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A SYSTEMATIC APPROACH FOR DECISION MAKING IN A CONCURRENT ENGINEERING ENVIRONMENT

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ABSTRACT

Anyone who has been involved in the introduction of a new product knows that during the project you will pass many major crossroads, where the choice of direction will be crucial to whether or not the project will be a commercial success. It is not only about developing products - hardware, software and services - that best satisfies the market wants and needs, but also about doing the job faster and more effectively than the competition. Those who have the best competence and methods for making the right choices will take the lead, become the dominant players in the market and do the best business.

The ability to understand the big picture of product development, so that in addition to making superior products companies can build efficient services around these with an optimized Life Cycle Cost (LCC), is crucial for their success.

In traditional development the product is designed for a supply system or the supply system is design as a second step after the design of the product. In concurrent engineering the supply system is designed in parallel with the product. To make the right decisions a complex structure must be handle by the development team. This structure also depends on where in the product life cycle the product/supply system under development is. Axiomatic Design provides principles that can help to take these decisions based upon actual facts, facts related to many parameters.

This paper focuses on the interaction between the market, product and supply system in a concurrent engineering environment. An outline of a decision model for the interaction is presented based on ongoing research within this field. By using this structured approach business managers can make the right decisions and obtain the objectives that were set up in the start of the development project within budget and time limits.

Keywords: Axiomatic Design, Concurrent Engineering

1 INTRODUCTION

In a time of increasing global competition, it is more important than ever to see marketing as an integral part of the product development process. The winners have left behind the market segmentation and positioning approach, and are instead focusing on real innovation and the creation of sustainable competitive advantage.

Product development in a customer-driven organization means developing products that bring new and greater value to the market. In other words, creating products that increase the customer satisfaction and the loyalty to the firm.

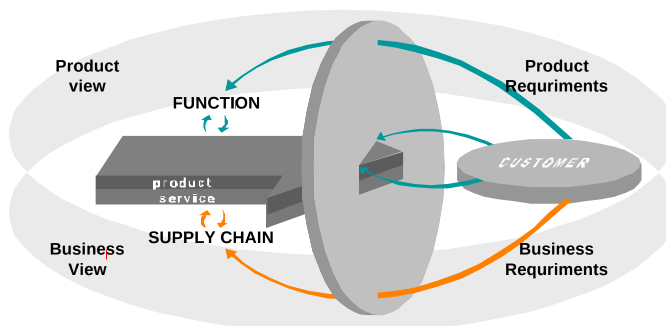

Figure 1 The "big" picture of product development

Since companies of today have access to similar information and knowledge, products within a specific category tend to get more similar. This imposes demands on the company to provide more values that are non-physical to the customers, in form of services and supply performance (Business view in figure 1). These kinds of performance are strongly related to logistics and the activities throughout the supply chain. In this paper, a model showing how to deal with decisions regarding the interactive relationship between the design of the supply chain and the design of the product are proposed. The model, when fully developed, will make it possible to make the right prioritization between supply chain requirements and product requirements from current market demands and position in life-cycle in a concurrent engineering environment.

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2 TOOLS IN CONCURRENT DEVELOPMENT

When working in a concurrent environment many issues must be taken in consideration such as: Teamwork, communication, interfaces, roles and responsibilities [1]. When working in cross-functional teams it is important that the team has a common view on the design and market possibilities. To create this common view, language and reference models are needed so that everybody understands and interprets these in the same way in the project. This paper is focusing on the supply flow and its interaction with the product. In order to get this interactions working the following frameworks are needed; the supply view, the product life cycle view, cost calculation and decision making.

2.1 THE SUPPLY-CHAIN MODEL

The reference model SCOR (Supply-Chain Operations Reference-model, figure 2) can be used to configure the supply chain based upon the business strategy. It provides standard descriptions for the activities within the supply chain, and identifies the performance measurements and supporting tools suitable for each activity. This reference system enables all involved parties in developing and managing the integrated supply chain to work together effectively. Each part of the supply-chain is designed separately as it is defined in the SCOR-model [2].

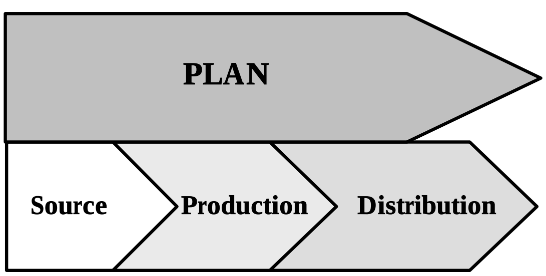

Figure 2. The SCOR reference model.

Supply-chain management requires a shift away from traditional functional models towards managing a set of integrated business processes. The company must implement these processes based on a vision of the entire supply chain. This vision derives from knowledge and understanding of the company's strategy, objectives, competition and customer needs. Developing integrated supply-chain processes enables companies to respond quickly to changes in the market. Once integration is in place internally, it can be extended to suppliers and customers, forming an integrated supply chain. In such an extended enterprise, planning is shared and execution processes are integrated. The supply chain now begins to truly encompass the business - from the supplier's supplier to the customer's customer.

2.2 PRODUCT COST ESTIMATION

Obviously, it is important that in every product development project to have a realistic idea of what all the processes and products costs are. A differentiation between accounting and business economics must be done. In a company, models are needed that enables decisions making about alternative realization paths. In product cost estimation, models are needed that clearly shows how the costs are distributed between the various operative activities that must be performed on the product.

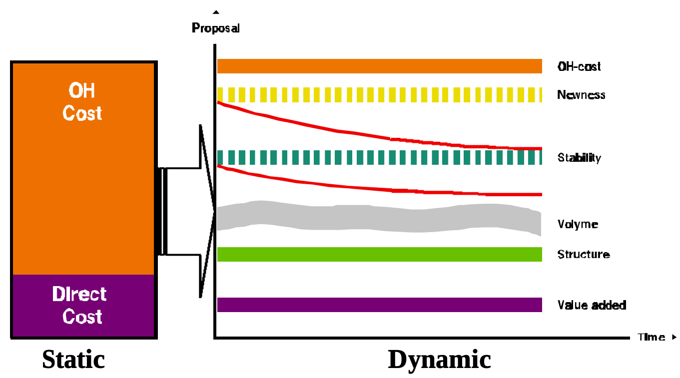

Figure 3 The dynamic business cost model

A model might look like the one in figure 3.

The Structure OH (overhead) gathers costs that arise as a result of the product's structure

The New OH gathers costs related to new technologies, suppliers, processes, etc.

The block called Stability OH gathers costs that are connected to the instability of the products and processes, such as yield, testing, re-engineering and repairs.

The importance of a "helicopter" view of costs cannot be sufficiently stressed. It is difficult, but extremely important for the project's profitability, to have an overall control of how costs in one part of the project are affecting other parts. Here are some examples:

The lowest price is not always the cheapest: A unit that is more expensive to purchase can give lower production costs and Life Cycle Cost (LCC).

Existing units control the design: It might be that in choosing between different design solutions, one should take into account what it is most appropriate to buy and what it is most appropriate to manufacture.

Investments that are not profitable on initial calculation can be profitable in the overall calculation: A major investment, such as the software for the design project, might not be profitable for this function but can turn out to result in costs that are so much lower for Supply that the total effect is an increase in profitability.

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Product development should aim at optimizing the whole – organizational circumstance and relationships must not lead to sub-optimization. Different volumes give different solutions: By being prepared for major changes in volumes (everything from a fifth to five times the originally estimated volume), alternative solutions can be chosen so that the best profitability irrespective of production volume can be achieved.

Thinking in terms of platforms and modularization gives economies of scale. An introduction of standardized norms for the interface, mechanical, electrical, etc, leads to re-use of modules from one project in many others.

2.3 THE PRODUCT LIFE-CYCLE MODEL

When planning companies marketing strategy firm's mainly uses the product life-cycle model. However, it also relates indirectly to the manufacturing strategy since the model covers issues such as volume, variety and industry structure. Other aspects of the product life-cycle are nature of competition and the product itself. The model provides a framework for the product's evolution over time.

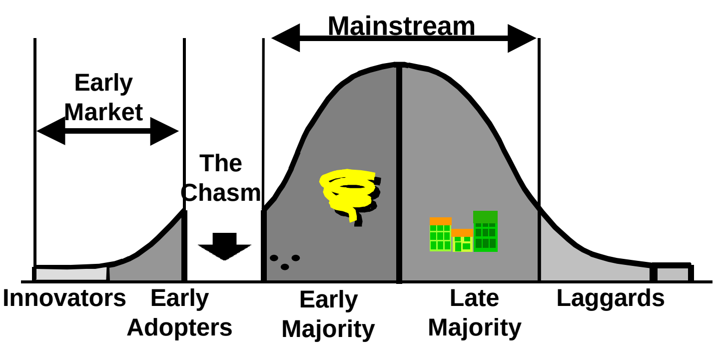

Figure 4 The revised generalized product life-cycle for high tech markets

What also is known is that the rates of product and process innovation shifts over time. In the beginning of a product life-cycle the product innovation is higher than the process innovation. However, over time the process innovation takes the lead. This change in innovation lead is linked to the transformations over time for product, process, competition, market and organization [3,4]

2.4 AXIOMATIC DESIGN

The Axiomatic Design Approach provides a compact visual way of expressing design intent and overall design objectives. The goal is to shorten the lead-time it takes to develop good solutions by making a rational design the very first time. The fact that axiomatic design provides the designers with a framework that guides them through the designing process makes it possible for inexperienced persons to quickly become good designers. This will for example reduces the random search process for the best solution and make it easier to choose the best alternative among many proposed [5,6,7].

The reason why this theory got the name axiomatic design is because it is based on two axioms. Axioms are truths that cannot be derived but for which there are no counterexamples or exceptions. The axiomatic design theory is based on the following two axioms:

Axiom 1 The independence axiom:
Maintain the independence of the functional requirements.

In an acceptable design, the functional requirements (FR) and design parameters (DP) are related in such a way that a specific DP can be chosen and adjusted to satisfy its corresponding FR without affecting any other functional requirement.

Axiom 2 The information axiom:
Minimize the information content.

The best design, among functionally uncoupled designs, is the design that has the minimum information content.

Axiomatic design follows the four design domains; the customer domain, the functional domain, the physical domain and the process domain. The domains are related in the following way:

Customer domain: This domain describes the customer needs (CN: s) or/and the attributes the customer is looking for in a product or a process.

Functional domain: In this domain the customer needs are specified in terms of functional requirements (FR: s). This translation must be done in a solution neutral environment, which means that FR: s must be defined without constraining yourself to look at already existing solutions.

Physical domain: Here are the design parameters (DP: s) defined that aim to fulfill the functional requirements.

Process domain: To produce the product specified in terms of DP: s a process is developed that is characterized by the process variables (PV: s) in the process domain.

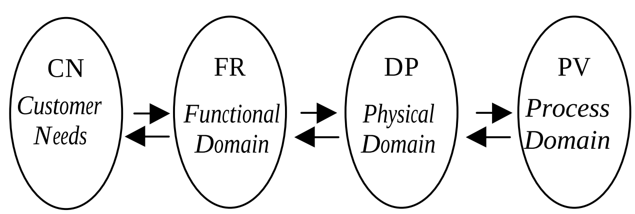

Figure 5: The domains are related in such a way that the domain on the left side represents "what we want to achieve" and the domain on the right side represents "how we can satisfy" the requirements of this left domain

The mapping process can be expressed mathematically in terms of the characteristic vectors. The relation between these vectors can be described as:

{FR: s} = [A] {DP: s} or
{DP: s} = [B] {PV: s}

In these equations A is a matrix defined as the design matrix and B is a matrix that characterize the process design. To find out if a specific design is coupled or uncoupled the pattern of the matrix in the equation can be studied. The matrix must be either diagonal or triangular to satisfy the independence axiom. When the design matrix is diagonal, the design is uncoupled. This means that each of the FR: s can be satisfied independently by means of one DP each. When the matrix is triangular, the design is de-coupled. This means that the independence of the FR: s can be guaranteed if and only if the DP: s are changed in a proper sequence.

A detailed design requires a decomposition of the design problem into a design hierarchy. Zigzagging between the domains accomplishes the development of the tree-shaped design hierarchies below. The illustration describes how the zigzagging should be done between the functional- and the physical domain.

2.5 OTHER DESIGN TOOLS/METHODS

Firms of today have a number of powerful tools for the product view such as CAE/CAD for designing, modeling, simulation and technically analyzing of our products. However, these tools must be strengthened by tools that make it easier to take decision in early phases, to stimulate creativity and, finally, to help us analyze/optimize different aspects of our product systems that have been created. Such tools are available [8,9]:

Theory of Inventive Problem Solving (TIPS) helps to stimulate creativity.

Modular Function Deployment (MFD) and similar methods supports in defining the product architecture and solve issues regarding concentration and location of modules, interfaces and technical risks.

Robust Design builds in and verifies robustness.

Pugh Concept Selection evaluates the concepts and selects concept for further development.

DFx (where x can stand for several things, such as Assembly, Manufacturing, Environment...) helps to optimize the modules.

Quality Function Deployment (QFD) to convert customer demands to requirements and makes prioritization between them, voice of the customer.

3 CONCURRENT DESIGN OF SUPPLY-CHAIN AND PRODUCT(S)

That order-winners and qualifiers for products are existing is clear to most people, but that order-winners and qualifiers for manufacturing also exists isn't so clear. Examples of criteria that can be stated for manufacturing are cost, delivery reliability, delivery speed, quality, demand increases and product range [10]. Depending on where the company is positioned on the product life-cycle the weight on these criteria are different. In other words different strategies are needed and the focus for our manufacturing system depends on where on the product life-cycle the product are. Out from this it can also be said that decision support for supply-product issues is needed in the product development process [11,3].

All the tools mentioned earlier needs to be used in a combination decide by the design problem and the market environment. The process to integrate design, supply-chain and marketing is an iterative process. The companies must throughout the product introduction process continuously monitor changes in the - market, product, supply-chain and technologies and adapt the ongoing work to these changes to hit the market with the right product package at the right time.

In conjunction with above the product must also be position in the supply-chain structure of the business and adapted to the "*clockspeed*" it is running with. The way of doing this is to use concurrent design of product, process and supply-chain [12]

By using the words of Hayes and Wheelwright it can summarize in the following way: "Designing a manufacturing process technology should not be an afterthought, a hurried response to market selection or product design. It must be configured around the needs of a particular product design and competitive strategy, while exploiting the availability of potentially applicable manufacturing technologies" [11].

3.1 AN AXIOMATIC VIEW OF THE CONCURRENT ENVIRONMENT

The idea of designing the production system by using axiomatic design as a framework has been studied and presented in several papers. However all contributions have more or less chosen to start from the company's interest in profit maximization. This is of course a good way but unfortunately it doesn't include customer satisfaction [13,14].

In addition, the previous work in this field tends to define either the production system or the product as fixed. The approach in this paper defines both product and production system as variables. By developing these two variables concurrently, the firm can make the right development with a focus effort in the product and the production system to maximize the overall performance in the current market situation.

As earlier mentioned the axiomatic approach divides the design world into four domains; customer, functional, physical and process. When designing product and supply-chain concurrently there will be two parallel flows as in figure 6. The first flow, on the top, is the domains for the product design and the second flow, in the bottom, is the domains for the supply-chain.

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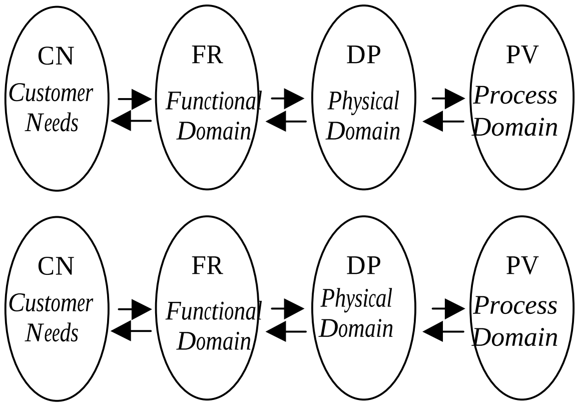

Figure 6 The two design domains for concurrent product and supply development

However, since the customer is the same for both product and the supply-chain and the process (supply-chain, manufacturing system) is the same there will be a design structure as shown in figure 7. This is valid for an uncoupled design between product and supply-chain in a concurrent engineering environment [15].

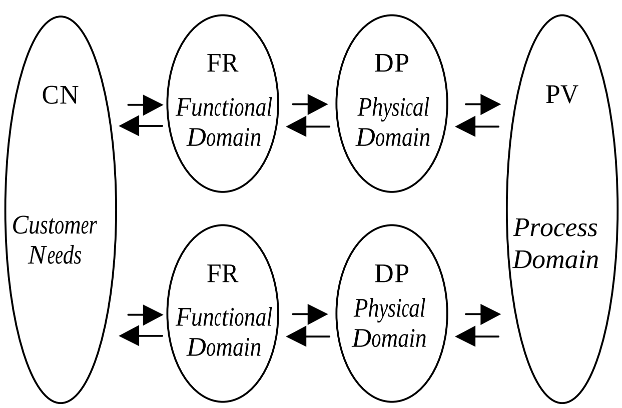

Figure 7 The design domains in uncoupled concurrent design environment

This is straightforward and gives a view on a marriage between the product and the supply-chain in the process domain. But isn't there an interaction between the domains during the process or can they be treated as two separately flows?

In the case that the two flows are uncoupled it can be treated as two separate flows. However, is this valid for all design environments? To answer these questions lets look at an example.

When designing electronic products many decisions must be taken that, both involve design, sourcing and manufacturing. The design environment is very complex with decisions that involved software, hardware and silicon design (Application Specific Integrated Circuits, ASIC) it also involves suppliers and manufacturing. When making design decisions in these environments companies must look at the market situation and the demand on flexibility, reaction times, quality and stability.

In the electronic industry there is a pressure to reduce/improve the size, weight, operator-handling etc on electronic products such as mobile phones, Walkman, video cameras and in many cases it is also a clear order winner for these products. At the same time it is known that delivery performance, quality, availability etc also are important since customers like to have this type of equipment directly when it arrives to the market. If any of these demands are not fulfilled the customer will go to the competition. This situation can be stated in following FR domain for the products (P) and supply-chains (SC) as:

FR1(P) = Reduce the size of unit by x %
FR2(P) = Minimize the weight of the product
FR3(P) = Easy handling for operator

FR1(SC) = Improve delivery performance (time)
FR2(SC) = Improve the yield
FR3(SC) = Improve the lead-time through supply-chain

This gives us following DP's for product (P) and supply-chain (SC).

DP1(P) = Use smaller components
DP2(P) = Use light weight material
DP3(P) = Use self explaining interface (software)

DP1(SC) = Predictable production process
DP2(SC) = Use known building practice
DP3(SC) = Use no-buffer strategy

This gives us following design matrixes.

$$\begin{Bmatrix} FR1(P) \\ FR2(P) \\ FR3(P) \end{Bmatrix} = \begin{bmatrix} X & - & - \\ - & X & - \\ - & - & X \end{bmatrix} \begin{Bmatrix} DP1(P) \\ DP2(P) \\ DP3(P) \end{Bmatrix}$$

The product will be an uncoupled design.

$$\begin{Bmatrix} FR1(SC) \\ FR2(SC) \\ FR3(SC) \end{Bmatrix} = \begin{bmatrix} X & - & - \\ X & X & - \\ - & X & X \end{bmatrix} \begin{Bmatrix} DP1(SC) \\ DP2(SC) \\ DP3(SC) \end{Bmatrix}$$

The supply chain will be a de-coupled design.

From this case, some linkage can be found between the four domains since the choice of components effects both the product and the supply-chain, this can be described in following links:

The product requirement domain and the supply-chain design domain.
The product design domain and the supply-chain domain.

The supply-chain requirement domain and the product design domain.

The supply-chain design domain and the product requirement domain

This cross linkage, see figure 8, between the two flows shows some kind of dependencies between the domains.

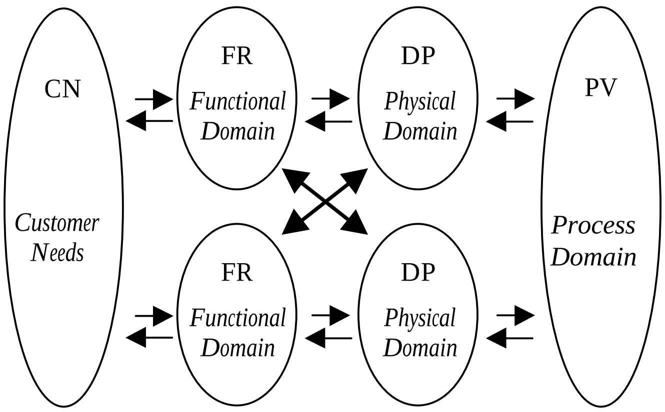

Figure 8 The revised x-link model for design domains in a concurrent environment for product development

One way of interpreting this x-link is to use the product maturity model that shows that different behaviors on the market exist depending on the maturity of the product. In the early phases of a product the focus are on technology issues. In the later phases of the product life cycle the focus is more on supply-chain issues. Using this model the x-link can be interpreted as follows:

In the simples cases the x-link is constraints for each functional domain.

In the case of acting in the early part of the product life cycle the link from FR(p) shows that changes in the supply-chain design domain has to be done.

In a mature market, the link FR(sc) shows that the product must fulfill these requirements to gain competitive advantage.

In-between these three cases further research has to show how, the interpretation of the x-link shall be done for different market situations in the decision process. The decisions that must be taken here are dependent on where on the product life-cycle the product is.

4 FUTURE RESEARCH

One of the goals with the first part of this project has been to connect 15 years of practical experience with deeper knowledge and understanding of the research field of product development. The research issue has been to see how to connect market situation with decisions taken in product development. One of the ways to succeed with product development is to use cross-functional teams. From this, it's about time that cross-functional research is used to find the answers on how to further improve our capabilities in the field of product development. The next step in the research project is to cross borders to find the pieces that are missing in the model and also to find examples in companies that shows that the model is working after needed adjustments.

5 CONCLUSIONS AND DISCUSSION

When making decisions in a concurrent development environment some framework is needed that guides our decision making in the design work. This framework has to be linked with the development of essential areas over time, which effects the success of the new product development. These essential areas are product, supply chain (incl. production system), competition, market and organization. The goal is a business driven "whole product" development environment, which is match with the market and time frame that it operates within.

Taken the four principles for design as suggested by Sohlenius [16], regarding functional independence, max probability, minimal energy and shortest time as a base for the decision framework. From the discussion above and together with these four principles a fifth principle regarding market and life-cycle situation for the product can be stated. A proposal for this can be:

A design matched with its business system and adapted to its market and product life cycle is superior.

6 ACKNOWLEDGMENTS

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