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DEMANDS ON ENGINEERING DESIGN CULTURE FOR IMPLEMENTING FUNCTIONAL PRODUCTS

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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…)

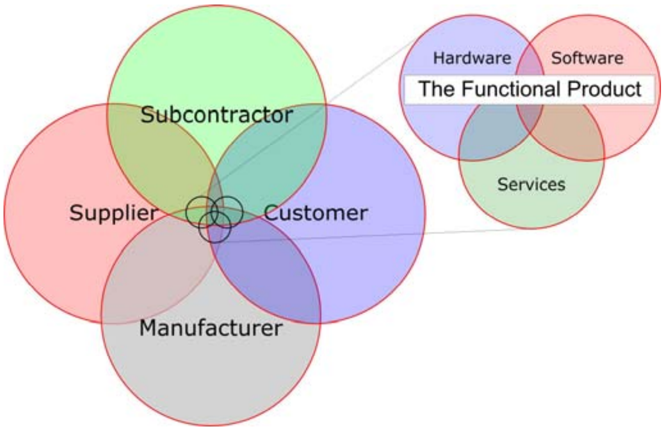

Figure 1: Two views of the functional product, business or communication view (left) and product view (right). Cooperation concerning functional products creates a wider partner network than what was in use previously.

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.

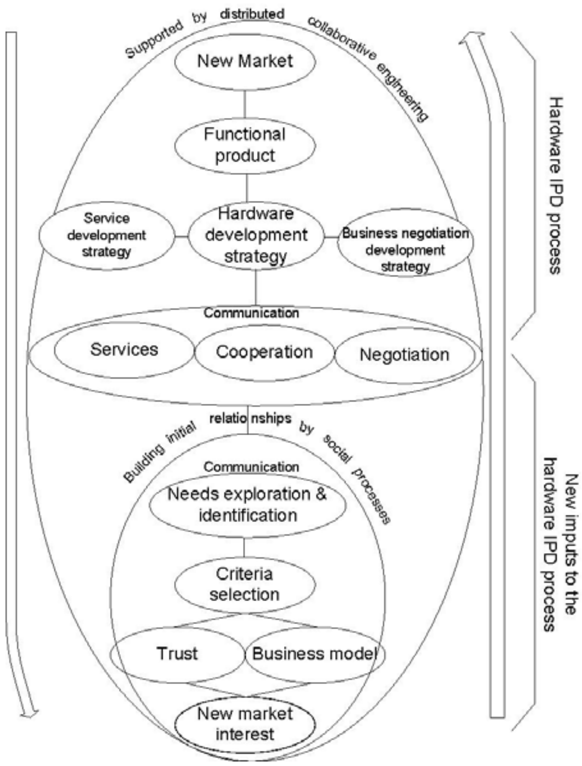

Figure 2: A model of assumptions for functional products success in industry.

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.

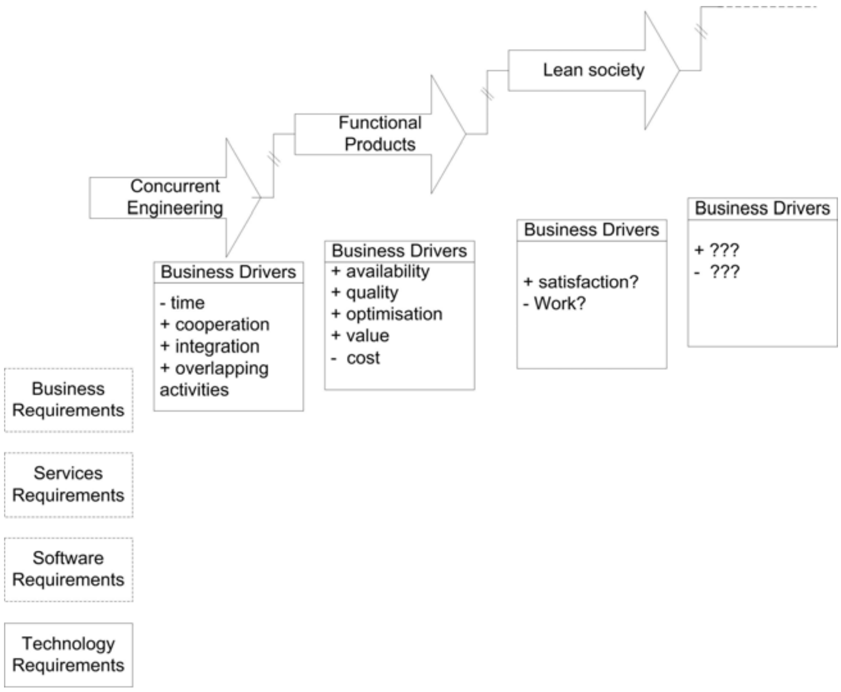

Figure 3: The changing nature of the business environment

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.

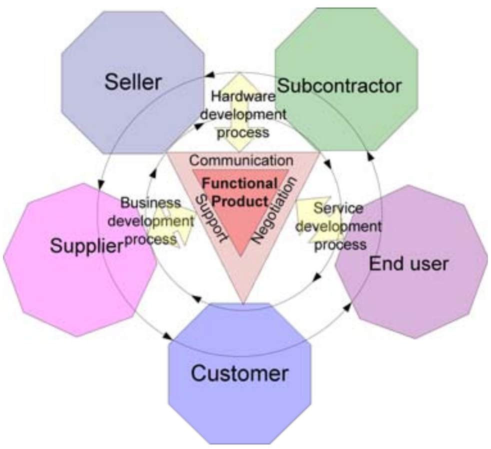

Figure 4: Process integration in networks for functional product development

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.

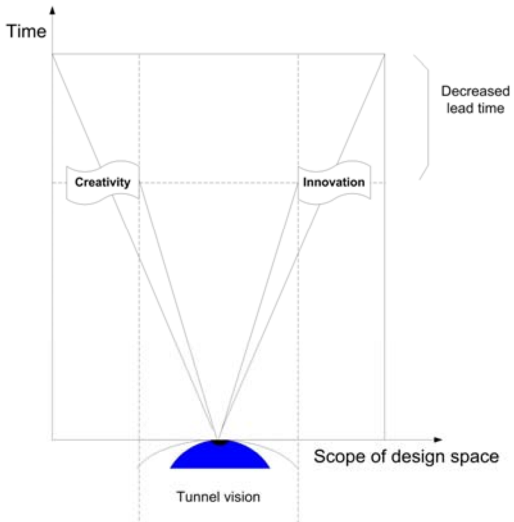

Figure 7 Increasing time and production demands tunnel vision

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.

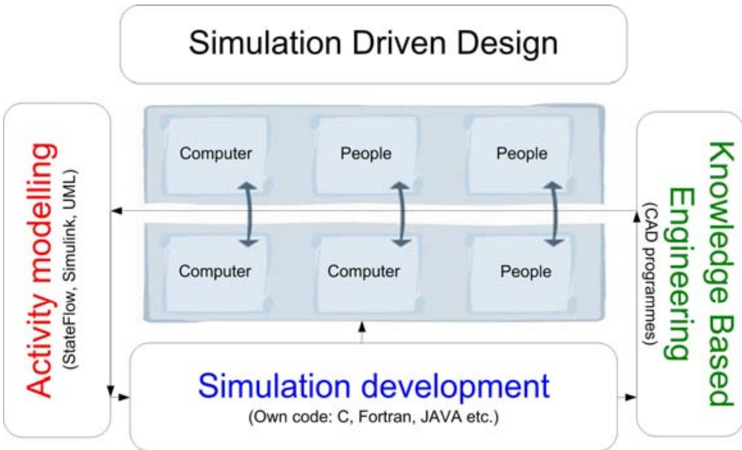

Figure 8: A schematic representation of a simulation support tool for functional product development

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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