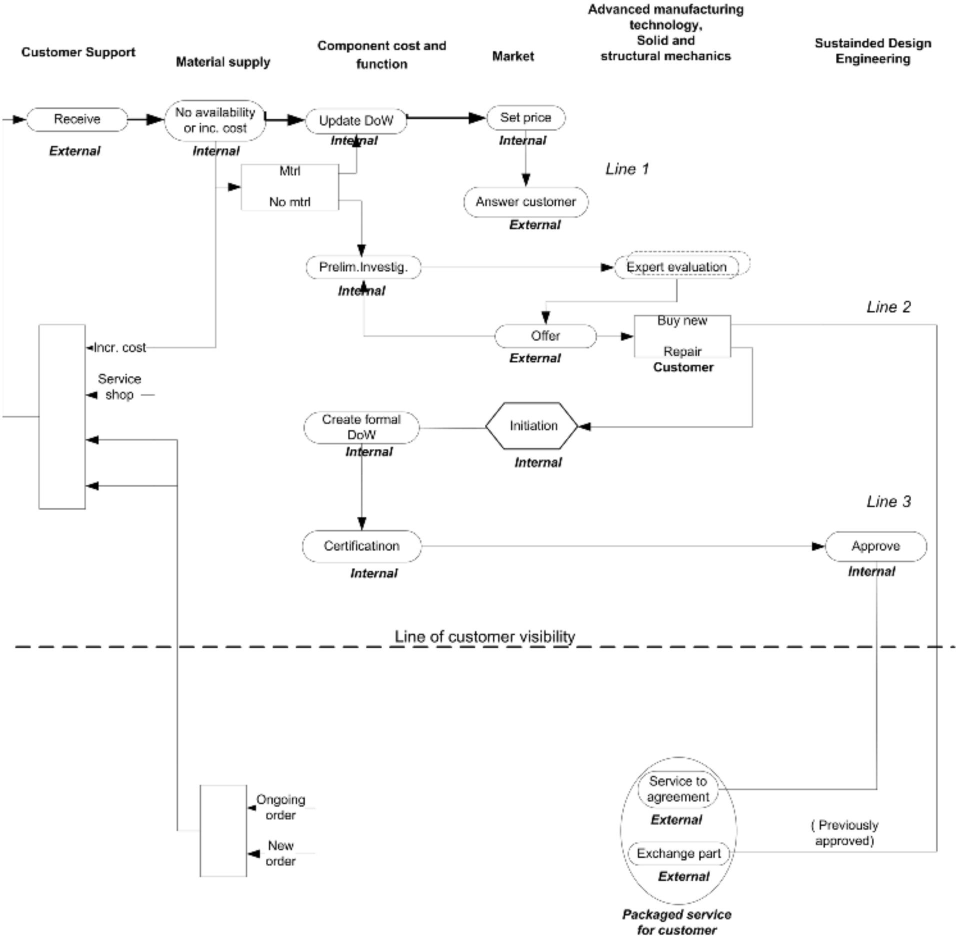

Figure 2: The work process that provides a service to an internal or external customer.

Here, the process has been described for the purpose of portraying the interaction and communication that must take place internally, before delivery of the intended service. Figure 2 relates to line 1 of Figure 1 as follows: Starting in the lower left corner with a new order from a customer, the order goes though a set of either external activities or internal activities (with no direct feedback to the customer). The order is processed by the customer support department when it is received, an increased cost (through usage of more spare parts) is identified, the service description of work is updated, a price is set and finally the customer receives an offer. The offer may be to repair a component, for example. The outcomes of line 2 and line 3 of Figure 1 represent other services that may be offered to the customer. While the studied process is an internal one, specific to Volvo Aero, it stands to reason that if this service is part of a larger (functional) product within an extended enterprise, two effects are expected:

- The number of interactions will increase dramatically between companies and competencies, which in turn requires additional resources in terms of distributed collaborative work.

- It will be increasingly important to be able to control the own company-specific process and to predict the performance of one's own products and functional product components, especially for reasons of risk minimization.

ACTIVITY-BASED SIMULATIONS FOR FUNCTIONAL PRODUCT DEVELOPMENT

Here, the particulars of the MATLAB model structure are discussed. Activity-based simulations are suggested as a suitable approach to making implicit information explicit and thereby enabling the use of late-stage design tools earlier in the development process, thus ultimately improving the quality of the outcome of the development process.

The MATLAB Model Structure

For decomposition and refinement purposes, the structure and general approach to modeling are introduced in Figure 3 below, based on the idea that modeling blocks contain references to other building blocks, creating a modular structure.

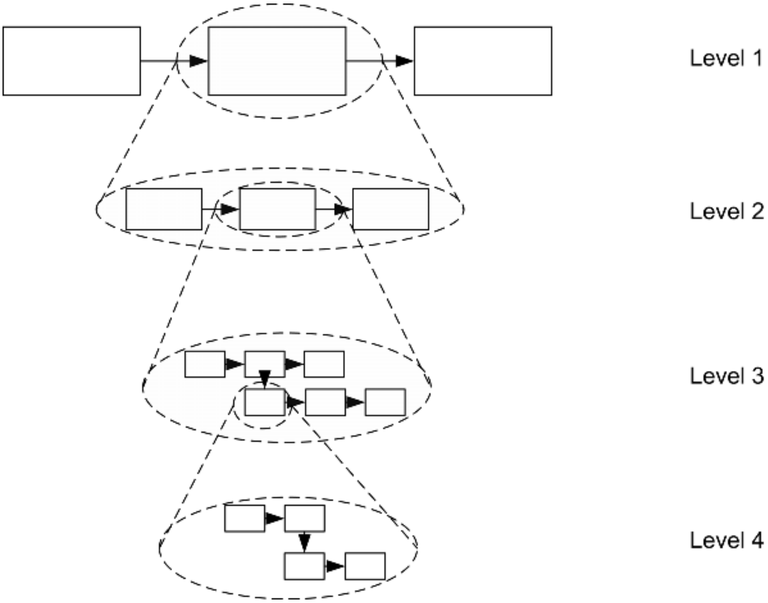

Figure 3: The structure of the MATLAB FPD models.

At the highest level of model abstraction (see Figure 3 – Level 1) one is interested in which activity blocks a design process consists of as well as the number of people involved and the time and costs associated with the activities. Level one corresponds to the business negotiation level.

A company generally has different levels of knowledge of different clients, and the clients generally have varying degrees of problems and varying knowledge of their own development processes. Say a company has cooperated for decades with some suppliers.

Based on that history and your existing knowledge, you would be more likely to create a more accurate model of your collaborative development process than if your company were required to come up with a model for collaborative development in response to a request from a new customer. This aspect is certainly something that may be included in this type of model.

At a second level of simulation the fluctuation of a currency exchange rate might be included, including its likely future fluctuation based on statistics and probability. This aspect would be of interest to many companies, particularly those that buy and sell their products and services at an agreed fixed exchange rate that varies from one business agreement to the next.

At level three the model-associated risks may be included. One can envisage the activity-based model including company-specific gates, each of which imposes new rules on e.g., user feedback concerning the model accuracy or technology readiness level.

At level four the model resembles the approach found in Knowledge Enabled Engineering (Bylund, 2004). The key concepts of Knowledge Enabled Engineering (KEE) are that the logics of the design object and the actual design process are described in a way that allows the automatic generation of design solutions, something which is possible using the activity-based modeling approach described herein. The advantages of KEE are appealing; lead-time for standard work activities can be dramatically reduced in combination with an improved and controllable quality. Standard solutions can be generated, evaluated and reported repeatedly at a low cost for each iteration. Engineers can concentrate on the more intellectual parts of engineering work rather than spending time doing routine work. The design team can thus investigate more design alternatives on a more detailed level than what is possible using today’s procedures.

The idea behind this model is somewhat similar to the one developed by Larsson et al. (2001), a tool that supports distribution of multibody dynamic analysis models in a modular way. In that case as in the current activity-based model, the modeling of sub-models is about getting a resemblance between the actual system and the modeled system. That is, between the actual design process and the activity-based model.

The activity-based model allows parallel development of the product development process and the hardware core product by suggesting which line to choose before the hardware has been developed. It facilitates the use of black-box simulation by allowing a partner access to input and output interfaces and not to the model itself. It can be used throughout the different stages of the development process, regardless of geographic location. If changes are made in the existing development process, use of this tool facilitates a simulation-driven design process. Finally, the simulation model allows for storage and retrieval of a number of outputs from execution of the model which, when viewed in retrospect, enhances understanding of the design rationale (Burge, 1998).

Supporting Collaborative Working Environments – Creating an Interface Between Companies in the Extended Enterprise

Here, a number of potential gains from using a simulation-driven CWE approach are presented. Then, some plausible positive effects on the actual teamwork are discussed.

Creating and using the activity-based model is an attempt to ensure that the company is working on the most relevant problem, or at least a problem within the most relevant set of problems. (For example, having the model suggest which line to choose, see Figure 1.) Another conceivable benefit is that it is also possible to outsource a part of the activities of the service provision process to an FPD partner, a supplier or a sub-contractor. If running the model, optimizing a selected line, indicates that performing a group of activities within a specific block costs significantly more than if another company performs them, these activities may be outsourced to the lowest qualified bidder. This frees time and resources for the first company to concentrate on activities that create more customer value. Having the two partners developing and tuning their own development processes via the fixed input and output interfaces between the blocks beforehand allows both parties to bring offers to the table that at least formally fulfill the requirements of the partner having the primary customer role.

The process model enables optimization in two ways. First, with known resources, it is possible to optimize how the process should most effectively be carried out, given a known set of goals and a design space for each variable. Second, it is possible to determine how much time and money may be spent, before associated costs equal created value.

This type of model would make it possible for a company to ensure that the same things are requested from a group of competing sub-contractors and act as a measuring device when choosing sub-contractors.

Finally, another benefit of this type of process model is the possibility of comparing the improvement potential of different concepts by simulating cost/gain ratios of the individual concepts and comparing them.

As evidenced by interviews and workshops, one challenge in doing distributed work in the context of the extended enterprise is that the distributed design team is likely to be more culturally, socially and functionally non-uniform than a locally assembled cross-functional team. As a response to this challenge the model may be run remotely by e.g., a sub-contractor with only levels 1 and 2 of the model visible together with audio and video collaboration. The model was discussed with industrialists as a business negotiation tool between two different companies creating a common ground – they are discussing something both have good knowledge of, i.e., their own product development processes. Additionally, both parties are free to use more information then they display – the sub-contractor may also do so if he has accepted responsibility for an outsourced block from the other party. The accuracy of the predicted outcome is thereby greater than it would be if the parties merely exchanged files.

A challenge in allowing a culturally and functionally non-uniform distributed team to collaborate effectively over distance lies partly in describing the design processes and in identifying which activities are truly important for the various aspects of creating a product the team judges to meet its requirements. Effects of a design change, captured as an activity in a simulation tool, could be displayed in different ways to people with different functions in a distributed design team or its management. According to Nemiro (2004), virtual teams run the risk of both information overload (due to the speed of electronic communications) and not getting enough information (due to the inherent limited richness in communication exchanges). The approach presented here would help the team to consider the development process from a few more angles, thus increasing media richness.

The value created by the suggested modeling approach is threefold: technical (identifies the optimal process composition), social (increased safety and security for the project manager) and economic (suggests demands on future business venture intakes through the simulation of time and cost of process activities).

CHALLENGES FOR DISTRIBUTED WORKING ENVIRONMENT PRACTICES POSED BY THE INTRODUCTION OF FUNCTIONAL PRODUCT DEVELOPMENT

Product-development-driven companies work in an increasingly globalized world, implying a need for involved parties to share resources, technologies, risks and profit to a greater extent, especially within FPD. This type of collaboration radically intensifies the demand on various-sized cross-functional teams working over organizational, geographical, functional and cultural borders. Currently, the concept of integrated product development (IPD) (Prasad, 1997) is well understood in the engineering design research community. Differences (in focus and degree) between IPD and FPD are introduced in Table 1 below:

	IPD through CWE	**FPD through CWE**
Need:	personal interaction	hard to identify and express
Problem:	easily defined	hard to define, wicked
Product:	hardware	combo of hardware, software, services
	tangible	hardware core probable, not necessary
Ownership:	transferred	wholly or partly non-transferred
Design space:	experienced, defined, taught	experienced, not defined, not taught
External limits:	few	many, increasing policy, law, environment
Setting:	B2C, (B2B)	B2B, (B2C)
Competitive		
Differentiation:	being the best, low price	being the best partner, optimized cost/gain
Value prod. in:	factory	interactions, consumption, factory
Value prod. by:	hardware, ownership	FP availability, knowledge, security
Value measured:	hardware performance	FP functionality, decreased risk
Team bounds:	interdisciplinary, uniform	interdisciplinary, non-uniform
Crossing:	time zones, languages	time zones, languages, companies, cultures
Responsibility:	company individual	shared in extended enterprise, Life-cycle
Simulations:	verificational	predictive, optimizing
	local, results shared	simultaneous, real-time

Table 1: Differences between CWE in a IPD and CWE in a FPD context.

Clearly, these issues challenge distributed collaborative work. Imagine selling collaboration ability to a global design team engaged in FPD. The demands on CWE methods and tools are increasing in terms of functionality, availability, usability, security, interoperability, personalization and knowledge availability.

To summarize, four different and interrelated issues for CWE have been found as a consequence of development of functional products in the extended enterprise.

- Because of the variety of challenges in functional product development a scenario approach that gives the team members a similar starting point is suggested, based on new user needs.
- Exploration of additional new simulation-driven methods and tools that facilitate other user needs than audio and video and may be used in early concept stages is beneficial. Such user needs include tools for design space exploration, i.e., to define the limitations that exist for the design team (Cost and time have been used as examples of important limiting criteria).
- Tolerances for problems related to the tool rather than to actual work decrease (Holtztblatt & Jones, 1993).
- Developing the ability to distribute other new tools with extensive demands on usability, interoperability and interface personalization.

Addressing the latter issue would be another step towards enabling relevant views of the same information, displayed differently according to the function of the person seeing it, thereby moving towards a shift from application to activity-oriented systems design. Engineers might need 3D-geometry views, while economists might want to see how the product cost is affected by a design change made by the engineer. One person might prefer dependencies described in terms of a design structure matrix while others prefer a functional breakdown of the product being sold, etc.

The described simulation tool is an attempt to display engineering-design-related information differently, based on what in a generic way may be seen as business information (i.e., cost and time) in a way that makes the information more accessible for business management. Concurrently, the model layout corresponds very well with the traditional engineering design process, thereby creating a shared frame of reference.

CONCLUSIONS

The paper discusses the challenges to CWE presented by Functional Product Development. It has been suggested that functional product development requires new tools and methods which in turn create new challenges for collaborative working environments. One such new tool, an activity-based simulation environment for a hardware-based service, has been presented above and shown to be useful. These new tools and methods also create opportunities for new research within the field of distributed collaborative work, since functional product development implies a need for increased distribution of people in terms of time-zones, distance and competence. The work shows that existing initiatives from the hardware development domain are applicable for the FPD domain. It has also been made plausible that a concurrent simulation approach that includes hardware as well as business development aspects may be developed, building on traditional engineering tools and approaches (Isaksson, Keski-Säppälä & Eppinger, 2000; Smith & Murrow, 1999; Dias &

Blockley, 1994) as well as approaches found, loosely speaking, in the business development domain (Pretorius & Steyn, 2005; Nilsson, 1999; Chowdary & Prakash, 2005; Paper & Chang, 2005).

The suggested approach poses significant challenges not only with respect to tools and methods for collaborative engineering, but also industrial collaborative work as a whole.

Distributed work in the context of functional products requires ability to distribute knowledge effectively amongst many different team members. The simulation model discussed in this article is an attempt to display engineering-design-related information differently, based on an actual engineering design process. The simulation of a hardware-based service process may be used to improve the predicted outcome of the process, which may then be offered as a function in a total offer.

Development and use of the suggested modular activity-based process simulation modeling approach enables relevant activity-based analysis throughout the process, which will ultimately improve product quality while optimizing the chosen variable, for example, cost or throughput time. The model can be used throughout the different stages of the development process, regardless of geographic location, for optimizing an actual engineering design process and integrating the engineering and business disciplines. This may enable design for best function by simulation-driven design of the functional product lifecycle.

Future work includes optimization of the tool. The model will be further developed in terms of its accuracy with respect to the activities within the design process and the value created thereof. One way to do this is to further develop the model to better account for the pareto optimal solution to the two-dimensional problem of finding the most efficient distribution of resources in terms of cost and throughput time.

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Paper F

Löfstrand, M., **Linking Design Process Activities to the Business Decisions of the Firm – An example from the Aerospace Industry**, Submitted for Journal publication.

Linking Design Process Activities to the Business Decisions of the Firm – An Example from the Aerospace Industry

MAGNUS LÖFSTRAND

Luleå University of Technology
Polhem Laboratory
Division of Computer Aided Design
97187 Luleå, Sweden
Magnus.Lofstrand@ltu.se

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Abstract

The research concerns the identification of the parameters that are most important for the studied organisation's success in service concept design and delivery. The paper describes customer and supplier business considerations, the as-is situation and the development of a to-be process based on results from the studies. Knowledge was gathered through interviews and participation in daily industrial work activities. Concurrently, the gathered knowledge was described in Microsoft Visio for later use in development of a MATLAB-based simulation model, of which the purpose is to improve the studied company's ability to develop hardware-based services at an early concept stage, and simulate, beforehand, the predicted performance of a given service scenario. This approach minimises the cost of each concept and allows simulation of several different concepts before the actual work is done. Results include the rationale for using a simulation approach, which addresses the need for predicting human-based work activities in the concept design stage. Done for the purpose of modelling, simulating and optimising the studied work process, parameter identification links engineering activities to company business decisions and the firm's success. This is supported by the identification of principal business-related considerations, introduced from the viewpoints of both service supplier and customer.

1. Introduction and background

At a general level, the aim of this research project has been to strengthen the Swedish aeronautics industry through development of new research results. The project has been a joint endeavour of Luleå University of Technology, Division of Computer Aided Design and Volvo Aero (a Swedish aeronautics supplier) in Trollhättan, Sweden. Volvo Aero is a main contractor to the Swedish Air Force, both in the delivery and service of engines as well as related hardware services. Volvo Aero develop and manufacture high-technology components for aerospace motors and gas turbines, in cooperation with the world's leading engine manufacturers.

As an introduction to this project, Volvo Aero identified the need to better predict the effects of future business decisions. The uncertainties in making business decisions increase, according to Volvo Aero informants, when more extensive offers are discussed. Such offers go beyond the traditional buyer-seller relationships and sale of hardware. One such offer is a functional product, as discussed by Alonso-Rasgado *et al.* (2004) and Löfstrand *et al.* (2005).

The term Functional Products refers to the sale of the function rather than the (hardware) product itself, since the value content of the product originates outside the physical artefact (the hardware) in the form of services and add-ons. Instead of hardware ownership, other needs such as availability and productivity are catered for. An interest in functional products is noted in a wide range of business areas such as aeronautics and mining according to Löfstrand *et al.* (2005).The interest in functional products is currently more intense and evolved in business-to-business relations than in business-to-consumer relations. Van Halen et al. (2005) discuss the related concept of product service system innovation and include examples from the business-to-consumer area as well, indicating that the challenge is in developing a system of products and services which are jointly capable of fulfilling specific client demands. Georgiopoulos (2003) has shown that engineering decisions affect the firm's profitability. Georgiopoulos discusses cases of sale of hardware, while the context of this paper is the sale of functional products; still, his results are relevant. The sale of functional products in the cases Volvo Aero is interested in, involves business-to-business offers. Here, the value, as well as potential gains and associated costs, increases. Additionally, risks increase, should errors occur which are the contractual responsibility of Volvo Aero. Supporting *development* of functional products, rather then merely supporting functional sales of hardware *designed as hardware*, therefore requires the development of new tools. An approach for the development of one such tool is discussed below.

The purpose of this paper is to introduce a rationale for using a modelling and simulation approach to human work process activities. Another purpose is to introduce the usefulness of the approach in linking engineering activities to company business decisions and to the success of the firm. A further aim of the research project was to gather and develop sufficient knowledge in collaboration with industrial partners to enable the creation of a modelling- and simulation- based demonstrator tool. The tool will be created for the purpose of linking engineering activities to company business decisions, decreasing the number of business and design uncertainties, enabling fast iterative simulations, and knowledge management and reuse.

The research project which forms the basis of this paper aims to strengthen Volvo Aero's ability to develop service-laden products within the above context. That includes improving the connection between business demands and the work of a cross-functional design team that creates the service-laden products. The identified industrial need is to increase industrial competence of developing hardware-based services at the early concept stage of development. As a response, the approach has been to study an industrial development process which is used to deliver different services to company customers. Throughout this paper the term errand is occasionally used. It refers to a problem, a challenge or an opportunity which is passed through the studied process and thus solved, met or evaluated.

The idea that arose during the initial project discussions was to use the (in engineering) common method of computer aided modelling and simulation to model the activities that supply a service to a customer. This idea was first suggested by the author in Löfstrand *et al.* (2005). The argument for using modelling is that models are relatively quickly created, safe to manipulate and may allow clarification of non-physical activities of the actual process. Such non-physical activities may, for example, include cost, time, quality and personnel distribution to meet a certain deadline. Modelling and simulation have long been used in product development to verify a hardware design. For example, Papalambros (2002) identifies that traditional design optimisation has focused on studying the tradeoffs among desirable engineering characteristics of an artefact. In this paper, modelling and simulation are suggested for the company-internal purpose of clarification and optimisation of process activities. Other uses of a process modelling approach have been identified by Wynn, Eckert and Clarkson (Wynn *et al*. 2006). They include supporting planning and risk assessment as well as identifying and evaluating improvement opportunities.

Modelling and simulation of industrial development processes require knowledge concerning what parameters affect the outcome of the work process and how they interrelate. Naturally, since many parameters could conceivably affect such a process, an interest developed early on during the research concerning identification of the parameters that the studied organisation deemed to be of the greatest importance. Other work by the author (Löfstrand 2007) carried out in the same research project identified and discussed the need for development of additional tools that link business and engineering during functional product development.

1.1 Research approach

Within the project the current (as-is) Volvo Aero service development process has been studied, on several occasions, with a focus on activities and information paths rather than on hardware function. The studies have aimed at creating an understanding of the information exchange process during the development of, for example, a repair description of work (DoW). Since both the Microsoft Visio (http://office.microsoft.com/sv-se/visio/default.aspx, accessed 23 March 2007) and MATLAB/SIMULINK (http://www.mathworks.com/products/simulink/, accessed 23 March 2007) models are based on the development process of Volvo Aero, the hardware used within the developed scenario is not critical; it is merely to be seen as an example, a point of discussion. What is critical are the demands created by the scenario, itself. A hardware component of some critical interest, having significant worth and which required high technical knowledge to develop and repair, was identified.

1. 2 The scenario approach

The motivation for using a scenario-based approach has been addressed by Caroll (Caroll 2000a, Caroll 2000b). Caroll discusses scenario-based design of information technology and notices that scenarios address five technical challenges:

- Scenarios evoke reflection on the content of design work, helping developers coordinate design action and reaction.
- Scenarios are at once concrete and flexible, helping developers manage the fluidity of design situations.
- Scenarios afford multiple views of an interaction, diverse kinds and amounts of detailing, helping developers manage the many consequences entailed by any given design move.
- Scenarios can also be abstracted and categorised, helping designers to recognise, capture and reuse generalisations and to address the challenge that technical knowledge often lags behind the needs of technical design.
- Finally, scenarios promote work-oriented communication among stakeholders, helping to make design activities more accessible to the great variety of expertise that can contribute to design, and addressing the challenge that external constraints designers and clients face often distract attention from the needs and concerns of the people who will use the technology.

Given the above indications and the researcher's interest in developing computer models and displaying output from them, a scenario approach was selected.

1.2.1 The developed scenario

The scenario, developed together with Volvo Aero, relates to a customer request for repairs of hardware components. The scenario includes an agreement concerning functional provision and availability that is already in place between Volvo Aero and the customer. (This represents the context of functional products in the project.) The welding repairs are not included in the existing agreement, the customer request and subsequent question for Volvo Aero is whether the company can repair a set of aircraft within a certain period should faults occur. In order to significantly cut development times, the scenario requires significantly faster modelling and simulation possibilities in terms of work-process simulation and design-space evaluation than what is currently available. In addition, it requires compiled knowledge about the activity-based process being used, in this paper exemplified by repair development.

Requirements from the above scenario, which are in terms of usefulness strongly related to the scenario approach discussed above, include a developed demonstrator that should support business decision-making. Therefore, the demonstrator model should indicate a capacity to optimise internal development processes and identify process bottlenecks. When completed, the demonstrator model should have captured engineering procedural knowledge and presented it in a way whereby its relevance outside to the domain of business is indicated.

The simulation model could be used to test the process sensitivity; for example, to evaluate what the effects on the cost and time would be if someone could not come to work, i.e. a decrease in the total number of personnel decrease. Thereby, the demonstrator simulation model would have usefulness in internal discussions concerning *potential process improvements*. For example, it would be possible to identify activities that, when reviewed, would be considered to take an unnecessarily long time. The simulation model would also have usefulness in internal discussions concerning *strategic choices*, for example, in prioritising errands and to evaluate market demands. Prioritising errands refers to the ability to evaluate cost, personnel distribution and required profit margins for different cases. Evaluating market demands refers to customers asking if a service (such as a repair) could be done by Volvo Aero in a certain time or to a certain price.

Indicating process outcomes thus, before the process activities have been carried out, would support business decision-making. The compilation of the procedural activity related knowledge is discussed below.

2. Data collection

The project started out with initial meetings between academia and industry to create a shared starting point. Initial issues included what would be a worthwhile research endeavour versus industrial interest and use. Scenario as well as hardware core and contractual agreements between Volvo Aero and current and potential customers were discussed. A period of investigating various Volvo Aero development processes followed the initial meeting in order to identify a process which fit the requirements of the scenario. Over time, requirements on such a process were identified. They included a comparatively high degree of in-house knowledge concerning:

- Hardware product use cases

- Hardware development procedures
- Future customer value definitions, and
- Future business agreement requirements

A suitable component (which meets the above requirements) to use as a demonstrator and as an example in discussions with industrial informants was identified through a process of evaluation.

The mapping of a subset of the organisation's communication forms with a focus on oral discourse, knowledge requirements and data exchanges was carried out. Mapping refers here to studying how work was carried out and describing the way that it was actually carried out as opposed to how it is described in formal work processes. The mapped process activities include input and output requirements for each activity block, based on the requirements of the scenario and the specific hardware component.

The research reported here has been guided by aspects of Participatory Action Research (PAR) as discussed by Whyte (1991) and Action Research (AR) as discussed by McNiff *et al.* (2003). Simply put, this may be explained and supported by the researcher having participated in and collaborated with personnel in the studied organisation. Sets of action-oriented goals have been developed by the researcher and the industrial informants over the course of the research project which is elaborated on in the scenario discussion above. Discussions have been carried out in an informal manner with key informants concerning the object of our enquiry and what the interpretations and conclusions may be made. As Whyte (1991) put it, key informants thus become active participants in the research. The research activities are discussed in more detail below. McNiff *et al.* (2003) identifies that action research, among other things, is practitioner-based, focuses on learning and change and can lead to personal and societal improvement, an improvement of the situation. In the context of the author the improvement McNiff refers to corresponds to understanding the as-is situation and changing it with a specific goal to the future, to-be situation.

The research within which this article has been developed includes ongoing investigations with 10 interviewees from seven departments of Volvo Aero. Additionally, less formal discussions have been held with seven other Volvo Aero employees. These discussions have given valuable insight into the workings of the company as well as into employees' interpretation of formal work processes and methods. Two week-long visits, two three-day visits and a number of shorter visits have been carried out by the researcher at Volvo Aero. While there, a series of interviews was carried out. The information was collected through field notes on a laptop computer when the researcher more or less participated in daily work or interrupted daily work to ask questions. The information sought includes how time, cost and available personnel are allowed to vary and how they are prioritised. In some cases, formal interviews were recorded. Between visits to Volvo Aero the data were interpreted and summarised. The information given by interviewees and the researcher's interpretations thereof were then discussed with other Volvo Aero personnel (aside from the interviewees themselves) regularly during the week-long visits, during quarterly project meetings at the university and at Volvo Aero. In doing the type of research (in terms of information or knowledge gathering) reported here, there is always a risk that the results are biased in some way due to researcher actions. To minimise such influences, the researcher has had to: listen more than to talk; remember to refrain from using words which are value-laden, and ask questions in such a way that they do not hint as to what the researcher would find interesting.

2.1 Modelling considerations

Modelling implies making the interpretations, conclusions and to a degree the scenario explicit, and making these instances part of a computer-based system. Since the purpose of gathering the information was to build a computer-based simulation model some considerations are in order concerning the choice of software to model the process. The studied process is an engineering based process mainly, with some market department activities included. However, the gathered knowledge is expressed in terms of cost and time as well as the order of activities being carried out which thus indirectly links the future models to, if not the business process, at least to business requirements and outcomes. Binder (2005) notes that when choosing an approach to business process modelling, from a practical perspective, there are three main issues to consider:

1. Properties of modelling objects.
2. Characteristics of the modelling environment.
3. Intended use of the model.

The modelling object, the service development process is (in the terms of Binder) of both an exact and an intellectual nature. In this paper the exact nature refers to activities that have to be carried out to, for example, pass a certain process state gate, the same regardless of the errand. Intellectual activities in the context of this paper refer to activities which have to be intellectually processed by humans to produce useful results.

Requirements on the modelling environment include that it should be well integrated in the engineering domain as a whole and should have the ability to exchange data with other computer-based modelling systems used in the business or engineering domain. Such systems may be tools for LCC analysis, Computer Aided Design (CAD) or tools for Knowledge Based Engineering. The model is intended for use by process managers and to support their business decision-making.

Several process modelling tools were identified. MATLAB and SIMULINK were selected for use due to their commonality in the engineering domain, flexibility and especially the programs' well developed ability to communicate with other software used in the engineering domain. The process of data gathering in industry and evaluation and development in academia was repeated in several loops. While at the university, the researcher not only evaluated modelling software for future use but also followed up on conclusions concerning research methodology, created static as-is models of the studied process, wrote project status reports and followed up conclusions and approaches in order to assure future industrial usefulness through e-mail and telephone conversations.

During subsequent visits to Volvo Aero, researcher interpretations as shown in textual descriptions, static process models described in Microsoft Visio and researcher conclusions were evaluated with the interviewees. During this phase, care was taken to gather points from as many of the involved departments as possible to ensure a well rounded view to minimise researcher bias towards a certain opinion or conclusion.

The interviews led to an increased understanding of how the service process is carried out. In addition, the interview studies have led to an understanding of how an errand passes through several different Volvo Aero formal work processes and between several company departments. Depending on the type of errand and the way in which it passes through the model, different outcomes are simulated. This information has previously not been summarised but has been directly associated with knowledgeable personnel only.

3. Results

The studied process is primarily a hardware-based service process used for creating and carrying out descriptions of work (DoW) pertaining to hardware repairs. It is also used for developing other types of more general services including maintenance operation descriptions and manuals, to name a few. The process consists of a number of consecutive activities. They are carried out by personnel from seven main departments/functions of Volvo Aero: Market, Component Technology, Customer support, Product Support, Material Supply, Advanced Manufacturing Technology and Solid & Structural Mechanics. The final two departments supply expert competence to Component technology, a department which was found to be central to the process outcome, owing to their responsibility for developing and maintaining work descriptions.

Three ways of carrying out the studied development process were initially identified (discussed by the author in (Löfstrand 2007)). They are described in Figure 1 below.

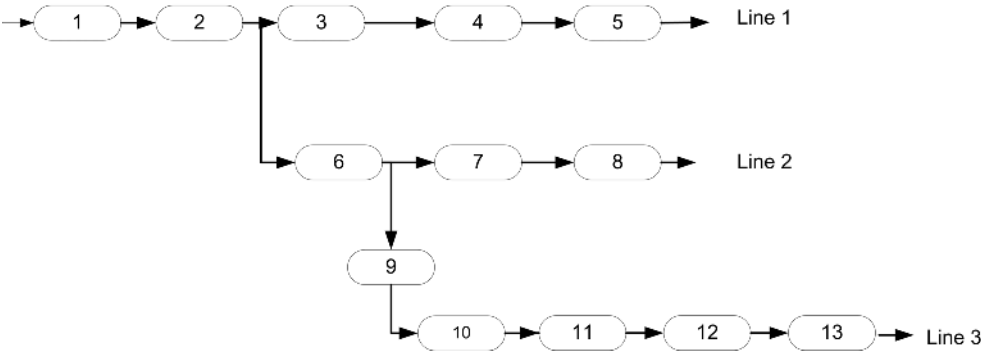

Figure 1: A 13-activity block process that delivers a service to a customer

The three ways by which an errand could pass through the process as it was initially described are introduced in Figure 1 above. Line 1 corresponds to a business situation where all knowledge is present to carry out the sale. Line 2 represents a comparison of carrying out Line 1 to the cost of replacing a faulty component with a new one. Finally, Line 3 represents a situation where a new service description of work must be developed and certified in-house before it may be carried out and sold as a service to a customer for the first time. The three options of Line 1, Line 2 and Line 3 may then be compared to ascertain which, if any, are economically beneficial. In terms of future dynamic models to be created, carrying out Line 3 and to express the results in terms of minimised work process time, minimised work process cost and both concurrently would be the main objective.

From evaluation of the processes described in Figure 1 to statements from various Volvo Aero personnel it became apparent that the initial model containing 13 main activities could be updated both in terms of the number of included activities, in terms of what information is passed between activities and in terms of requirements related to that information. For example, the interviewee that first presented Figure 1 stated:

"*I suppose that there should be a line here as well*"

The discussed line would have created a feedback loop in the diagram allowing information to be evaluated by another department before a decision to go further would be taken. While visiting Volvo Aero it became apparent that passing information (i.e. using the feedback loop) could be done formally as well as informally. Formal collaborative work in meetings and work groups is supported by informal work. Informal work include discussions over lunch, in chance meetings, coffee breaks etc. where courses of actions are developed. Such exchanges support two contentions. First, informal discussions such as the one above do occur. This has been previously discussed in literature by for example Whittaker et al. (1993). Comparable discussions were carried out continuously during researcher visits. Second, informal discussions indicate a challenge in terms of developing industrially as well as academically useful work process simulation and optimisation models that support knowledge reuse and information restructuring.

Since models are representations of reality, the researcher could not, as foreseen, gain a singular, representative view with respect to the varying opinions and interpretation of the interviewees concerning the accuracy of Figure 1. The model presented in Figure 1 was found lacking, especially in terms of the knowledge exchanges that takes place in the organisation. Therefore, in the next process iterations, additional process descriptions were developed using Microsoft Visio. The analysis of getting from one process description to the next (i.e. from the as-is to to-be) is discussed in more detail under section 3.2, Developing the to-be process, below.

3.1 An updated business scenario

While studying process requirements and activities the researcher came to further understand the business environment; thus, an updated business scenario was developed. Results indicate that customer considerations include price and time separately as well as concurrently. Volvo Aero's considerations include cost, time, fixed cost, number of replacement components in storage, available personnel and prioritising different incoming and ongoing errands.

3.1.1 The customer considerations

Seen from the customers' perspective, in doing business with Volvo Aero, one business scenario related to hardware repairs involves making choices between:

- Repairing a faulty component or buying a new component
- Repairing a faulty or buying a (non-repaired) surplus component
- Repairing a faulty or buying a repaired component

Different customers evaluate the above options against different related criteria. They are, as may be expected, mainly price and time. Some customers prioritise lowest cost and some prioritise short time to delivery to minimise production losses. Finally, most customers want to minimise the price paid for a service (for example a repair) while also meeting a specific deadline.

An additional consideration that affects Volvo Aero as well as the customer is how many hours of life the component has left. It is in some cases possible or even preferable for the customer, for example, to replace a faulty component with a surplus component twice if the aircraft happened to be on ground for service for another reason.

3.1.2 The supplier considerations

Volvo Aero has in this developed scenario two main ways of becoming lucrative. One is becoming more cost efficient and the other is to increasing the customer perceived value and hence increasing the price of the service. (In the case of functional product especially, the value may be greater than if selling a physical hardware artefact.)

The customer has three choices to make, as described above, and Volvo Aero must be able to prioritise and negotiate which of the above customer choices best meets the customer demands and at the same time meets internal Volvo Aero strategic goals or goals in terms of production cost. A repair process (DoW) must be verified and certified before being used to deliver a repair to a customer. Thus, when an errand is created by either an external customer or because someone notices a potential problem internally, Volvo Aero must first evaluate cost and prioritise issues related to:

- Updating an existing repair description of work (DoW).
- Updating an existing repair DoW and selling the service that is delivered using the DoW.
- Creating a new repair description of work (DoW).
- Creating a new repair DoW and selling the service that is delivered using the DoW.

3.1.3 A case for modelling

Remembering both the customer and supplier considerations in the above scenario, modelling and simulation became relevant for Volvo Aero in order to gauge their own ability to deliver what is required by the customer by using the models to:

- Identify process bottlenecks.
- Prioritise different potential process improvements.
- Evaluate the process sensitivity; for example, what happens if someone cannot come to work? This affects both the total number of personnel and the activities the person was involved in.
- Evaluate what a customer time requirement demands of Volvo Aero

If these goals can be met, the chance of creating a win-win business agreement that keeps the customer loyal over time increases.

Through several loops of questioning, evaluation and comparisons to formal internal Volvo Aero process descriptions an updated process was identified and developed by the author, described schematically in Figure 2 below.

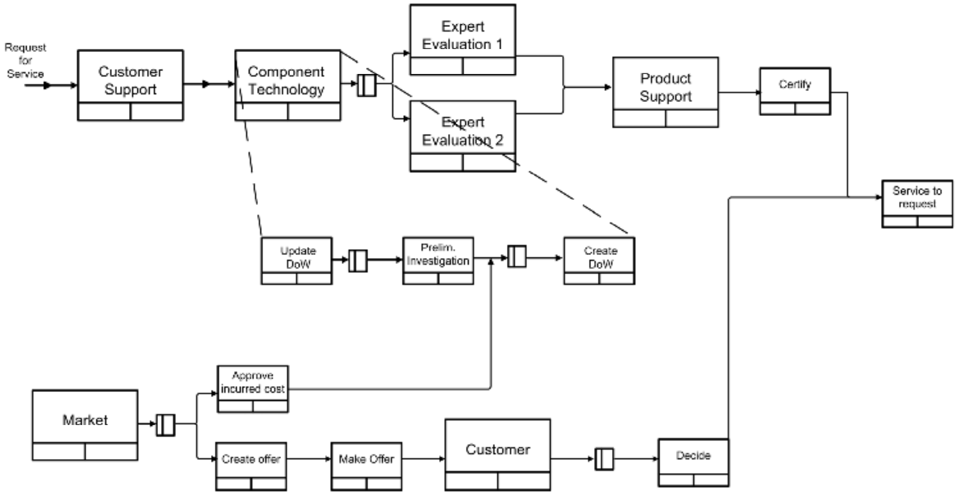

Figure 2: A public version of the current activity based process

In Figure 2 the top level of the mapped process is described. In the example of Figure 2 the Market activity block is triggered only as a consequence if the initial request for service, other options are possible in practice. The actual Volvo Aero proprietary model consists of 15 main activities, activity blocks (blocks for short). The parameters of special interest for Volvo Aero project managers involved in the research project are:

- Time
- Cost
- Collaboration
- Personnel
- External factors

Time refers to both individual activity block time spans identified by informants and to the total time to carry out the studied process.

Cost refers to cost per hour at the departments that are involved in the process. It also may refer to the total simulated or optimised cost of the whole process.

Collaboration refers to how well an activity is improved by adding additional personnel to carrying it out. One example of an activity in the studied process includes answering the phone to receive a customer request. Having two more knowledgeable colleagues in the room may sometimes help. In making a strategically important decision, on the other hand, having three additional competent people involved may increase the group output tremendously. Comparing the two activities of answering the phone and a brainstorming session it is apparent that different activities do not always respond alike when adding additional personnel to carrying it out. Common sense indicates that adding more people gets more work done up to a point. It is even likely that adding more people after that point might actually result in less work being done.

Personnel refers to maximum available personnel at each involved department. It also refers to minimum personnel required to be able to handle an errand. Personnel in general and especially maximum available personnel, refers to prioritising different errands.

External factors refer, for example, to waiting for a potential customer decision. This affects the total time of carrying out the whole process even though it does not affect the workload of the individual Volvo Aero employee, as long as there is other work to be done.

The author could conclude another point from interviews and general discussions:

- Activities strongly related to new product development are handled differently then routine actions as the errand is passed through and refined in the process. In terms of the developed process, such activities take another route through the process than do repetitive errands. (For example updating an existing DoW.)
- The profit margin is related to the cost of the entire process, since it is common to want to at least meet the break-even point so that the cost of, for example, developing a new DoW is covered by the customer. The profit margin also relate to the company strategy.

3.2 Developing the to-be process

To make work process modelling and simulation a viable option it is imperative that the parameters deemed to be most influential to the process outcome be identified; some important ones are discussed above. Also important is that the relations between these parameters are evaluated, for example, by developing and testing assumptions. Current formal Volvo Aero process descriptions are not activity-based but rather function-based. That is, when studying how an errand is handled in the organisation it became apparent that the flow of activities passes through a number of formal internal processes and information is being passed between people employed at seven different departments. Thus, describing the models in Figure 1 and Figure 2 included aspects of both mapping the current practices (as-is) and process development of activity-based process descriptions (to-be) by which fulfilment of specific client demands may be enabled.

3.2.1 Data analysis for model development

According to informants, a to-be process should reduce lead times compared to current practices and should be created so that current good practices are included. Uncertainties that slow down or prevent development and improvement should ideally be identified and circumvented or removed.

Possible changes to current practices to reach the to-be process might include developing new procedural milestones and gates, changing the company-internal administrative processes or the organisational structure. However, the latter two are quite extensive and should probably be avoided. More probable would be to increase the focus on activity-based processes while keeping the focus on hardware functionality. Other changes may include identifying additional previously unknown external factors or breaking down process activities further, thereby possibly identifying activities which are related to new product development. A final example is identifying the need for and the development of new methods that ensure the exact same procedural handling of two different errands. Thus, the effect on quality of work based on personal experience is diminished. That is, with the correct procedural rules, the quality of work may be significantly improved.

The initial as-is process description was created using pen and paper. Analysis was carried out by the researcher in collaboration with individual informants from each of the studied Volvo Aero departments. Then, the process description of Figure 1 was created, followed by an additional round of analysis, evaluation and suggestions by industrial informants to the researcher, a process here referred to as a research iteration. The research iteration was then repeated and a third process description was created by the researcher. The fourth time the research loop was repeated a process of which Figure 2 is a public subset was created and again analysed in collaboration between the researcher and the industrial informants. The academic analysis was done to develop as much knowledge as necessary for creating industrially useful, dynamic models which allow simulation and optimisation. During these research iterations the updated business scenarios including customer and supplier considerations were developed.

During the fifth main research iteration the process described in Figure 2 was further developed into a to-be process. That was carried out by starting from the current (mapped or developed) process of Figure 2 and further breaking down the process, thereby creating additional subsets of activities. Those activities are included in the non-public version of Figure 2 as internal sub-boxes. These so-called boxes include activities which are not currently carried out as stringently as the industrial informants would deem necessary. The to-be process will be used to certify the process of developing individual new services, for example repairs. Future usage of the to-be process would ensure that new repairs which have not been carried out previously are properly certified the first time they are used to meet a customer need. The process for certifying future repairs is proprietary information of Volvo Aero. However, it may be discussed in very broad terms. Here, the information is shown as a checklist, but it may also be given as a matrix or as a flowchart. It includes investigating:

- Type of component
    - Critical or non-critical
    - Flying or on ground
    - Static or moving
    - Pressurised or not
- Type of process (For example a repair method)
    - Glue, weld, materials processing
- Type of control method
    - Etching
    - Measuring (geometry)
    - Penetration tests using liquid
    - Pressure tests
- Ascertain affects on surrounding systems
- Define simulation requirements
- Identify existing material regarding simulations
- Define objectives, initial conditions, additional constraints
- Carry out expert simulations
- Receive feedback from experts
- Create the repair description of work
- Certify the specific description of work
- Create customer offer
- Do repair

On the basis of the potential changes given as examples above, the checklist is mainly related to developing new procedural milestones and gates, which ensures the exact same procedural handling of two different errands, thus certifying the process of repair development.

3.4. Rationale for the initial modelling approach

Within the research project, the idea of using a dynamic approach to work process optimisation was developed. Modelling and simulation is thus a logic choice. The rationale for using this approach is based on the need for predicting human-based work activities in the concept design stage. To do this is challenging in all parts of the design process and may be supported by the development of new tools where procedural rules are included. The effects of varying competencies are thereby reduced by raising the lowest accepted standard in quality of work. Another way to do this is, for example, to add specific automatically created checklists for each developed customer service.

Another rationale has to do with the drawbacks of existing static approaches such as the Design Structure Matrix (DSM). Browning (2001) points out that chief strength of matrix-based approaches is that they create concise, visual representation of complex systems. This is certainly true and also supported by development of dynamic models. However, results depend on who creates the matrix and the knowledge gained by doing so is specific to the matrix creator and is not easily disseminated. In addition, the DSM-method is not quickly repeated, which poses a challenge in the concept design phase, where enabling evaluation of many concepts in a short period of time is preferable.

In addition to the above mentioned rationale, the identified parameters are interesting and initial modelling approaches have been appreciated by the industrial partners. Time, cost, personnel, collaboration and external (customer) activities have been found relevant to include in executable models created for the purpose of linking engineering activities to company business decisions.

Regarding the method discussed above used for studying an as-is process to create a future desired to-be situation, collaborating with industrial partners and creating knowledge together has been found to greatly support the progress of the project. The results in terms of gathered and developed information concerning the identified parameters, supported by the identification of the seven main business related considerations, support future development of an industrially useful modelling and simulation-based computer application.

The current version of the model includes cost, time and personnel and a collaboration-related assumption. For each of the seven departments a cost per hour and an initiation cost have been identified, as well as maximum and minimum times to carry out the activity, and maximum available personnel. Since the total number of process activities is greater then the seven departments, several of the identified activities are carried out by the same department or organisational unit.

Modelling and simulations for design of engineering systems have been discussed by Sinha *et al.* (2001). They claim that:

For simulation-based design, modelling languages and simulation environments must take into account the special characteristics of the design process. For instance, languages should allow models to be easily updated and extended to accommodate the various analyses performed throughout the design process. Furthermore, the simulation software should be well integrated with the design tools so that designers and analysts with expertise in different domains can effectively collaborate on the design of complex artefacts.

These same conclusions have been drawn by the researcher and are the basis for selecting MATLAB and its related modules for modelling the studied design process. Initial modelling results include the selection of MATLAB and SIMULINK as the base modelling and simulation software, possibly using Stateflow, if necessary, in later stages. Initial tests using SIMULINK have given promising results. They include relative ease of creating system feedback loops, for example. Other work in the general area of process simulation includes Wynn et al. (2005) and Wynn et al. (2005), which indicates that the academic interest in the area is currently growing.

3.5. Goals for future modelling and simulation

The goal is to create a computer-based demonstrator model for modelling and future simulation and optimisation of the current (as-is) practices. The model should facilitate quick responses to a customer request pertaining to service. The model should support the process by an ability to indicate probable outcomes given certain input data from the customer and an ability to compare the different simulated results. As such, the developed models should act as support tools for determining if a suggested business offer is viable in terms of activities, costs, times and personnel distribution.

4. Conclusions

By focusing on the information flows it has been possible to map the knowledge exchanges in the studied service development process of Volvo Aero. The research reported here indicates the need for, and motivates the development of, a computer-based development model that supports business decisions based on engineering activities. Results also indicate that, to do that to link design activities to the business considerations and to the profitability of the firm, the model should include the parameters cost, time and some type of collaboration factor that pertains to how much more work may be carried out by the inclusion of more personnel. Results indicate that the duration of an activity in the studied process depends on a number of attributes. They include:

- Personal experience.
- The type of activity (new or routine).
- The amount of available knowledge related to the technical problem.
- The amount of available knowledge related to the customer and the customers usual criteria.

It has been shown that the supplier (Volvo Aero) and the customer (military or civilian) arrive at a total of seven main considerations, especially with respect to an after-market service supply business. As reported above, the customer may consider three choices:

- Repairing a faulty component or buying a new component
- Repairing a faulty or buying a (non-repaired) surplus component
- Repairing a faulty or buying a repaired component

These considerations are in part likened to the strategic decisions and the degree of cost effectiveness of the suppliers' production. Here, the supplier considers four options of which two are directly relevant for the customers' alternative choices above.

- Updating an existing repair description of work (DoW).

- Updating an existing repair DoW and selling the service that is delivered using the DoW.
- Creating a new repair description of work (DoW).
- Creating a new repair DoW and selling the service that is delivered using the DoW.

These seven considerations are used within the business scenario to make a large number of evaluations regarding what the best business is for each company. Developing a model which identifies costs, times, price and personnel distributions that correspond to the seven considerations would significantly support the decision-making process and thus indirectly reduce business risks.

Conclusions may also be drawn as to the existence of potential for process improvements. These improvements may include carrying out activities more concurrently. For example, the market department may be able to do some initial work without having a fully certified DoW. In this example the two activities of developing the DoW (component technology) and developing the customer offer (market) are related mainly in that they have the same final deadline.

The cost for carrying out the different activities depends on involved departments and to a certain extent also on different individuals. Thus, given the developed scenario, the customer and supplier business-related considerations discussed above, it is safe to conclude that it should be possible to use the information for development of a tool for work process simulation and optimisation. The approach would not only improve the connection between the business demands and the actual work of the development team; it is also thereby likely possible to increase early knowledge concerning a customer request for quotation concerning services in the aeronautic business. Thereby, business risks are indirectly reduced.

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Paper G

Löfstrand, M., Isaksson, O., **A Process Modelling and Simulation Approach for Business Decision Support in Pre-Conceptual Product Design**, Submitted for Journal publication.

A Process Modelling and Simulation Approach for Business Decision Support in Pre-Conceptual Product Design

Magnus Löfstrand[1*]
Ove Isaksson[1]

[1] *Luleå University of Technology, Polhem Laboratory, Division of Computer Aided Design, SE-971 87 Luleå, Sweden*

Abstract: This paper discusses work process modelling and simulation for the purpose if creating a decision support system for early phases of design, based on a case study concerning a development process in the Swedish aeronautics industry. In this paper the creation of a support tool for work process modelling and optimisation based on simulation-driven design (SDD) is presented. The SDD approach is referred to as such since simulations are used before development of the product as a predictive tool rather than after development as a verifying tool. The SDD approach further allows identifying a set of solutions that meets the criteria, thus, in engineering terms supplying evaluated, accepted concepts for the designer. In the paper a SIMULINK model of collaborative work is introduced. The support tool is created so that the collaboration description on which the support tool is partly based may be easily exchanged and updated when more information becomes available through future validation in industry. The basic activity module is the same for each activity and differences between activities are introduced in the indata file. The purpose of the simulation model is to improve the studied company's ability to develop hardware-based services in an early concept stage, and to predict performance of a given service scenario before development through modelling and simulation. The paper introduces work process modelling and simulation as a viable way to clarify and optimise work process activities. The approach is useful as a decision support tool in evaluating and prioritising business offers and activities in the business offer process, especially in the context of business-to-business relations during development of functional products. The modelling and simulation approach minimises the cost of each concept and allows simulation of a number of different concepts before the actual work is carried out.

Key Words: Process Simulation, Functional Product Development, Design Support, Cost, Delivery Time

1. Introduction

The engineering product development area has developed considerably over the past decade. Increasingly, the value content of the product originates outside the physical artefact (the hardware) in the form of services and add-ons. Instead of hardware ownership, other needs such as availability, productivity and risk minimisation are catered for. This trend may be noticed in a wide range of business areas, particularly in business-to-business relations. An emerging area of interest related to engineering product development is Functional Products [1], [2]. Högman and Berglund [3] describe some of the challenges in the aerospace industry of today. They state that:

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[*] Author to whom correspondence should be sent. Magnus.Lofstrand@ltu.se

Customers of the aerospace company studied act primarily as system integrators today. This means that the company studied is expected to take full responsibility for a component or sub-system, including developing new innovative technologies within their specializations. For a supplier, the global trends and general expectations of the industry may be reasonably clear, but how this should be translated to technology development is not necessarily a clear-cut process.

This paper concerns the modelling, simulation and optimisation of work processes. The industrial application is a service supply work process of Volvo Aero, a component supplier in the aeronautics industry in Sweden, interested in functional product development and sale. Modelling and simulation of industrial development processes require knowledge concerning parameters affecting the outcome of the work process and how they interrelate.

To demonstrate simulation of immaterial, business-related properties in functional products, a model designed to predict the cost and delivery time of carrying out the activities included in a functional product design process is presented below, based on a service-supply scenario developed by the author in collaboration with Volvo Aero personnel. This is one of several ways in which Volvo Aero is developing their current (as-is) ability towards a future (to-be) ability in development and sale of profitable functional products that exceed customer expectations. The Simulation Driven Design (SDD) approach is a progression of the common verificational simulations that have long been used in engineering to investigate hardware functionality after the hardware has already been designed [4], [5].

The knowledge which forms the basis of this paper was gathered, based on a case study in the aeronautics industry, through interviews and participation in daily industrial work activities at Volvo Aero [6]. Löfstrand [6] together with industrial partners developed a scenario including the process schematically described in Figure 1 and seven interlinked supplier and customer business considerations. Löfstrand and the industrial partners further identified four aspects that should be included in a simulation model.

The interlinked supplier and customer business considerations are for the customer:

- Repairing a faulty component or buying a new component
- Repairing a faulty or buying a (non-repaired) surplus component
- Repairing a faulty or buying a repaired component

These considerations are in part likened to the strategic decisions and the degree of cost effectiveness of the suppliers' production. Here, the supplier considers four options, of which two are directly relevant for the customers' alternative choices above.

- Updating an existing repair description of work (DoW)
- Updating an existing repair DoW and selling the service that is delivered using the DoW
- Creating a new repair DoW
- Creating a new repair DoW and selling the service that is delivered using the DoW

These seven considerations are used within the business scenario to make a large number of evaluations regarding what the best business is for each company. The scenario is based on a need to predict company performance faster and more accurately than today. The changing business demands require that a simulation which today takes two weeks will in the relatively near future have to be done in less than a day. The ability to supply a hardware-based functional product to a variety of customers is a driving force behind this development.

The purpose of this paper is to show how work process modelling and simulation have been carried out, based on a case study in the aeronautics industry. Another purpose is to introduce work process modelling and simulation as a viable way to clarify and optimise work process activities. Finally, the approach is useful as an industrial decision support tool in evaluating and prioritising business offers and for evaluating the business offer process. In the remainder of the paper the modelled process is introduced, the mathematical model for collaborative work is presented and discussed and the rationale for the chosen modelling approached is discussed in relation to other work related to process modelling and simulation. Thereafter, model and business-related results are presented, and finally the results and the work process modelling and simulation approach are analysed and discussed.

2 The modelled process

The approach in the research reported in this paper is simulation in order to determine whether a challenging business contract based on an internal Volvo Aero process can be carried out and if so, the delivery time needed for supplying the required service and the internal costs associated with it. *In this paper, all model output is based on reasonable indata, yet not the true indata of Volvo Aero. This has been done to protect proprietary information.* Based on the scenario discussed above, the model contains a number of activities or "blocks" which are mutually dependant.

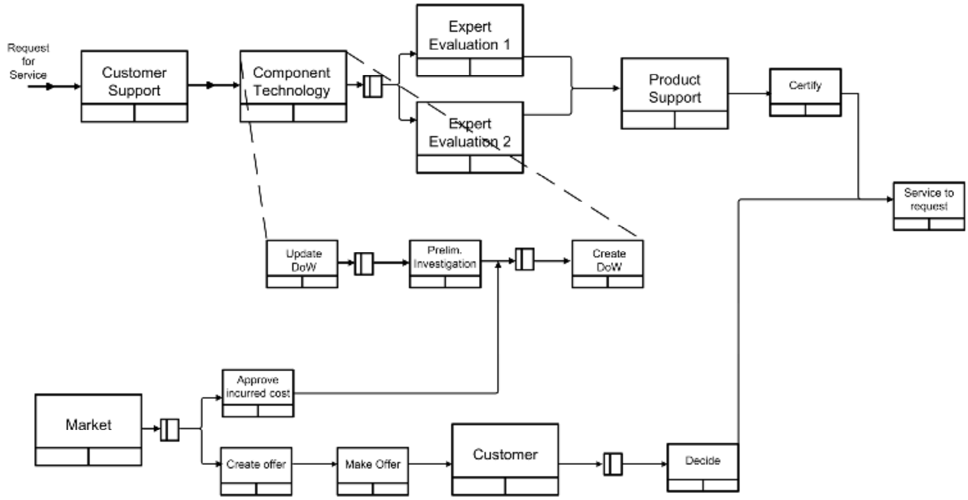

Figure 1: A public (as-is) version of the simulated work process.

In Figure 1 above, a public version of the studied process is described. Figure 1 describes the process as it is currently carried out at Volvo Aero, the as-is process. In the upper left corner of Figure 1 a request for service is made by an external customer, asking the Volvo Aero Customer Support department for information concerning price and time to have a component repaired.

(This request and associated work process activities is in this paper called an “errand”.) Customer support initially screens the customer’s request for service and creates the errand by entering it into their internal database for open cases. The errand is then taken over by the department Component Technology which investigates whether there exists a repair description of work (DoW) that meets the customer’s requirements or if a new DoW needs to be created. Assuming a new DoW needs to be created, Component Technology carries out a preliminary investigation of the technical problem and its requirements and, if need be, requests expert evaluations from, for example, the department Solid and Structural Mechanics. After having reached an agreement with the Market department, Component Technology creates a new DoW, certifies it and passes it on to the department of Product Support which evaluates and finally certifies the newly developed description of work. At this point the Market department creates and makes an offer to the customer. Finally, the customer considers the offer for some time before accepting or declining it. The order in which this process is carried out is schematically described in Figure 2 below.

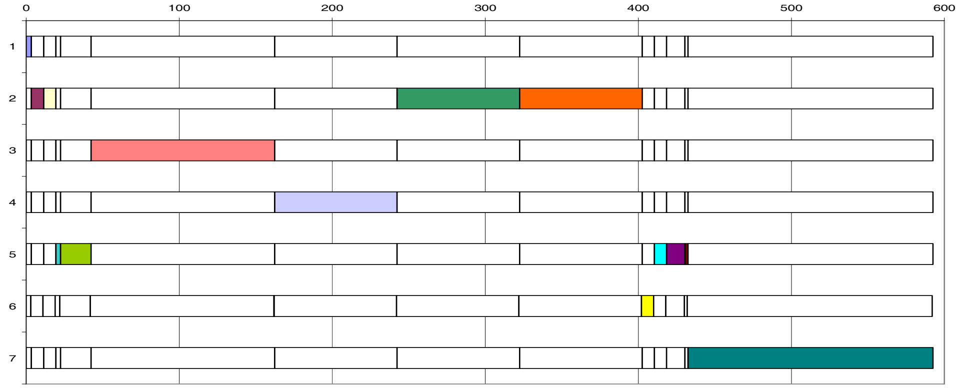

Figure 2: Process activity map depicting a sequential process. The white parts of the bar chart indicate when a department is inactive and the coloured parts indicate when a department is active i.e., carrying out an activity. Figure 2 indicates that the process (described on a general level in Figure 1) is sequential rather than concurrent.

3. Rationale for the modelling approach

Different approaches to create the simulation models presented below were considered. Szegheo [7] presents a number of modelling approaches. Szegheo concludes by stating that before choosing the modelling approach, the model builder or the modelling team has to define precisely what the purpose of the model is. Each modelling technique was developed to satisfy some particular needs. The model builder and the user of the model can benefit most from the model if the right tool has been chosen for their purpose. Research concerning design process improvement has been expanding recently, as may be identified from the review of Clarkson and Eckert [8], and several different modelling approaches may be taken.

Cronemyr et al. [9] present a computer-based decision support tool for predicting the impact of development process improvements. Cronemyr et al. identify the drawback of using flow charts for mapping iterative processes; since a flow chart does not make the iterations visible, they prefer to transform a flowchart of an iterative process into a Design Structure Matrix (DSM) [10] [11]. A main reason for not using a DSM-based approach in this paper is that, while the DSM approach may support the inclusion of the model presented in Equation (1), it would likely not support the optimisation procedures presented in this paper.

Another process modelling approach is presented by Wynn et al. [12], who introduce a modelling framework for design process improvement called applied signposting. This approach focuses on incorporating the benefits of popular descriptive tools including informal process maps and Gantt charts. In the work reported by Wynn et al. the concept of confidence is included. Confidence is in their approach an abstract quality which may take a number of meanings, typically referring to the designers' belief in their solution or some other aspect of design maturity. For the approach presented in this paper, data maturity and goal attainment probability is an interesting point for future development.

After some consideration, MATLAB and SIMULINK were selected for use, due to a number of reasons including:

- Ease of use for updating or exchanging the collaboration assumption presented in Equation (1) as new pertinent information is developed or identified without undue changes to the SIMULINK program.
- In current use at Volvo Aero, enabling industrial implementation of research results.
- MATLAB further has the modules StateFlow and SimEvents, allowing for future model development in terms of discrete event systems enabling evaluation of system parameters such as congestion, resource contention and processing delays [13].
- MATLAB allows for exchange of data with a range of other proprietary software packages.

3.1 The simulation and optimisation approach

Figure 3 below represents the developed SIMULINK model. Figure 5 represents output from the model where "develop new repair" represents the whole company-internal development process and "develop and sell new repair" represents the whole company-internal development process plus the customer interactions necessary for selling the product or offer.

The SIMULINK model consists of 15 singular activities which have been separated into four main groups of activities or "paths".

- Path 1 is an "update" process exemplified in Figure 3 and includes five activities.
- Path 2 is a "technical development process" exemplified in Figure 3 and includes six activities.
- Path 3 is an "offer development process" exemplified in Figure 3 and includes three activities.
- Path 4 is a "carry out repair" process exemplified in Figure 3; it includes one activity.

One additional activity which is included in the SIMULINK model is an external activity; that is, waiting for a customer decision.

All 15 included activities may be described by Equations (1), (2) and (3) below. The costs and delivery times for each of the four execution paths discussed above are calculated using

Equations (4) and (5) below.

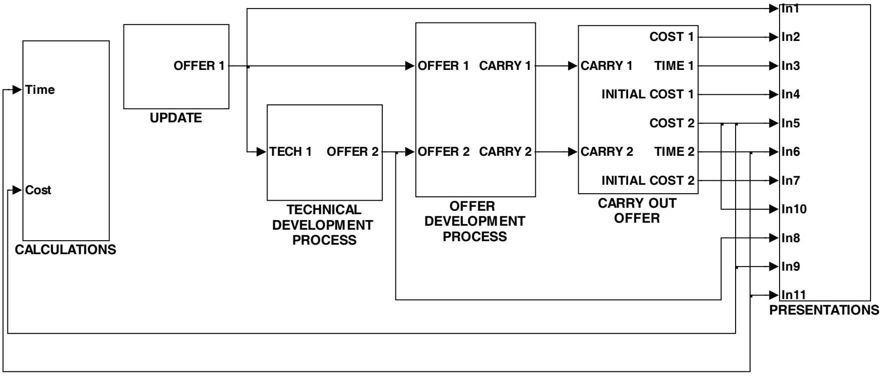

Figure 3: A public view of the developed to-be SIMULINK model consisting of six main blocks: Calculations, Update, Technical Development Process, Offer Development Process, Carry out Offer and Presentation.

Figure 3 above consists of six main blocks, four of which are related to the studied process directly and two of which are related to the requirements of the developed program.

The two program-related blocks, depicted in the far left and far right of Figure 3, are Calculations and Presentations. The calculations block consists of the main calculations which are required for creation of program output, naturally based on the remainder of the process blocks. The presentations block consists of the routines that allow for the creation of a graphical user interface and the plot functions which create graphs of cost versus personnel and time versus personnel described in Figure 7 and Figure 8.

3.2 Equations

The assumption concerning relations between work, people and collaboration is presented in Equation (1) below:

$$P_i = pers_i^{p_i} \qquad (1)$$

In this paper the main point is to introduce the possibility of simulating work processes. In this context, Equation (1) is an initial assumption and is included to indicate the need for a mathematical description of collaborative work. Equation (1) is based on researcher interpretations of interview data. Due to the degree of uncertainty the SIMULINK model is created so that Equation (1) may easily be updated or exchanged. In Equation (1), P_i is the amount of work carried out by a group of people. "pers" represents the number of people in the group and the exponent p_i is a group collaboration factor (gcf) for the group.

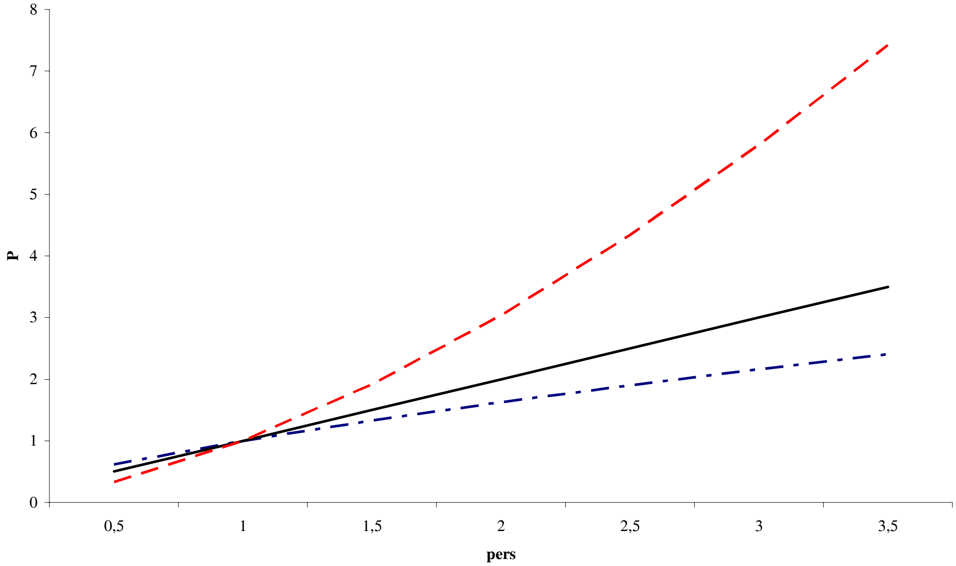

Figure 4: Amount of work (P) carried out as a function of manpower (pers). ---- represents p=1.6, —— represents p=1 and – • – • – represents p=0.7.

Figure 4 depicts the effects of having different values on the collaboration effect for different activities by plotting Equation (1). In this case, which one to use depends on researcher evaluations in industry together with the industrial informants. In Figure 4 the collaboration factor is presented as a function of the number of active people in a specific activity. The top line of Figure 4 represent p=1.6, the middle, solid line, p=1 and the bottom dashed line p=0.7. Having p=0.7 indicates that the work (activities) are carried out effectively by one person and that the effectiveness decreases when more personnel are added. Consequently, having p=1.6 indicates that the work (activities) are carried out effectively by more then one person and that the effectiveness decreases when personnel are removed.

The SIMULINK model has been created so that the assumption presented in Equation (1) concerning work process collaboration above may be easily updated or exchanged when new information has been gathered concerning this subject. A discussion on the effects of the proposed mathematical model for collaborative work is carried out below.

3.3 Time and Cost

The time to carry out an activity is described by Equation (2) below and is based on the initial assumption concerning collaboration as described by Equation (1) above.

$$T_i = T_{ai} \cdot pers_i^{-p_i} \qquad (2)$$

In Equation (2) above, T_{ai} represents the time it takes for one person to carry out the activity i; the corresponding cost of an activity i may be computed according to Equation (3) below:

$$C_i = C_{init,i} + C_{ai} \cdot pers_i \cdot T_{ai} \cdot pers_i^{-p_i} \qquad (3)$$

In Equation (3), $C_{init,i}$ represents the initial cost upon starting activity i and C_{ai} is the cost per hour to carry out the activity. The total time for the project can now be computed according to Equation (4) below:

$$T = \sum_{i=1}^{n} T_{ai} \cdot pers_i^{-p_i} \qquad (4)$$

The project time (T), according to Equation (4), is influenced by three factors: time to carry out a specific activity (T_{ai}), the number of persons involved (pers) and the coefficient of collaboration (p).Thereafter, the total cost, including initial cost, $C_{init,i}$ may be computed according to Equation (5) below:

$$C = \sum_{i=1}^{n} C_{init,i} + \sum_{i=1}^{n} \left[C_{ai} \cdot pers_i \cdot T_{ai} \cdot pers_i^{-p_i} \right] \qquad (5)$$

3.4 SIMULINK related output

Model output from the SIMULINK model includes an internal consideration interface (Figure 5), and a customer consideration interface (Figure 6). Two outputs as indicated by Figure 7 and Figure 8 are presented when the SIMULINK model is executed. Additional SIMULINK model output (not further presented in this paper) related to the internal consideration interface includes an interface which suggests the optimal personnel distribution in each of the 15 internal process activities.

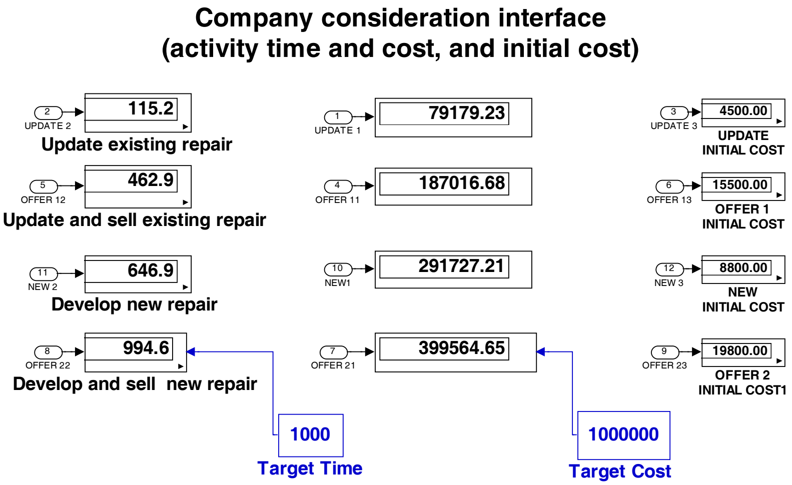

Figure 5: Output from the developed SIMULINK model, a company consideration interface.

Figure 5 shows activity times, activity cost and initial costs for the four main company considerations as discussed in Chapter 1 above. In the interface presented, the user may input a target time and a target cost.

Paths 1 through 4, as discussed above, are the basis for the data presented in the company consideration interface according to Table 1 below.

Process	*Included paths*
Update existing repair	Path 1
Update and sell existing repair	Path 1, Path 3 & Path 4
Develop new repair	Path 1 & Path 2
Develop and sell new repair	Path 1, Path 2, Path 3 & Path 4.

Table 1: The relations between the developed SIMULINK model and its output.

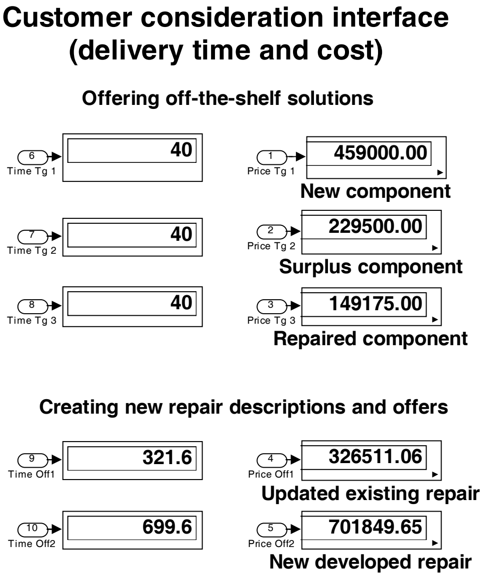

Figure 6: Output from the developed SIMULINK model, a customer consideration interface.

Figure 6 shows some common customer considerations discussed in the introduction above. By comparing Figure 5 to Figure 6 it is clear that the three first customer considerations, presented under the heading “offering off-the-shelf solutions” are primarily not related to the modelled internal development process of Volvo Aero. However, it is also clear that the last two customer considerations, presented under the headings “Creating new repair descriptions and offers” “updated existing repair” and “New developed repair” are the same as two of the four main company considerations presented in Figure 6. When run, the developed program automatically creates plots of simulated cost as a function of delivery time (Figure 7).

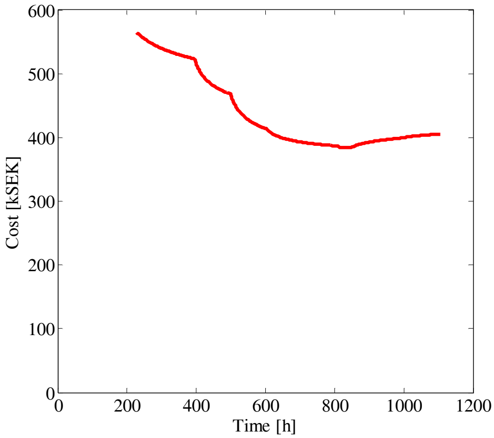

Figure 7: Simulated cost versus delivery time.

By comparing the two parts of Figure 8 it is clear that the outputs may be used to identify bottlenecks in the process. In addition, plotting cost versus delivery time as introduced above provides the decision-makers with a useful tool. Reducing the delivery time requires an increase in cost. Minimum cost is obtained at about 840 hours, while shortest delivery time of 228 hours is reached with full-time maximum staffing.

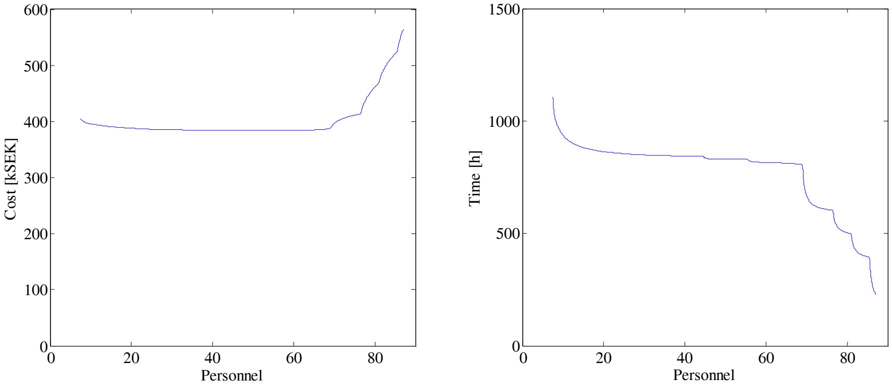

Figure 8: An example of simulated cost as a function of personnel (left) and simulated delivery time as a function of personnel (right). (Minimum cost of kSEK 384 at 44,5 personnel.)

4. Optimisation

Optimisation has been carried out in two different but related ways. Optimisation of the *whole process* has been carried out using SIMULINK and embedded S-functions. The problem was also formulated as a deterministic non-linear programming problem and handled in MATLAB directly, outside of SIMULINK.

In order to find the best offer (for both supplier and customer), optimisation is used firstly to meet a certain deadline at lowest cost and thereafter change the personnel distribution to find shortest project time. Simulations start with a minimum number of workers in each activity. In the presented model, the manpower is limited by minimum and maximum personnel available at each department that carries out the different work activities. To approach the deadline of the "project" the number of workers is increased. Simultaneously, the program keeps the cost as low as possible. Therefore, the manpower is first increased at the activity that has the lowest associated cost per work hour and continues with the next activity until the deadline is reached or all activities have been staffed to the maximum. The program uses the derivatives presented in Equation (6) below to find the optimum way to increase the number of personnel of each activity according to the flowchart in Figure 9.

$$\frac{dC_i}{dpers_i} = C_{ai} \cdot (1 - p_i) \cdot T_{ai} \cdot pers_i^{-p_i} \tag{6}$$

$$\frac{dT_i}{dpers_i} = -p_i \cdot T_{ai} \cdot pers_i^{-(p_i+1)} \tag{7}$$

If the deadline is not reached, the optimisation continues by changing the personnel distribution to a more time-favourable distribution but keeping the total number of workers constant. Equation (7) is used in all 15 activity calculations to find the best way to change personnel distribution. A flowchart describing the simulation approach is presented in Figure 9 below.

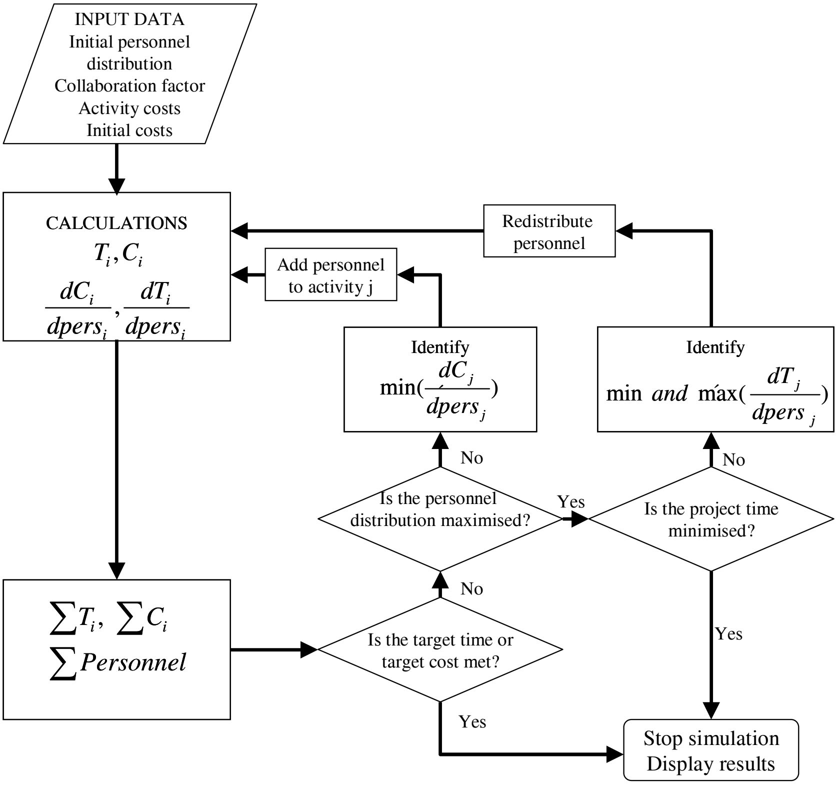

Figure 9: A flowchart describing the logical functionality of the optimisation routine in the developed support tool, executed for each of the four possible execution paths.

Figure 9 above describes the logics of the optimisation part of the support tool presented in this paper. The in-data file includes an initial personnel distribution for each block in the process, the collaboration factor for each activity, initial costs per active organisational unit (department) and activity cost defined by the cost per hour for each active department. The user specifies a target cost and a target time in a graphical user interface created by the SIMULINK program and executes the program.

As stated above, the problem was also formulated as a deterministic non-linear programming problem and handled in MATLAB directly:

Minimise $f_1(pers,T) = (C_{init,1} + ... + C_{init,n} + C_{ai} \cdot pers_1^{-p_1} + ... + C_{an} \cdot pers_n^{-p_n}) / C_{Scale}$ (8)

Minimise $f_2(pers,T) = (T_1 - ... - T_n) / T_{Scale}$ (9)

Subject to:

$$pers\min_1 \le pers_1 \le pers\max_1$$
$$...$$
$$pers\min_n \le pers_n \le pers\max_n \tag{10}$$

f_1 presented by Equation (8) and f_2 presented by Equation (9) above represent the total process cost and the total process time, respectively. The constraints persmin and persmax are the minimum and maximum personnel available, respectively. As discussed above, the constraints presented in Equation (10) are also valid for the problem as presented in the SIMULINK model in Figure 3. Numerical scaling is necessary when optimising both for cost and time. Firstly, cost and time are optimised separately, giving optimum cost, C_{opt}, and optimum time, T_{opt}, respectively. The numerical scaling of f_1 and f_2 is carried out as follows:

$$C_{Scale} = C_{opt}$$
$$T_{Scale} = T_{opt} \tag{11}$$

5. Model-related results

As discussed above in Section 4, optimisation has been carried out in two different but related ways. The model-related results represent the first, related to the developed SIMULINK model, and the second is related to the developed MATLAB model. These results are discussed further below.

5.1 SIMULINK-related results

To get the most accurate results from the model it is imperative that extensive tests are carried out using live cases to “dial in” the p-values as well as possible. Then, if the results are found to unsatisfactorily describe the reality, the model will be updated until it does so sufficiently well. This requires extensive testing in collaboration with the studied company.

In Table 2 below, the sensitivity of the model to variances in the collaboration factor p and change in personnel distribution is introduced for the benefit of the reader.

	Update existing repair		Update and sell existing repair		Develop new repair		Develop and sell new repair	
Case	**Time**	**Cost**	**Time**	**Cost**	**Time**	**Cost**	**Time**	**Cost**
	[h]	[kSEK]	[h]	[kSEK]	[h]	[kSEK]	[h]	[kSEK]
1	12,5	69	155	217	86	416	228	564
2	10,2	55	147	196	74	357	211	498
3	8,3	44	140	178	64	307	197	441
4	6,8	36	134	163	56	265	183	392
5	17,3	68	86	320	64	483	132	734

Table 2: Indicating the sensitivity of the collaboration factor, p.

Case 2-4 shows the sensitivity of the collaboration factor. The p-factor, compared to Case 1, has been increased by 10, 20 and 30% for all 15 groups, respectively. Figure 10 below indicates that when p-values are set larger then one (p>1) for a given activity, the model presented in Equation (1) and Equation (2) give that work (P) is less effective for pers<1 and more effective if pers>1. The black solid line represents Case 1, the red dashed line represents Case 2, the black dashed line represents Case 3 and the blue dashed line represents Case 4. The average p-value is highest for the blue curve in Figure 10. Therefore, the blue curve is higher at the start of the program's iteration process and lower towards the end of the iteration process. At the start of the iteration process, pers<1 and towards the end of the iteration process, pers>1.

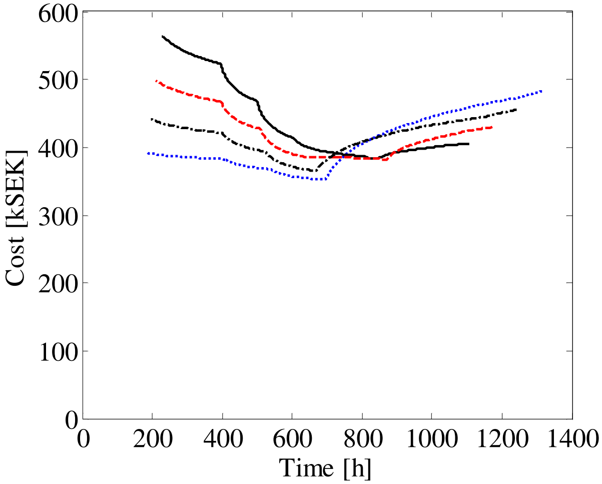

Figure 10: The figure display cost as a function of delivery time dependent on the values of p. Black solid line represents Case 1; p_{mean}=0,92 and std=0.16, red dashed line represent, Case 2; p_{mean}=1.01 and std=0.18, black dashed line represent Case 3; p_{mean}=1.10 and std=0.19 and blue dashed line represents, Case 4; p_{mean}= 1.19 and std=0.21.

By optimising the personnel distribution, keeping the total number of workers constant, it is possible to reduce the delivery time as shown in Figure 11 below.

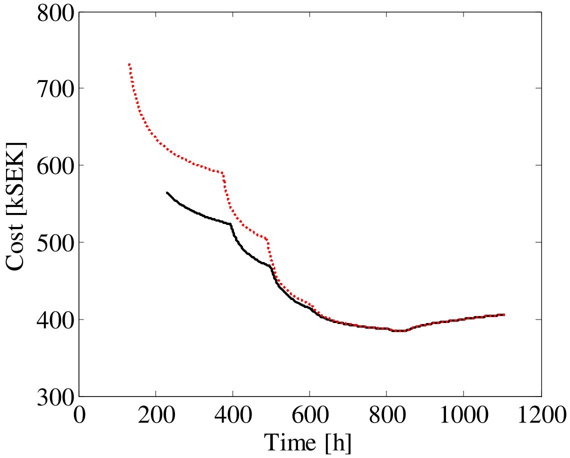

Figure 11: Varying the personnel distribution for each of the 15 internal company activities affects both the total delivery time and the total cost of the work process. The black curve represents Case 1 full personnel distribution (max pers for all activities) and the red, Case 5, optimised personnel distribution.

SIMULINK optimisation results are shown in Table 2, Case 5, and the new personnel distribution is given in Table 3. For the results presented here, all of the upper boundaries of Equation (10) (persmax) were increased to allow the personnel distribution to be optimised. The project time is reduced by 42% after the final iteration. However, the drawback is that the cost increases by 30%.

	Personnel distribution														
	Activity														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Distribution at the start	3,0	8,0	8,0	8,0	8,0	4,0	4,0	4,0	2,0	8,0	8,0	5,0	5,0	4,0	8,0
Final distribution	1,8	2,9	3,0	8,9	2,9	3,0	3,6	1,3	16,9	12,5	0,5	11,4	11,4	1,9	4,7

Table 3: Changed personnel distribution at the beginning of optimisation compared to the start of iteration.

5.2 Optimising the develop and sell new repair process

In Table 4 the optimisation results are shown for delivery time, cost and time/cost optimisation. Optimising subgroups results in higher total project cost as is indicated by Table 4 . * Shows optimised results when optimising each subgroup. The results from each subgroup are then added together. ** Indicates optimised results from optimising the whole "Develop and sell new repair"–process.

	Time			**Cost**			**Time and Cost**		
	Personnel	**Time**	**Cost**	**Personnel**	**Time**	**Cost**	**Personnel**	**Time**	**Cost**
Update	35	12,5	73,3	25	31,4	71,6	35	12,5	73,3
Offer	12	5,5	12,2	6	11,5	11,3	6	11,5	11,3
Technical Development	38	113,2	368,8	14	526,8	232,1	32	155,5	319
Carry out offer	2	97,1	142,1	2	97,1	142,1	2	97,1	142,1
Develop and sell new repair*	87	228,6	596,4	47	666,8	457,1	75	276,6	545,7
Develop and sell new repair**	87	228,4	573,9	47	833,2	393,9	76	294,2	508,3

Table 4: Comparing optimising the whole process to optimising its subgroups.

6. Discussion

The suggested approach thus improves the connection between business demands and the work of a cross-functional design team and it also allows capture of engineering procedural knowledge, presenting it in a way that indicates its relevance outside to the domain of business.

One may ask how large variations in the parameter p may be expected in a real-life scenario. In this paper the authors have used the range of 0.7 to 1.45, which represent that two people do the work of 1.6 people and 2.7 people that work alone.

6. 1. Supporting previous academic results

Cooper et al. [14] suggest two best practices for teamwork in new product development: making the team responsible for the end or performance result of the project and establishing ways of making it easier for the team to handle outside-the-team decisions. Both these issues are supported by the modelling and simulation approach introduced in this paper. The output of the models and the ability to run the model with different indata for different purposes make the strategic process goal more visible for the project team.

Holland [15] presents an integrated model of cross-functional teamwork. In her graphical description she introduces three sets of team performance enablers. Under the heading organisational context three performance enablers stand out in relation to results in this paper: *clear mission*, *resources and time* and *team accountability*. Under the heading Task Design the team performance enabler *customer focus* may be noted. These four team performance enablers may be supported by the industrial use of the models introduced in this paper.

The decision-support system discussed in this paper clarifies the mission in terms of delivery time, cost, customer price and personnel distribution. This makes the mission clear to the design team, indicates required resources and time and makes the design team accountable. By the introduction of not only internal cost but also the customer price the developed decision-support system shows a customer focus and may be helpful in supplier-customer negotiations.

Koberg et al. [16] also point out factors that favour radical innovation include environmental dynamism, intrafirm linkages, experimentation, and transitioning or sequencing from one project or product to another. Volvo Aero's interest in extended enterprises is an intrafirm linkage, which is a driver for the research project discussed in this paper. By further development of the decision-support system it may include intrafirm as well as interfirm linkages which would support development of products in an extended enterprise [17] setting.

7. Conclusions

The main results of this paper are considered to be the introduction of the SIMULINK program which allows the possibility of simulating an engineering-based work process for traditionally speaking, non-engineering-related usage. The developed support tools relate to both industrial business scenarios for functional development and sale, and to the development process. The developed work process simulation models show the possibility of obtaining:

- Simulated minimised cost, related total delivery time and personnel distribution
- Simulated minimised delivery time, related total cost and personnel distribution
- Simulated minimal delivery time and cost and related personnel distribution
- Corresponding delivery time and personnel distribution for a user-defined target cost.
- Corresponding cost and personnel distribution for a user-defined target time.

These simulated results support users in:

- Deciding if a customer request is viable or not.
- Deciding how much of the available workforce is affected by deciding to accept the particular customer request, this information may then be used to prioritise the ongoing and upcoming work.
- Deciding if the company process is cost-efficient enough when comparing the optimum to an offer from a sub-contractor.
- Giving estimates of time of delivery and price to the customer within minutes rather than in days.

Thus, the modelling and simulation approach supports users in evaluating the cost of future business before costs are incurred, evaluates product development ability and links company technology and business processes further. It also increases the user understanding and knowledge concerning the product development process and its limitations and allows for comparison of alternative versions of the same design process well before the actual development work has been carried out. Additionally, the developed model allows knowledge reuse and information restructuring through the ability to simulate different outcomes according to user need.

The herein presented modelling approach is industrially useful in a number of ways. One example is that the developed program may be used as a decision-support tool to make strategic choices and prioritise errands, thank to the model’s ability to evaluate cost, personnel distribution and required profit margins for different cases. Another example is that the model may be used to evaluate market demands. This is exemplified by the program’s ability to respond to the common customer question regarding if a service could be done by Volvo Aero in a certain time and to a certain price. Additionally, the model’s short execution time of normally not much more then a few minutes allows for repeated testing of many different scenarios; thus, industrial users may evaluate effects of a concern that they might have.

The developed program is being applied by users in industry and academia. An evaluation has been started and initial industrial feedback has been positive.

8. Acknowledgements

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