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# CONCURRENT DECISION MAKING FOR HIGH-TECH PRODUCTS AND SUPPLY SYSTEMS

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## 1. Introduction

In a fast moving business world with limitations in resources and highly complex products, managers have to make the right decisions in short time frames with far from perfect information. To improve these decisions, tools and methods are needed to guide and support decision-makers in a time-limited environment. To survive companies need to be first on the market with excellent products and services. Support tools are needed to focus on the right opportunities and to get the right solutions in the right order for the highest profitability out of the innovation projects. Those who have the best competence and methods for making the right choices will take the lead and do the best business. The winners are focusing on real innovation and the creation of sustainable competitive advantage in all dimensions of the product.

When working in an integrated synchronized environment many issues must be taken in consideration such as; teamwork, communication, interfaces, roles and responsibilities. When working in integrated cross-functional teams it is important that the team has a common view on the technology, supply and demand possibilities. To create this common view, language and reference models are needed so that all team members understand and interpret the common view in the same way.

The purpose of this research is to elucidate decision making in the context of the innovation process by providing a model, which combines the decision making with innovation process. The model will be based on a concurrent engineering way of thinking. The questions for this research are as follows:

- Which processes occures in the innovation system?
- What are the properties of the decision-making mechanism?
- How do the decision-making interact with the innovation process?

By answering these questions, we hope to provide the means to achive a better decision making in the innovation system. With a better decision-making, we believe that the information, to support the decision-making in the innovation system, is more reliable and effects the quality and productivity of the decisions.

## 2. Research Method

The purpose of this study was to create a generic model that provides answers to the research questions. To structure the research process, the model of research presented in figure 1 was used.

The object of observation is the innovation system with the decision-making process. It was observed in order to develop a generic model of the combined system. What was actually observed can be stated in three main objects:

- theories concerning concurrent engineering
- methods dealing with innovation processes
- case studies dealing with the innovation process

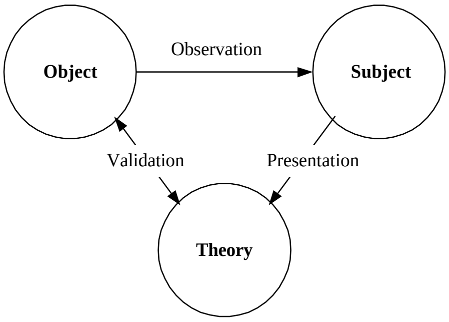


**Figure1. Model of Research [Fagerström and Moestam Ahlström, 2001]**

Some of these objects are dealt with in studies performed earlier by the authors. Naturally, many other publications influenced the study and could consequently be considered as objects (Andreasen and Hein, Hubka and Eder, Pahl and Beitz, Ulrich and Eppinger, Suh, Pugh…). However, to announce all of them here is neither possible nor desirable.

The observations have been carried out according to a hermeneutic research method. The work followed the hermeneutic circle [Føllesdal, et al., 1993]. That is, the research started by putting up a hypothesis stating a generic model with the objective to answer the research questions.

The subjects observed, analyzed and created synthesis. The analysis was done of each hypothesis, comparing it to the results of the observations of the objects. Since earlier stated theories were observed, the subjects could hardly influence the objects with their observations. However, the background and experience of us, as being the subjects, naturally, had affect on how the objects were interpreted. Furthermore, the knowledge about Axiomatic Design and the Business Processes were used as tools for both analyzing and synthesizing the hypothesis.

The theory is presented in the form of a generic model with an appurtenant written description. One can argue that a theory is always a model, but a model is not necessary a theory [Føllesdal, et al., 1993]. However, in this case the model is being used as an information carrier with the purpose to guide the designers to good decisions in the innovation process, and is to be considered as a theory supporting an efficient innovation process.

The validation of the model is naturally best performed if the model proves itself to be useful in innovation processes. Unfortunately, this type of validation is a far to extensive operation to cope with within this project, but it could be an object for further research. However, the use of a recognized research method provides the means for other researchers to evaluate the results of this paper.

## 3. The phases in a generic innovation system

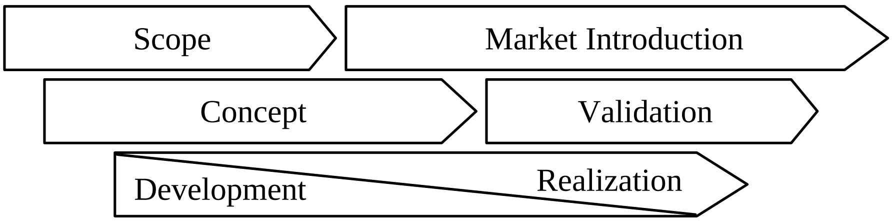


**Figure 2. A generic innovation system**

Figure 2 presents a model for the phases of a generic innovation system. The model will be used in this paper as a framework for describing how decisions are connected to the innovation system. A successful innovation system requires cross-functional collaboration across many disciplines, effective management and parallel syncronized development of technology, demand and supply systems as well as competence.

The five phases of a generic innovation system in figure 2 are:

| | |
|---|---|
| Scope | In this phase the company evaluates business opportunities, using assumptions of the future. These assumptions needs to be clearly identified and reviewed. |

| | |
|---|---|
| Concept | Alternative product and supply processes are generated and evaluated here. The phase ends with a selection of a single concept. Furthermore, the competence gaps are defined. |
| Development/Realization | Complete specification of the product, supply process and identification of all purchased parts are conducted in this phase. New competence development is also conducted. |
| Validation | In this phase a complete evaluation of the physical system design, competence and supply process are performed. This phase ends with preparations for volume production and deliveries. |
| Market Introduction | This phase includes product launch marketing, sales channels preparation, volume production, distribution and support of the product. |

## 4. Decision-Making in the Innovation System

After studying several methods for innovation systems, it becomes clear that these methods help the designer to create a model of what is essential in the real world. The data, collected in the models, are used to formulate information, which created a foundation for decision-making. There is also often some decision criteria attached to the methods.

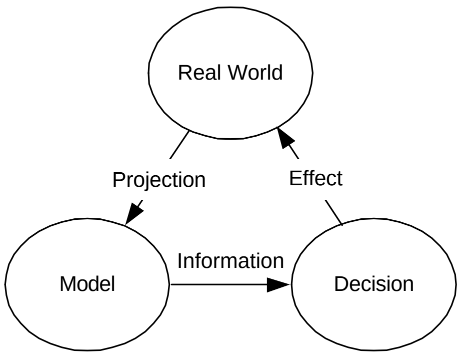


**Figure 3. Fagerström's model concerning basic parts and relationships in methods for development processes**

The model in Figure 3 shows the basics in the theory on the characteristics in innovation processes, that is, how the real world, the model and the decision-making are connected. The model is a projection of the real world. The data collected in the model forms the basics for the decision-making. The decisions will, when carried out, give an effect in the real world.
To be able to communicate on specific parts in the theory, it is important to establish a common view. The author's view is described more in details in the following solutions in this chapter.

### 4.1 The Model

The aim of this chapter is not to give a complete view of models in general, but to highlight important aspects of models put up for developing processes. The use of the word model in this paper refers to a model that makes it easier to see, understand and focus on the important factors that are hard to grasp in the real world. A good model could be described as a representation of something, where certain characteristics, which are important for the purpose of what the representation is going to be used for, are accentuated, while the other characteristics are left out [Føllesdal et al., 1993].
In order to get an overview on models, it is useful to clarify what kind of models that exist, and classifying the models does this. An easy way to keep track of different kinds of models is by their appearance. Models are often classified by their appearance in the following way:

- Physical models
- Mathematical models
- Analogous models

The models presented above have in common that different persons could observe them. However, there is another, most important, type of model that only appears to one person. This is the mental model [Fagerström and Moestam Ahlström, 2001].
The mental models are important both for the observation of the real world and for the presentation of the observed object. The mental model is, naturally, the most used model and functions as the foundation for all other types of models.

### 4.2 Projection of the Real World into a Model

When choosing models for development work, the following basic rules must be taken into consideration:

- The definition of the model's purpose
- Viewpoints on the model
- Detailing level in the model

Once the starting point for the model creation is determined – in terms of purpose, viewpoint and detailing level – the development process can start.

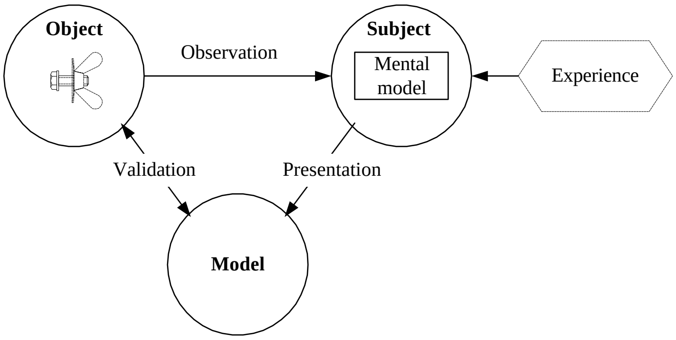


**Figure 4. The process for development of models**

The process, for the development of models, follows the same structure as creation of theories, see chapter 2. The projection of the real world into a model follows the same basic principles presented in Figure 1. In accordance to this, the projection of a model can be broken down into the same three steps as the creation of a theory [Fagerström and Moestam Ahlström, 2001]:

- Observation
- Presentation
- Validation

### 4.3 Information

To start with, a distinction between data and information has to be done. Data is captured in the real world and put into the models. The data in the models are, when used for decision-making, transferred into information. This is done by the user with the help of his or her interpretation of the data. How data can be transferred into information is closely related to how the model is presented and, later, understood by the user. This is especially important to think of when the one who puts up the model is not the same person as the one who transfers the data into information.
The better information you have when making the decisions, the more likely it is that a good decision is made. However, there is also a backside of gaining perfect information and that is the cost to obtain the information. Consequently, a trade-off has to be made between the value of the information and the cost of it [Fagerström and Moestam Ahlström, 2001]. Two measures can be used for this; how hard it is to collect the information and what value the information will have for the decision-making process. In the end, naturally, it is the importance of the decision that determines how accurate information that is needed. The more the decisions affect the real world and the more sensitive the real world is to bad decisions, the more can the information be allowed to cost.

## 4.4 Decision-making

The decision-making is the key factor for successful innovation projects. Bad decisions in the innovation processes can be disastrous for the whole company. A good decision in a innovation process is a decision that gives an effect in the real world, which brings you the closest way to the goals that were put up for the innovation process.

Today many decisions are taken on poor grounds. In a decision-making situation, the social context often has greater impact than the actual facts. Authority and conceptual framework are examples of factors that are decisive rather than objectivity and analytical ability.

The critical part when making decisions is to have the right information. If perfect information is provided, it is theoretically possible that all decisions will be good. However, the perfect information is a theoretical construction and is never achieved in the real world. This is why most of the decisions are made with a certain degree of uncertainty. Decision criteria have been put up based on experience and statistics in order to help the decision-maker to make good decisions. Most innovation methods have decision criteria that are related to the information, which is gained from the models used in the method. Decision critera should as far as possible is based on scientific ground. Good decisions are also depending on how the goals are defined.

## 4.5 Uncertainty in Decision-making

The ideal situation would be if the model provides the decision-making process with all the information needed to make a good decision. Unfortunately, this is not the condition in most cases. Three different kinds of uncertainty in a decision-making process can be classified:

- Uncertainty concerning the outcome
- Uncertainty concerning values
- Uncertainty concerning connections

Uncertainty concerning the outcome of a decision can most often not be exactly determined. This is especially hard to control if the outcome is depending on factors that cannot be controlled.

Uncertainty concerning values, expresses the uncertainty with what is desired and considered important. For instance, if there are several goals for a innovation process and the goals are in conflict with each other, some confusion about how to fulfill them might occur.

Uncertainty concerning connections emerges when there is an information gap between, for instance, different sub-processes in the innovation process. That is, if a decision in one part of the organization, for instance marketing, is affecting decision-making in another part of the organization, for instance supply, an uncertainty emerges due to the lack of information on decisions made in other parts of the organization. The knowledge of these kinds of connections is, for practical reasons, often limited, which makes them difficult to take into consideration.

## 4.6 Decision Criteria in Innovation Process

The decision criterion is defined and named differently in different development methods. Examples on criteria for decision-makings frequently occurring in methods are; decision axioms, guidelines, decision roles, rule of thumb, maximizing rules, minimizing rules. The common denominator is that they have been put up to guide the designers to good decision-making.

How to understand the criteria and which one to use are, naturally, depending on the context for the decision-making and what type of decisions that are to be made. It is crucial to have the right information when a specific criterion is to be used. The criterions listed in Figure 5 are perhaps the most basic set that exists today.

When making decisions concerning functionality and certainty it is helpful to use the models in the method Axiomatic Design. Axiom 1 and Axiom 2 are decision criteria in Axiomatic Design [Suh, 1990].

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

**Figure 5. Decision and Criterions in Innovation work [Sohlenius 2000][Sahlin 2000]**

Axiom 1 states that an uncoupled solution is better than a coupled solution.
Axiom 2 states that a solution with less information content is better. Information content (I) is calculated according to equation 1. The fundamental meaning of this axiom therefore is: A design with higher probability of success (meet FRs with tolerances) is superior.

$$I = -\sum_i p_i \log p_i \quad (1)$$

The decision criterion used to achieve robustness is minimization of variance of the objective function. The objective function must be measurable to be able to get information to support the decision criterion.
Cost is probably the best and most used decision principle for measuring of effort that exists in the industry today.
Making decisions concerning access is, naturally, a question of measuring and estimating time consumption. The importance of time in innovation processes is obvious, especially when the project is running with a commercial purpose.
Timing is about getting the product to the market at the right time with the right content. It's also about knowing the rhythms of the market so that products and inventions are available at the right time. A key concept for timing is time pacing, which refers to creating new products, launching new business, or entering new markets according to the calendar [Eisenhardt & Brown, 1998].
In innovation processes, trade-offs often have to be done between different interests. This is, unfortunately, also the case with the criterions that is pointed out here. This becomes obvious when trying to achieve effects in the real world.

### 4.7 Simulation

In order to make good decision the decision-maker needs access to the appropriate information. The information can be provided using different computer tools. Computers are handling the simplest form of information, namely the collected raw data like, for instance, numbers or sentences that are describing certain properties of the observed real world object. The models used for decision-making are built up of static relationships between data. [Ullman 2001] To be able to test the characteristics of the real world object projected in the model, the behavior of the model must be studied.
The testing of characteristics on models is normally referred to as simulation, see Figure 6. To do a simulation means that the decisions are tested on models and not on the real object. That is, the decision guides the direction of the effect tested on the model. Useful information can be obtained by doing simulations. This information is later used as a base for decisions to achieve desired effects in the real world.
Computer aided simulation as a decision support technology has been used for many decades. In the manufacturing industry, simulation has been used for rapid system prototyping. Testing of subsystems and full systems is considered a bottleneck in the system design process. The simulation is in this

context seen as a mean of reducing the extent and the time of hardware and software testing.
Simulation can, during the earliest phases of system design, be used for design concept evaluation without any need for hardware testing. Later on, the different simulation techniques such as hardware in the loop simulation (software models running together with real hardware) and human in the loop simulation (where interfaces are tested) can be utilized.

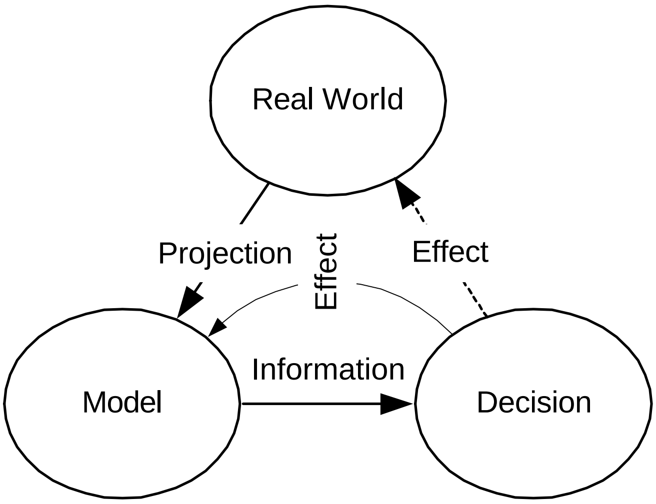


**Figure 6. Model of simulation [Fagerström and Moestam Ahlström, 2001]**

Different simulation tools are used in different decision situations during the development of different systems. In concurrent development of products and their production systems, the simulation tools are used in all innovation phases. The simulation tools and methods that are often used during the mechanical product design are, for instance, Finite Element Analysis, Multi-body System Dynamics, and Computer Aided Tolerancing. These products are manufactured in a production system developed using simulation tools like, for instance, Discrete Event Simulation and Multi-body System Dynamics.
All data that describe models of products and production systems are manipulated by, and shared between, different computer tools. Those data are stored and retrieved in/from different persistent storage systems such as relational and object databases. In large enterprises, the data that is manipulated during the development activity is distributed across different databases. The users do not need to be concerned with tracking the data but with the design that they are creating. Therefore, all data that the development team members are manipulating during the development process must appear as stored in the same central database. This central database is central in logical sense but is physically distributed across different servers and is managed using some system for product data management (PDM) [Aganovic 2001].

### 4.8 Effects in the Real World

The effects you want to have in the real world are the effects that bring you closer to the goals that were put up. What these effects might be, differs from case to case. What could be concluded, though, is that the direction in which the effect should work is determined by the goals, and the direction it actually will act in, is determined by the decisions that the effect was based on. If it is a good decision, the decision's direction will be towards the goal.
To carry out decisions in the real world is, naturally, not that easy as it might appear. Depending on what decision that is made, different skills and methods are required, for instance: leadership, knowledge, communication and cross-functional cooperation.

# 5. A model for decision making in the innovation process

The model in Figure 8 shows how the decision making is done throughout the innovation process. Decisions are made both in vertical direction for coordination of the concurrent work and in the horisontal direction for controlling the  progress in the development work.

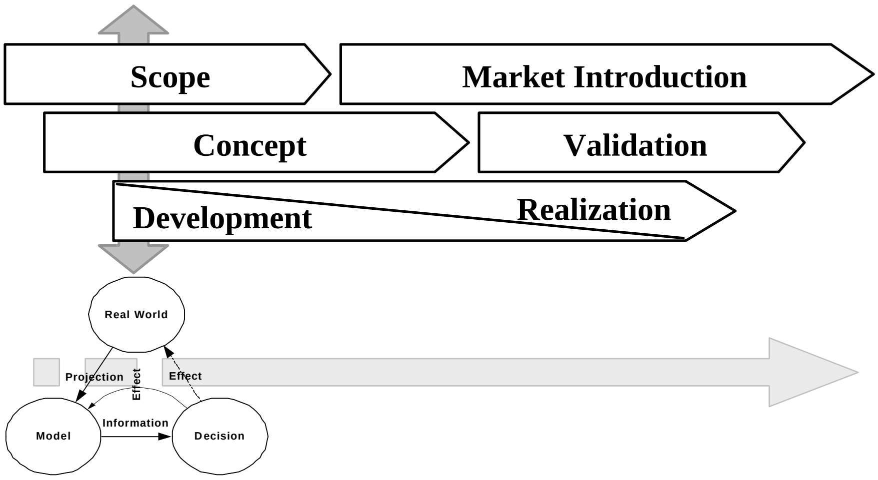


**Figure 8. Decision making in the innovation process**

Information from both the digital model and the mental model are used for decision making. In the beginning of the innovation process most of the information for decision making is fetched from the digital model. But during the innovation course, when the realization of the product and the corresponding production system enlarges, gradually more information are collected in decision makers the mental model and used for decisions.

# 6. Examples from high-tech industries

## 6.1 Electronic products

Development of electronic products as personal computers and mobile phones are made under very hard time press. To reach the market first or at the same time as the competitors launches their corresponding products are of highest importance.

The integrated product development comprises both the product and its building blocks and their production processes. Electronic products consist of hardware and software, and the software is executed in the hardware to perform the product functions. Hardware realization is made by choosing and combining different types of building blocks, interfaces and processes. Building blocks are modules, components and parts.

During the design of the hardware for a new product, decisions has to be taken early and concurrent about what type of production processes that will be used. This is due to the production technology can be coupled to the type of modules and component packages. For instance, if critical components for performing some of the product functions, like processors, memories or ASIC:s ( Application Specific Integrated Circuits), only can be purchased and supplied (from the component supplier) in specific packages, the supplier (assembler) of the PBA:s (Printed Board Assemblies) must use the corresponding production technology for mounting and soldering/bonding the components on boards. Different types of component packages are adapted for hole mounting and surface mounting, but components can also be delivered without packages for bonding of naked chips on boards.

Processing time in semiconductor fabs are normally very long (several months) for complex integrated circuits as ASIC:s. This means that every extra redesign of circuits due to engineering changes, for instance correcting errors in design or changing package for the circuit, delays the product introduction with at least the corresponding time (several months). It is therefor important that design decisions are concurrent and correct to keep short lead times in product development.

### 6.2 Product Packages

The main intentions with Product Packages are to standardize product offers to the market, reduce delivery time for customer orders and decrease costs in the Supply Chain. The Product Packages are realized by standardized building blocks (Modules). Functions and characteristics of the Product Packages are provided by different configurations of standardized Modules.

Product Packages and Modules are formed early in the product development process so the product offers can be launched to the market before the Product Packages and the Modules are realized completely. Modules can be made by different suppliers and assembled according to configuration rules to the ordered Product Packages.

Product Packages can be regarded as sales objects in Marketing, as design objects in Product Development and as order and delivery objects in Supply Chain. By introducing Product Packages decisions about forming the Product Packages and the corresponding Modules have to be taken concurrent by Marketing, Product Development and Supply Chain.

## 7. Conclusions and Discussion

Due to inaccurate information, lack of solid decision criteria and fuzzy requirement specifications, the efficiency in innovation processes is lower than it could be. The common strategy can be expressed as a build-test-fix strategy. By improving quality in requirement specification, decision criteria and modeling, quality and productivity could be improved. We can aim at a requirement-consept-improve strategy in the innovation processes. The business strategy has to be combined with a competence strategy where competence gap filling is a part of the innovation process. To be able to make good decisions in a concurrent environment a framework, that guides the decision-making in the innovation process, is needed.

Three models are presented in this paper: a model of the processes in an innovation system, a model of the decision mechanism in innovation processes, a model which elucidate decision making in an innovation process. These models structure the processes in the innovation process and then provides a transparency for decision makers working in the innovation system.

The methodology used in this paper follow a hermeneutic approach. This emphasize that the work have been carried out following the hermeneutic circle. This approach might not be the most common in nature science. However, the research carried out here is closer to social science and therefore is the hermeneutic method appropriate even if the study is conducted in a natural science environment.

The focus in this study is on decision-making in an innovation system and good decisions are the most important factor for a successful innovation of new products.

Similar models to both the innovation process model and the decision–making model can be found in literature [Fagerström et al. 2002] [Fagerström and Moestam Ahlström 2001]. In this paper are the sub-processes of an innovation system represented as they are carried out concurrently whereas in the paper Multi-Viewpoint Modelling of the Innovation System – Using a Hermeneutic Method [Fagerström et al. 2002] are the sub-processes carried out in sequence. Most of the theory for the mechanism in decision-making is the same in this paper as it is in the paper Demands on Methods for Developing Work Focused on Concurrent Engineering [Fagerström and Moestam Ahlström 2001]. However the theory is here used in a completely different context which brings new understanding to a new area of research.

A limitation in the results is that the models presented in this paper has not been validated in a real innovation process. Thus, it is difficult to say how well it can support an innovation process. It has also been difficult to validate the models by comparing them with well-known and accepted models described in literature. However, this may on the other hand confirm the uniqueness of the models.

An other limitation is that the usefulness of the models in other business areas than the business for high-tech products, has not been considered during this study.

A few matters have been identified for further research: a case study, or several, to validate the models, increase the scope of the models to include organization and company strategy design and a more thoroughly analysis of all the information flows in an innovation system.

Ideally, it is vital to know what part in the product offer 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 design more clear-sighted than ever. Without systematic approaches, the dependence on single individuals familiar 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 innovation phases is known to be profitable. Optimal solutions are however often time consuming to find. Two of the fundamental strengths of the model presented in this paper are the combine used of model and real world to improve the information for decisions  and the divition in coordinating and detail decisions. 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.

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