Proceedings of ICAD2002
Second International Conference on Axiomatic Design
Cambridge, MA – June 10-11, 2002
ICAD 016

A DECISION FRAMEWORK FOR INTEGRATED SYNCHRONIZED DEVELOPMENT OF HIGH TECH PRODUCTS

Michael Sahlin
michael.sahlin@era.ericsson.se
KTH, Department of Production Engineering and Ericsson AB
Brinellvägen 68, SE-100 44 STOCKHOLM

ABSTRACT

In a fast moving business world with constraint in resources and highly complex products development managers have to make the right decisions in short time frames with limited information. To improve these decisions tools and methods are needed to guide and support decision-makers in this tough time limited environment. To survive companies need to be first on the market with excellent products and services. On the other hand they have limited resources, complex design problems and high profitability demands to handle. To focus on the right opportunities tools are needed to get the right solutions in the right order for the highest profitability out of the development projects. Those who have the best competence and methods for making the right choices will take the lead and do the best business.

In traditional development, the product is designed for a supply system. The demand system is often given by mainly using existing system. In an integrated synchronized engineering environment, the demand and supply systems are designed in parallel with the technology to optimize the total product offer. With resource constraints, the need to focus on the highest business potential is necessary. Traditionally this focus has been on the product technology for technology driven high tech companies. In a global highly competitive economy the focus has to be on the right areas of the total product offer. To make decisions in this complex environment, a framework is needed to guide the decision-makers. Axiomatic Design provides principles and a framework that helps to make these decisions based on actual facts, facts related to many parameters in a complex environment.

This paper focuses on the interaction between the technology, the demand system and the supply system in an integrated synchronized engineering environment. An outline of a decision model for this interaction is presented based on ongoing research within this field. By using this structured approach, business managers can focus their decisions to the right areas of product offer to obtain the best business objectives for the new product.

Keywords: Axiomatic Design, Concurrent Engineering, Supply Chain, Demand Chain

1 INTRODUCTION

Change is important for survival in a fast moving world. Competing in this environment puts high demands on the people involved in product development. Each new product is a new opportunity for the company to succeed. To do this, the efforts have to be focused on the right issues that gives the highest return on the investment in shortest time. Traditionally companies compete with new technology in the products but to be a leader its not enough to be good in the technology dimension; the company has to be good in all dimensions of the product. A product can be viewed in three dimensions:

· The technology dimension; which is the functional view of the product or the actual service that operates on the customer site.

· The demand dimension; which is all activities in the company that interact with the customer to create a demand of the service.

· The supply dimension; which is all activities in the company to fulfill a customer demand.

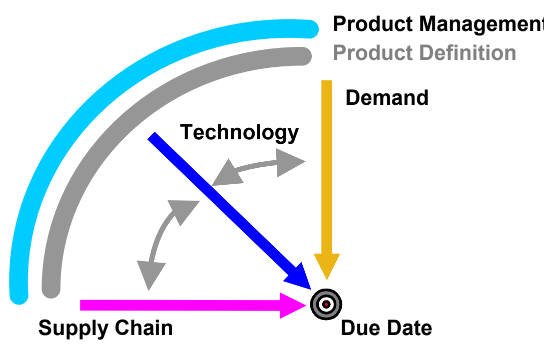

Figure 1. The three dimensions of product development

A forth dimension is the service dimension which in this model is viewed as a product itself connected to the main product that creates the service demand.

In a time of increasing global competition, it is more important than ever before to work with a product from all dimensions in the product development process. The winners are focusing on real innovation and the creation of sustainable competitive advantage in all dimensions of the product. Or as

Gary Hamel [2000] says; "competition is no longer between products or services, it's between competing business concepts".

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

Since companies of today have access to similar information and knowledge, products within a specific category tends 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, demand and supply performance. These kinds of performance are strongly related to the demand and supply chain activities of the company. In this paper, a model showing how to deal with decisions regarding the interactive relationship between the design of the product technology and the design of the demand/supply chains (processes and systems) is proposed. The model, when fully developed, will make it possible to make the right prioritization between the three dimensions of the product over the product life-cycle in a synchronized engineering environment.

2 BASIC FRAMEWORK

When working in an integrated synchronized environment many issues must be taken in consideration such as; teamwork, communication, interfaces, roles and responsibilities [Sohlenius 1992]. In the integrated cross-functional teams, it is important that the team has a common view on the design, supply and demand possibilities. To create this common view, language and reference models are needed so that all team members understand and interpret these in the same way. Combined with an effective communication and implementation of the company's mission, vision and objectives as proposed by Werneman, et al. [2000] the context for a creative environment is set. This paper is focusing on decision making after the initial definition phase of product development and the interaction between the demand/supply flow and the technology flow. In order to get these interactions working frameworks are needed for value chain, product portfolio management, product life cycle and decision making.

2.1 THE HIGH TECHNOLOGY VALUE-CHAIN

The design goal is a product that contains all the necessary values or an appropriate combination of values at the minimum lifetime cost. The values of a product come in various forms, such as: functionality, reliability, portability, producibility, serviceability, availability, emotional satisfaction etc.

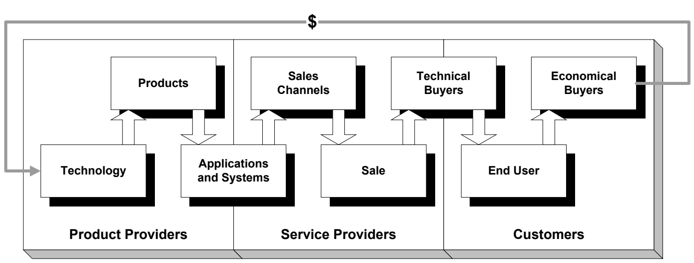

Figure 2. The High-Technology Value-Chain

The important issue is the lifetime value of the product. The design team must identify the required values and include these into their design during all phases of development and for all dimensions of the product [Moore 2000].

All parts of the value-chain contain activities from the demand and supply dimensions of the product. For example, the applications and systems box, in figure 2 includes production, material handling and order handling for the system product.

2.2 PRODUCT PORTFOLIO MANAGEMENT

There are a number of techniques that are used to establish how company project and product portfolios should evolve over time to preserve and enhance the company's competitive advantage. Many organizations have good experience with technology roadmaps for deriving likely paths to feasible products, and the technology that has to be acquired or developed to bring them to the market. These may be used in conjunction with matrix plots to examine the technological position of the company or its business units in relation to the maturity of the sector or markets in which they operate.

A similar approach may be applied to the individual projects that make up the portfolio to ensure balance (strategic fit) in terms of risk/reward, impact on competitive position/market familiarity, short and long term activities. The availability of appropriate resources now and in the future is an essential element of a good portfolio.

Portfolio management is a complex process, bringing together people from Technology, Supply, and Demand function. Constant interaction between the portfolio management and the road-mapping process will ensure a balance between strategic aims and feasible outcomes [Cooper 2000][McGrath 1995].

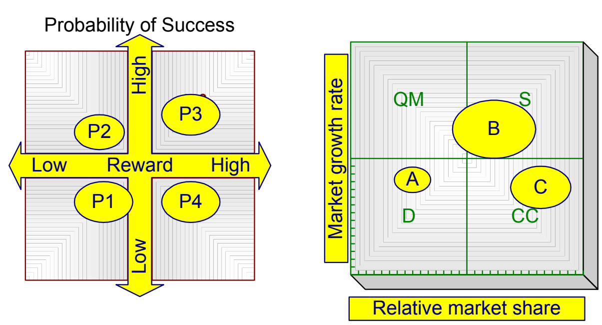

Figure 3 Project and Product Portfolio Management

Product development should aim at maximizing the customer value – organizational circumstance and relationships must not lead to decrease in customer value. Different supply and demand structures give different technology solutions. By being prepared for major changes in volumes, response times and perception, alternative solutions can be chosen so that the best profitability irrespective of change can be achieved.

2.3 THE PRODUCT LIFE-CYCLE MODEL

When companies plan their demand strategy they mainly uses the product life-cycle model. However, the model also relates indirectly to the supply and technology strategy since the model covers issues such as volume, variety and industry structure. Other aspects of the product lifecycle are nature of technology adoption, competition and the product itself. The model provides a framework for the products value evolution over time.

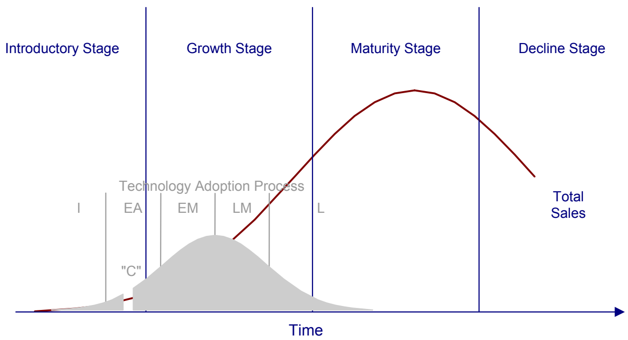

Figure 4 The generalized product and technology adoption life-cycle

What is also known is that the rates of technology and demand/supply innovation shifts over time. In the beginning of a product life cycle, the product innovation is higher than the demand/supply innovation. However, over time the demand/supply innovation takes the lead. This change in innovation lead is linked to the transformations over time for product, demand/supply, competition, market and organization [Utterback 1994][Moore 1999].

2.4 Decision And Criterions In Development

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. Using a framework that guides the designer through the designing process makes it possible for inexperienced designers to quickly become good designers [Suh 1990, 2000][Nordlund 1996].

In Axiomatic Design, it is necessary to start with a definition of relevant, accurate and independent Functional Requirements. Decisions are using axioms as decision criteria in the selection of Design Parameters. FRs must be defined with target values and tolerances for acceptance. The two initial axioms focus on functional quality.

Axiom 1: A Design causing less Coupling between FRs is superior

Axiom 2: A Design with higher Probability to meet FRs is superior

Add to these the two additional axioms for productivity, proposed by Sohlenius [2000]:

Axiom 3: A design requiring less energy to create is superior

Axiom 4: A design requiring less time to create is superior

Axiomatic design uses four design domains:

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 the design parameters (DP:s) are 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.

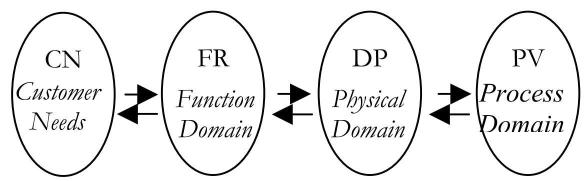

Figure 5: Your design appears in the design domain. The question why, is answered to the left and the question how, is answered to the right. The design has to be described and simulated in a model that also evolves within the design process.

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.
- Triangular, the design is de-coupled.
- Other, the design is coupled

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 domain and the physical domain.

Combining Axiomatic Design with the principles about robust design as suggested by Sohlenius [2000], with the timing principle suggested by Sahlin [2000], a base for the design decision framework is formed.

DECISION	CRITERION	PRINCIPLE	EFFECT
Functionality	Functional Independence	Axiom 1	
Certainty	Max Probability	Axiom 2	Quality
Robustness	MinVariance Sensitivity	Rob. Design	
Effort	Minimal Energy	Cost	
Access	Shortest Time	Time Estimate	Productivity
Timing	Right Time	Market Rhythm	

Figure 6: Decision theory for engineering design [Sohlenius and Sahlin, 2000]

3 INTEGRATED SYNCHRONIZED PRODUCT DEVELOPMENT OF TECHNOLOGY AND SUPPLY/DEMAND-CHAIN

That order-winners and qualifiers for products are existing is clear to most people, but that order-winners and qualifiers for demand and supply also exists isn't so clear. Examples of criteria that can be stated for supply are; delivery reliability, delivery speed, quality, volume flexibility and product range [Hill 1993]. Criteria for the demand dimension can be stated as launching method/time, tender response time, order flexibility, ordering method and more. Depending on where the company is positioned on the product life-cycle and in the product portfolio the weight on the three dimensions are different. In other words different strategies and focus are needed for our technology, supply and demand system depending on the position in the product life-cycle and the product portfolio. In other words a decision support for demand-supply-technology issues is needed in the product development process that can handle the interaction and time issues between the three dimensions [Utterback 1994][Hayes 1984].

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

3.1 THE TECHNOLOGY DIMENSION

The technology dimension of a product consists of all hardware, software, services, knowledge and information needed to build the physical or non-physical product that are delivered or performed for the customer. For a new product, system or service most of the components that are used are new for the companies that are involved. Depending on the technology life cycles and product modularity, carry-over components from other products can be used in the new product to reduced risk. In all cases, changes are needed in information and knowledge about the new product. For all new technology an interaction with the other dimensions will occur.

3.2 THE SUPPLY DIMENSION

The supply dimension of a product consists of all activities, transactions, systems and information needed to supply a new product/service until payment by the customer. In most cases, the company can use existing activities with minor changes, but in some cases, it is necessary to redesign activities and support systems. Every time a new product is introduced, changes are needed in information and knowledge about the new product. An interaction with the other dimensions will occur at any change in the supply system.

3.3 THE DEMAND DIMENSION

The demand dimension of a product consists of all activities, transactions, systems and information needed to launch a new product and until the company get a confirmed order. In most cases, the company can use activities in place, but in some cases, it is necessary to redesign activities and support systems. In all cases, changes are needed in information and knowledge about the new product. When change is needed, an interaction with the other dimensions will occur.

3.4 THE INTEGRATED DECISION SUPPORT MODEL

The idea of designing the product or the production system by using axiomatic design as a framework has been studied and presented in several papers. The previous work in this field tends to define either the supply system or the product as fixed. As shown by Sahlin [2000] or Mårtensson/Fagerström [2000] there are interactions between the supply and technology dimensions. The approach in this paper defines technology, supply and demand system as variables. By developing these three dimensions synchronized, the company can focus the development effort on the dimensions that 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 technology and supply/demand-chain synchronized, there will be three parallel flows as in figure 7. The first flow, on the top, is the domains for the demand-chain design and the second flow, in the middle, is the domains for the technology. The flow in the bottom is the domains for the supply-chain.

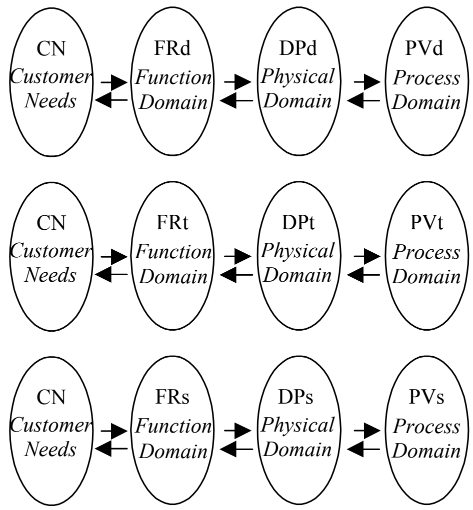

Figure 7 The design domains for technology and supply/demand development

However, since the customer is the same for all three dimensions and the process domain can be divided into demand and supply process the model will change into the structure as shown in figure 7. This is valid when we have the activities before the actual buy order separated from the execution or fulfillment of the order. This structure is valid for an uncoupled design between the three dimensions in a concurrent engineering environment [Killander 1995].

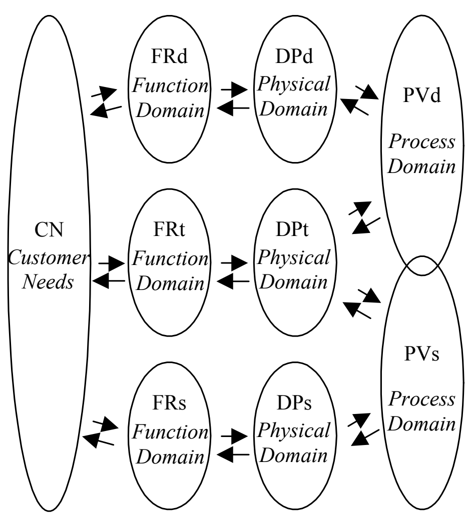

Figure 8 The design domains in uncoupled concurrent design environment

This is straightforward and gives a view on a dual marriage between the product technology and the two processes, demand-chain and supply-chain, in the process domain. This is traditionally handled as a second phase in product development called industrialization where the supply and demand systems are designed after the technology are developed for the new product. In addition, what happens is that the technology has to be redesigned to fit in the demand/supply systems. This is a time and resource consuming way of product development. A better way is to develop the three dimensions in parallel. If we can separate the three dimensions, we will have an uncoupled design of the total product and no interaction between the dimensions. However, in many cases actions have to be taken to solve the interactions between the three dimensions. This can be illustrated by following case.

When designing electronic products many decisions must be taken that involves the three dimensions technology, supply and demand. The technology environment is very complex with decisions that involve software, hardware and silicon design (Application Specific Integrated Circuits, ASIC), and it also involves sub-suppliers, suppliers and manufacturing. An other interaction area is the sales objects of the product, which includes the solutions, and features that the customers are requiring at a certain time. When making design decisions in these environments designers must look at the market situation and the demand on flexibility, reaction times, cost sensitivity, 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 mobile-phone-systems. At the same time it is known that delivery performance, quality, price, 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 competitors. This situation can be stated in following FR domain for the technology (T), supply-chain (SC) and demand-chain (DC) as:

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

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

FR1(DC) = Launch the product at fair XY
FR2(DC) = Improve the tender lead-time
FR3(DC) = Improve the tender accuracy

This gives us following DP's for technology (T) and supply-chain (SC) and demand-chain (DC).

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

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

DP1(DC) = Use visual working prototypes
DP2(DC) = Use web-based support system
DP3(DC) = Use sales objects

This gives us following design matrixes.

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

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.

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

The demand chain will be a de-coupled design.

Looking on the interaction matrix's between the three dimensions. The I(t) in the matrix indicates a time dependent interaction between FR(T) and DP of supply and demand dimensions. These interactions are bi-directional. In the FR-DP direction, it indicates a constraint for the DP. In the DP-FR direction it indicates a constraint or a new FR in technology domain, see also Mårtensson/Fagerström [2000].

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

$$\begin{Bmatrix} FR1(T) \\ FR2(T) \\ FR3(T) \end{Bmatrix} = \begin{bmatrix} I(t) & - & - \\ I(t) & - & - \\ - & - & - \end{bmatrix} \begin{Bmatrix} DP1(DC) \\ DP2(DC) \\ DP3(DC) \end{Bmatrix}$$

In this simplified case, the time dependent interaction-matrixes are introduced to handle the interaction between the different dimensions of a product in an Integrated Synchronized Product Development environment.

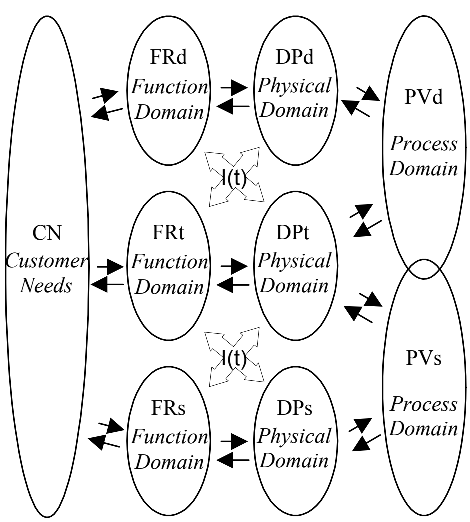

Figure 9 The revised interaction model for design domains in an integrated synchronized environment for product development

These two cross linkages, see figure 9, between the three dimensions are showing some kind of time related dependencies between the domains.

One way of interpreting the interaction matrix is to use the product life-cycle 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/demand-chain issues. Using this model, the interaction matrix can be interpreted as follows:

- In the simple cases, the x-link introduces constraints for the functional domain in each dimension depending on the interacting dimension solutions in the physical domain.
- In the case of acting in the early part of the product life cycle the links from FR(t) shows that changes in the supply-chain and demand design domain has to be done.
- In a mature market, the links FR(s) and FR(d) are showing that the technology dimension must fulfill these requirements to gain competitive advantage.
- In between these two cases above the x-link introduces constraint on and lower level FR's in the interacting dimension. The interpretation of these interactions depends on the productivity effects on the product (see figure 6).

4 FUTURE RESEARCH

The research issue has been to see how to connect the market and supply situation with decisions taken in product development. Integration and synchronization of the three major flows in the company are a major issue for the overall business success. 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 are showing that the model works after needed adjustments.

5 CONCLUSIONS AND DISCUSSION

Making decisions in a concurrent development environment a framework that guides the managers in the product development work is needed. 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 technology, supply chain (incl. production system), demand chain, competition, market and organization. The goal is a business driven product development environment, which is synchronized with the market and technology pace.

Ideally, it is vital to know what dimension in the product to continue to work with, what to change and what to abandon. However, you never know. On the other hand, engineering methods for design can improve the business performance for organizations. Making conclusions based on this study should leave the need for systematic approaches in product development more perspicacious than ever. Without systematic approaches, the dependence on single individuals familiar with the total system will remain. Therefore, the results will change over time. Sustainable solutions for organizations are necessary in a world rapidly changing. The presented framework should facilitate logic solutions leading to sustainable products.

Applying the framework presented in this paper requires analysis of customer's and companies demand, this takes time.

However, decision making in product development is concurrently done without any systematic approaches and this is time and resource consuming. More investment of resources in the initial design phase of an organization is known to be profitable. Optimal solutions are however often time consuming to find. One of the fundamental strengths of the model presented in this paper is the enabling of the time dependent interactions between the product dimensions. Furthermore, the complexity of product innovations are difficult to remove, the awareness of it should provide a logic understanding for finding the best solutions. Applying the framework thus integrates the work of increasing productivity, quality and learning in many aspects.

6 ACKNOWLEDGMENTS

I would like to sincerely thank my colleagues at the Department of Production Engineering at KTH and at Ericsson for the contributions enabling me to conduct this research.

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