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MULTI-VIEWPOINT MODELING OF THE INNOVATION SYSTEM – USING A HERMENEUTIC METHOD

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1 ABSTRACT

A multi-viewpoint modeling was conducted to obtain a better understanding of how to work in a concurrent engineering way within an innovation system. The modeling was carried out using a process-, a design- and a function centric viewpoint. The *process centric viewpoint* divides the innovation process into a development and a realization phase. The development phase was further divided into preparation, development and validation. The realization phase was divided further into source, make and deliver. The *design centric viewpoint* dealt with the iterative design processes both within and between development processes, from an Axiomatic Design perspective. It also dealt with the connection between development processes in terms of constraints and decision-making. The *function centric viewpoint* stated the functions and different kinds of flow that occurs in an innovation process. In the *multi-viewpoint model* the connections between the different viewpoints were stressed. This raised the understanding, of the whole innovation system, to a higher level. A better understanding of the innovation system provides the means for good decision-making concerning both productivity and quality.

Keywords: Innovation System, Concurrent Engineering, Multi-viewpoint

2 INTRODUCTION

A product-supplying enterprise operating with the objective to maximize its profit has to focus both on finding an efficient way of working within the enterprise and to get its products out on the market. To work in an efficient way is normally a necessary condition to be able to successfully promote the product on the market.

One way to insure that the enterprise will meet a ready market is to work with a good market mix[1]. The most well known market mix consists of the four P:s, that is Product, Price, Place and Promotion [Kotler, 1997]. The first three P:s are supported by the innovation process[2] of the enterprise. The innovation process is, naturally, executed in the innovation system[3]. This concludes that an efficient innovation process should provide the enterprise with the right products (quality) to the right price (effort) at the right place (time). To complete the market mix, support from the fourth P, promotion, is needed. The promotion can bee seen as a way to put the results of the other factors in the market mix to use and make them visual to the market. Working with this market mix provides the enterprise with good qualifications for a successful market strategy, resulting in a profitable business.

The focus of this paper will be on how to achieve an efficient innovation system, that is how to support the first three P:s in the best way. This entails that the promotion factor will not be dealt with directly. However, one can always argue that the innovation system provides the promotion factor with good arguments and is, consequently, dealt with indirectly.

In order to get an efficient innovation process within the system, decisions have to be made concerning both quality and productivity [Sohlenius, 2000]. With quality we mean that the right product functions are realized within tolerance, and at the time and to the price that the customer demands. In other words, the product will fulfill the objectives that the market has put up for it. With productivity we mean both the time and the effort needed for realizing the product, that is, the time needed to gain access to the product and the effort needed to realize the product. Working with quality and productivity is in line with the market mix's demands on the innovation process. That is, it requires high quality to provide the right product, short time to meet the market window and, finally, the use of as less effort as possible in order to keep the price down.

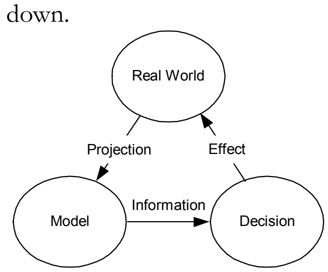

Figure 1: Fagerström's model [Fagerström, 2001]

In order to make good decisions, the need for the right information and suitable knowledge to interpret it is crucial

[1] Market mix is the set of marketing tools that the firm uses to pursue its marketing objectives in the target market [Kotler, 1997].

[2] The innovation process in normally considered to be a course that incorporates the birth, the development and the establishment of ideas in the technical-science area [Agdur, 1996].

[3] The definition of the innovation system is (according to OECDs); the innovation system consists of a network of organizations, human beings and game rules in which creation, spreading and innovative exploration of technology and other knowledge occurs. In this paper we refer to the innovation system as if it consists of both the development and the realization of products and a responding manufacturing system.

[Fagerström, 2001]. With good decisions we mean decisions that brings you closer to your objectives. With the right information we mean the information needed to make good decisions. The information is collected in models, which are projected from the real world. That is, the model is a projection of the real world, the information collected in the model forms the basics for the decision-making, the decisions will, when carried out, give an effect in the real world that hopefully brings you closer to the objectives of the innovation process. This is visualized in Fagerström's model, see Figure 1.

All processes are initiated by a decision and a meaningful decision must be followed by a process in order to be conducted. To be able to make good decisions during the innovation process, there is a need for transparency in the innovation system [Moestam Ahlström and Kjellberg 2001]. This transparency requirement indicates an obvious need for a model consisting of the generic parts in the system and steps of the process. This model could act as a map to navigate after when making decisions with the purpose to establish an efficient way of working in the innovation process.

2.1 Research Questions

The purpose of this research is to gain transparency in the innovation system by providing a model of the generic steps in the system. The model will be based on a concurrent engineering way of thinking.

The questions for this research are as follows:

- What kind of generic processes occur in the innovation system?
- When (in which order) should the processes be conducted?
- Which functions are executing the processes, and how are these functions connected?
- How are the design decisions connected to the processes?

By answering these questions we hope to provide the means to get a better transparency in the innovation system. With a better transparency we believe that the information, to support the decision-making concerning quality and productivity, in the innovation system, becomes better.

2.2 Business Processes in an Innovation System

The business processes are referring to the unique ways in which an organization coordinates and organizes its operations to produce valuable products and/or services [Laudon and Laudon, 1998]. The operations of an organization include various, directly or indirectly, value-adding processes which involve creation, communication and the utilization of material, information and knowledge.

Different ways of organizing the operations in a business process have evolved over the decades, for instance, the functional organization and the process organization of which the latter is the most recent evolved. Whereas the functional organization focus on *who does what,* the process organization focus on *how the result is produced*. In a process organization the customer demands are better understood and, thus, easier satisfied. In addition, unnecessary operations can be cut while streamlining the core value-adding business processes [Aganovic and Jonsson, 2001]. However, even if the process organization is applied, the enterprise must still have an understanding of the functions that are needed to execute the set of processes.

A process organization way of working implies that the whole business process is divided into different phases, which are carried out in a stepwise manner. The division into phases is defined based on the shifting of focus, as the business process life cycle is accomplished. In this paper the focus is on the innovation process phase, which is an important phase of the business process. In each sub-phase of the innovation process phase, analysis and synthesis are performed in order to fulfill its objectives. This type of model is often referred to as a *state-gate* model [Cooper, 1988] [McGrath, 1996].

The key driver of the analysis and synthesis in a phase is the decision-making. In addition, another type of decision-making occurs in the interface between two phases. This decision-making handles the question if the previous phase is completed and the project can move on to the next phase or not, this is presented in the *Phase Review Model* by McGrath [McGrath, 1996]. In this model, three optional outcomes of the decision are identified; *go*, *no* and *redirect*. Where *go* means that the objectives of the previous phase are fulfilled and the next phase can be initiated, *no* means that the process is terminated and will not be continued and *redirect* means that the objectives of the previous phase are not fulfilled and, consequently, some rework has to be done. This decision-making that occurs between the phases is often referred to as tollgates.

2.3 Axiomatic Design

Axiomatic Design [Suh, 1990] is a method that provides the designer with a logic approach to design tasks. Thus, the designer will get a good structure and documentation at all hierarchical levels of the design object regardless the extent of the design task. The logic structure and its documentation help the designer to come to decisions based on solid foundation and also to transfer the design information to other designers in a comprehensible way.

Furthermore, Axiomatic Design states two design axioms that assist the designer to make good decisions about the quality when choosing between different design concepts. The design axioms also provide rational means for evaluating the quality of proposed solutions at all levels. The independence axiom (the first axiom) entails that the independence of functional requirements should be maintained. The information axiom (the second axiom) entails that the information content should be minimized. In addition, Professor Sohlenius suggest some further axioms concerning productivity [Sohlenius, 2000].

In the Axiomatic Design theory the design process is divided into four domains. The first domain is the customer domain, in which the customer's needs are collected, that is, the input that will affect the design object. The second domain is the functional domain, in which the functional requirements (FRs) are stated. FRs are extracted from the needs that the final product or process must satisfy, that is, the customer needs. The third domain is the physical domain, in which the design parameters (DPs) are stated. Every DP is a concept to fulfill one FR, that is, one DP corresponds to one FR. The fourth domain is the process domain. In the process domain process variables (PVs) are stated.

Every PV is a process to fulfill the concept stated by one DP, that is, one PV corresponds to one DP.

Besides the domain, there is an additional feature that has to be taken into consideration to complete the design process model, and that is the constraints. The constraints are limiting the available solution space. There are two types of constraints: input constraints and system constraints. Input constraints are extracted from the customer domain and are often the result of decisions made outside the current development process. System constraint is the result of earlier decisions made within the current development process, often at higher levels in the design hierarchy.

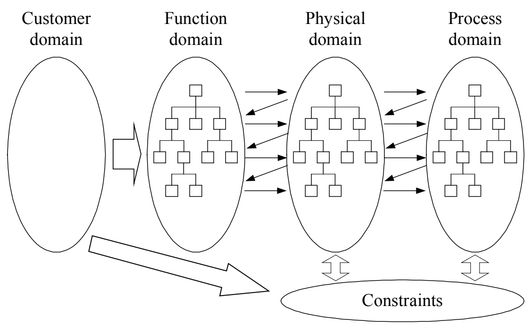

Figure 2: The process model in Axiomatic Design

Axiomatic Design also deals with the hierarchical nature of designs, which appears in the functional-, physical- and process domain as trees with, in the ideal case, identical structures. The functional-, design- and process trees grow throughout mapping between the domains and decomposition within them. The mapping between the domains creates the trees on each level. One level has to be mapped between all domains, before the decomposition to the next level starts. This process, carrying out the decomposition into new layers and mapping between the domains, is called zigzagging.

3 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 3 was used.

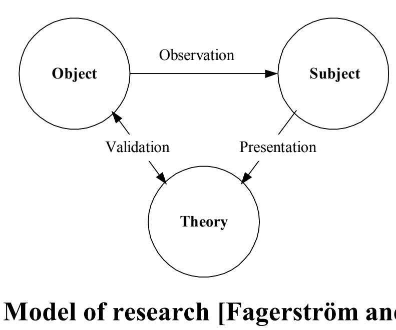

Figure 3: Model of research [Fagerström and Moestam Ahlström, 2001]

The object of observation is the innovation system. It was observed in order to develop a generic model of the innovation system and it's processes. To get a generic model, the need for an extensive review of innovation systems in several enterprises is obvious. However, within this project there was not enough time or resources to do such an extensive study. Because of this the object could not be observed directly and, consequently, the object had to be observed through already existing theories. Nevertheless, this is not to be considered as a disadvantage but rather a way to achieve a study that covers a broader field.

What was actually observed can be stated in four main objects:

- theories concerning concurrent engineering
- innovation process plans
- methods dealing with development processes
- case studies dealing with both the product development process and the manufacturing system development process.

Some of these objects are studies performed earlier by the authors [Aganovic et al., 2001] [Aganovic and Hallander, 2001] [Fagerström, 2001] [Fagerström and Moestam Ahlström, 2001] [Mårtensson and Fagerström, 2000] [Fagerström and Boman, 1998] [Fagerström and Pettersson, 1998] [Fagerström and Engelhardt 1999a, 1999b]. Naturally, many other publications influenced the study and could consequently be considered as objects [Andreasen and Hein, 1987] [Clausing, 1994] [Cooper, 1993] [Hubka and Eder, 1988] [Laudon and Laudon, 1998] [McGrath, 1996] [Pahl and Beitz, 1996] [Pugh, 1998] [Suh, 1990, 2001] [Sohlenius, 2000] [Ulrich and Eppinger, 2000]. However, to announce all of them here is neither possible nor desirable.

The observations have been carried out according to a hermeneutic research method [Ödman, 1994]. The research 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. After this the hypothetic model was compared with the theories used as objects for the research. This analysis resulted in a rejection of the first hypothesis since it was not accurate enough. The new knowledge, gained in the analysis, was used to form a new hypothesis stating a new generic model. The new hypothesis was tested just as the first one. This new hypothesis was also rejected and yet another hypothesis was stated and tested. This went on in many circles before a model fulfilling the objectives for the research was founded. This research process became an iterative process where synthesis and analysis [Ueda, et al., 2001] was alternated, just as whole and parts [Føllesdal, et al., 1993], as it is often expressed in connection to the hermeneutic circle.

The subject, in this case, is the same as the authors. The subjects observed, analyzed and created synthesis. The analysis was conducted on each hypothesis, comparing it to the results of the observations of the objects. The synthesis process creating a new hypothesis was made based on the earlier hypothesis and the new knowledge gained in the earlier analysis. When performing the analysis and creating the synthesis, the following basic rules were used. These rules were originally stated as guidance when choosing models for development work [Ross]:

- the definition of the model's purpose
- viewpoints on the model
- detailing level in the model.

Since earlier stated theories were observed, the subjects could hardly influence the objects with their observations. However, the background and experience of the subjects, naturally, had affect on how the objects were interpreted [Chalmers, 1996]. Furthermore, the knowledge of Axiomatic Design, IDEF0 and the Innovation Process were used as a tool both for analyzing and synthesizing the hypothesis. This resulted in three different views on how a generic model of the innovation system could be formed, one view derived from each tool. Finally, a generic model combining the three perspectives was founded.

The presentation of the three viewpoints of a generic model of the innovation system, and the combined generic model of the innovation system, is introduced in the section *Results*.

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 represents 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 many different innovation processes. Unfortunately, this type of validation is a far to extensive operation to cope with within this project, but it could be a good object for further research. However, the use of a recognized research method and a detailed method section, provide the means for other researchers to evaluate the results of this paper.

4 RESULTS

This section consists of four sub-sections. The first sub-section deals with the basic processes in an innovation system. The second sub-section deals with the functions and the information flow of an innovation system. The third sub-section deals with the design process in an innovation process. In the fourth sub-section, a generic model is presented, showing how all the previous presented perspectives of an innovation system are related to each other.

The purpose of putting up the models is, naturally, to answer the research questions. The detailing level corresponds to the detailing level of the answer to the research questions. The viewpoints on the models are specific for each sub-section and are, consequently, presented there. It should also be kept in mind that a concurrent way of working with the product development process and the manufacturing development process is applied in the innovation process. Furthermore, the term design object is used when referring to the product and the manufacturing system.

4.1 BASIC PROCESSES IN AN INNOVATION SYSTEM

In this section a generic model of the basic processes in an innovation system is presented. It has been modeled with a process centric viewpoint. The result of this section is presented in the form of a table in Appendix A.

Four theoretical product development process models [Andreasen and Hein, 1987], [Cooper, 1993], [McGrath, 1996], [Ulrich and Eppinger, 2000], as well as three product development process models that are currently employed at various manufacturing enterprises, [Ericsson, 2001], [Carlsberg, 1997], [Scania, 1998] have been reviewed. In addition to these models, the supply process model developed by the Supply Chain Council is also reviewed [SCOR, 2001]. Two basic stages of the innovation process, each consisting of three sub-stages, have been identified and defined. However, it should be noted that the interfaces between these sub-stages are not unambiguous. Therefore they have been classified according to their main characteristics.

Stage 1 – DEVELOPMENT: In this stage the design objects are developed. The knowledge in an enterprise is transformed into the models of the design objects. The sub-stages of this stage are controlled by various stakeholder requirements.

Sub-stage 1.1 – Preparation: In this sub-stage the organization of the project and the project outline are determined. Market needs are investigated and recognized. These needs are then organized and a formal requirement structure is established.

Sub-stage 1.2 – Development: In this sub-stage the synthesis of the design objects are carried out. The design object concept is first synthesized from the formal requirements. Thereafter, the synthesis on the system level is carried out and the design object architecture is established. Finally, the syntheses on the detail level, where modules and components of the design object are determined.

Sub-stage 1.3 – Validation: In this sub-stage the design objects are more thoroughly analyzed and their conformance towards the stakeholder requirements is checked. The results of the analysis can thereafter be used as a basis for further synthesis in the current or other projects. The validation sub-stage is the last step of the development stage.

Stage 2 – REALIZATION: In this stage the design objects are realized, using the design object models created in the development stage as a blueprint. Here, the product development project is ordering the prototype manufacturing, the installation of the manufacturing system, and the verification of the manufacturing process. Furthermore, the products ordered by early customers are made and delivered in this stage. The definition of this stage and its sub-stages is based on the Supply-Chain Operations Reference (SCOR) model [SCOR, 2001]. The SCOR-model provides standard descriptions for the processes within the supply chain, and identifies the performance measurements and supporting tools suitable for each process.

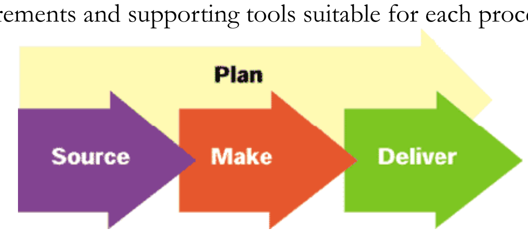

Figure 4: The basic SCOR-model

Sub-stage 2.1 – Sourcing: In this sub-stage the physical instances, that is, material, components and modules of the design object are inserted. The processes, in which the supply sources are identified, are triggered and carried out. Finally, deliveries of physical instances of the design object are planed, transferred, received and verified.

Sub-stage 2.2 – Making: This sub-stage involves the processes that must be implemented in order to transform components and modules to a specific configuration of the design object. Some of the main processes that are carried out are planned, realized and verified.

Sub-stage 2.3 – Delivering: In this sub-stage all order management steps, from processing customer inquiries and quotes to routing shipments, are encompassed. This is the last sub-stage of the realization stage and, consequently, also of the innovation process.

Virtual Stage – Planning: This virtual stage is embedded in both the development stage and the realization stage. The planning activities are executed in all the sub-stages. The interaction between sub-stages and between stages is also planned in this virtual stage.

4.2 Basic Functions in an Innovation System

In this section an IDEF0[4] model, called the *Functional Model of an Innovation System*, representing the different functions of an innovation system is presented, see Appendix B. When developing the functional model a function centric viewpoint has been used. The relationship between the function view and the process view is that functions of the production system execute the different processes. The following functions have been identified:

- **Product development –** the function where the product is developed and designed.
- **Manufacturing system development –** the function where the manufacturing system is developed and designed.
- **Manufacturing system realization –** the function where the manufacturing system is manufactured and installed, or reconfigured to meet the new product specification and the new manufacturing system specification.
- **Customer specific configuration –** the function where the product and the manufacturing system are configured according to a particular customer order.
- **Product realization –** the function where the product is manufactured. That is, where material, components and modules are transformed into a final product.

The five functions above are related to each other through different types of flow via the input, control, output, and mechanism interfaces. Three different categories of flows have been identified: *information* captured in models; *knowledge and experience* interpreted by humans, and carried by humans and models; and flow of *physical objects*. In addition, different systems and tools are used to support these functions.

The first flow consists of information and knowledge carried by models from one function to another. A model created in one function is, mainly, used to constrain other functions. Two examples of this are the *open product model* and the *open manufacturing system model*, which both are used as outputs and controls in the iterative process of the *product development* and *manufacturing system development* function. An open model means that the final design is not yet determined. Thus, the open product model will finally result in a frozen product design represented by the *product model*. Analogous, the open manufacturing system model will finally result in a frozen design represented by the *manufacturing system model*.

Another important model is the *configured product and manufacturing system model*. This model defines how the final product should be configured, and how the supply chain and manufacturing system are configured and controlled. The model is the result of the *customer specific configuration* function, which is controlled by the *product model*, the *manufacturing system model* and the *status model*. The status model is a snapshot of the actual status of the manufacturing system in the *product realization* function, and is used to control how a customer order is best realized, considering the current situation. The *customer order*, which is also a model, triggers the customer specific configuration function to be executed.

Other models of importance are the *product plan model* and the *manufacturing strategy model*. These two models incorporate the requirements from all the stakeholders, such as product platform requirements, product requirements and manufacturing system requirements.

The second flow consists of knowledge and experience. Both knowledge and experience are created and used by humans in the innovation process. Knowledge is considered to be a mix of framed experience, information and expert insight [Davenport and Prusak, 1998], for instance, product- and manufacturing system platforms and product- and manufacturing system models. It provides a base for evaluating and creating new experience and information. Thus, incorporated knowledge is used as input to the two design functions to generate new knowledge represented in the output as different models.

Experience is created in all the functions and controls all functions. However, the experience created in *product realization* and its control over the product development and the manufacturing system development has been considered to be the most important. Thus, this is the only flow of experience that is represented in the functional model of an innovation system.

The third flow considers the flow of physical objects, such as material, components and modules. These are used for the realization of products and manufacturing systems. This flow represents what is usually called the supply chain. Naturally, the output from the innovation system is also a physical flow.

Finally, the systems and tools supporting the functions have been considered. The systems can be of different kinds, such as CAD-systems, simulation systems and planning systems. That is, systems that are used to, for instance: define what and how to manufacture, manage information and support decision-making.

4.3 Axiomatic Design in an Innovation System

In this section a model, intended for an innovation system context, is presented. The model is created with an Axiomatic Design perspective. That is, the viewpoint here is a design centric description of the processes that occurs in a development process. What differs this approach, from the usual way of using Axiomatic Design, is that two or more systems are developed in parallel. Four systems, which are partly developed in parallel, are the product, the manufacturing system, the organization and the company strategy. All of these systems are closely connected whit each other, both during the development phase and the realization phase.

[4] See *Integration Definition for Function Modeling* [FIPS, 1993] for a description of IDEF0.

The starting point for the creation of the model that describes the parallel development of two systems is that all development is primarily about making decisions [Fagerström, 2001]. When a decision is made, constraints are born. The constraints cause limitations in the solution space, which create restrictions for future decisions.

Systems developed in parallel processes are connected to each other by constraints. That is, a decision made in a development processes will limit the solution space not only for future decisions within the development process, but also for future decisions in the development processes running in parallel. Most of the information that flows between parallel development processes is upon arrival constraining the solution space in the other process.

There are two ways to understand these common constraints. First, they could be understood as input constraints if the development of one system provides input to the development of the other systems. If this is the case, the constraints are first caught in the customer domain for the receiving development process, and will then be formed into a constraint adjusted for this development process. Second, they could be understood as system constraints if there is a connection between the development processes on a higher level, in the same design hierarchy. They will then become two leafs in the same design process. If this is the case, there is actually one main development process, which has been divided into two leafs and these two leafs are the development processes that are considered.

In this paper the focus is on the product development and the responding manufacturing system development. Consequently, other development processes, such as the organization development and the company strategy development, are managed as controlling input constraints. In this case the controlling input constraints are not considered results of an iterative process between the development processes, but rather as a frozen model. Examples of such frozen models are the product plan model and the manufacturing strategy model in Appendix B.

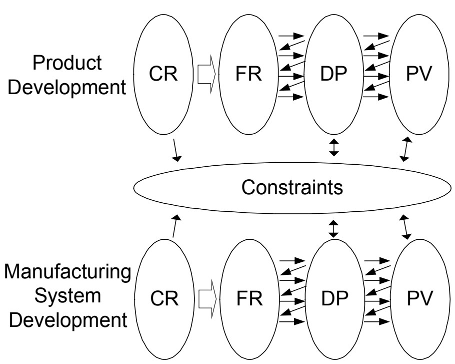

Figure 5: Communication between product and manufacturing system development

The communication between the product development and the responding manufacturing system development is conducted through open models, see Appendix B. A frequent communication between the two development processes is necessary to avoid violating constraints driven from decisions made in the other development process. This iterative process results in a product model and a manufacturing system model, which control the realization of both the product and the manufacturing system.

What is communicated varies, naturally, from case to case. Examples of constraints that are communicated between these development processes are: from the product design process – geometries, special surface finishes, grasping surfaces, weight, materials, reference points [Fagerström, 2001], and from the manufacturing system design process – the need for clamping possibilities [Mårtensson and Fagerström, 1999], already existing manufacturing equipment and limitations of what is possible to manufacture.

The process domain in the product development process has a special position in the communication between the manufacturing system development processes. It operates as a bi-directional communication platform, where the two development processes meets [Mårtensson and Fagerström, 1999]. From the product development view the process domain is used when choosing suitable processes to fulfil the design parameters, examples of these process variables are drilling, grinding and milling. The solution space, when choosing processes, is constrained by what is possible to produce in a manufacturing system, which is under development or already existing. From the manufacturing system development view the process domain becomes an important input constraint stating what processes the manufacturing system must contain.

The communications between the two development processes, in a concurrent engineering development process, can be divided into four different situations.

The first situation occurs if there is a new product and a new manufacturing system that is to be designed. In this case it is especially important that the communication between the two development processes is conducted frequently, since there is no specific information to start with concerning either of the designs.

The second situation is if there is a new product and an already existing manufacturing system, that is, a new product is to be produced in an existing manufacturing system. In this case is it important that the product designers are well informed about the manufacturing system, so they can take the constraints from the manufacturing system into account during the product design.

The third situation occurs if the product exists and a new manufacturing system is to be designed. In this case it is important that the manufacturing system designers have good knowledge about the products, which is to be manufactured. It is also important to have a good documentation on the product in order to know if any of the constraints, driven from the product, are negotiable. This is true also for the second case, even though it is not as important there.

The fourth situation occurs if both the product and the manufacturing system exist. In this case it is a question of improvements in form of a redesign. The documentation is, in similarity to the third situation, important.

4.4 The Unified Innovation System and Process Model

The purpose of this section is to present a multi-viewpoint model, see Figure 6, which combines the three previous described viewpoints; process, function and design. This section will primarily deal with the interaction between these different viewpoints.

The multi-viewpoint model can be looked upon as a map to navigate after when working in the innovation process. This map provides a transparency of the interaction of the different viewpoints. This transparency will result in a better decision-making and, thereby, contribute to a better fulfilment of the objectives of the innovation process.

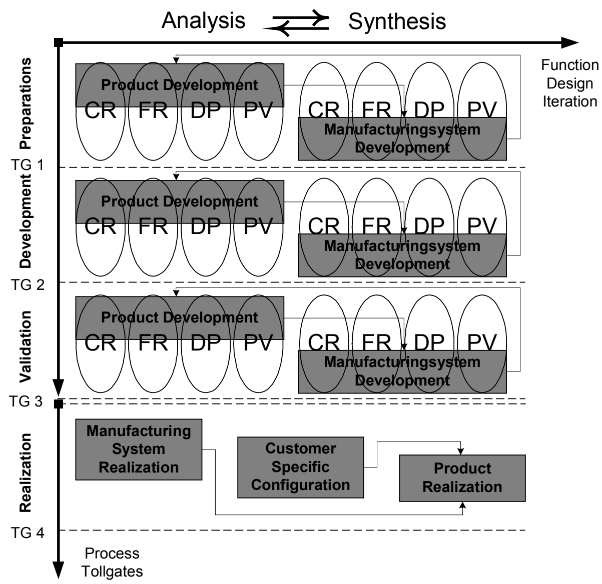

Figure 6: Multi-viewpoint model of the innovation process

The multi-viewpoint model is built up along two axes: the *process and tollgate axis* and the *function, design and iteration axis*.

The order, in which the main phases of a project are executed, is presented along the *process and tollgate axis*. There are two main phases along this axis: the development phase and the realization phase. The distinction between these phases is obvious along the function design iteration axis. In the development phase, synthesis and analysis are the main activities, whereas in the realization phase the main activities are source, make and deliver.

The *function, design and iteration axis* combines the function and design viewpoints, the most conspicuous common factor are the iterations[5] both within and between the two parallel development processes. The boxes in the multi-viewpoint model represent the functions that are present in the different phases of the innovation process, whereas the eggs presented in the development phase represent the design of both the manufacturing system and the products. The eggs are not present in the realization phase since the design has already been frozen. Consequently, the design viewpoint is not changing in the realization phase.

Furthermore, decisions in the process view are mainly about what to do, while decisions in the function and design view are mainly about how and why things should be done.

A decision in a development process creates constraints that limit the solution space, not only for the development process in question but also for connected development processes. Consequently, the information flow between the product development functions and the manufacturing system development functions are represented by constraints communicated in the open product model and the open manufacturing system model.

The design of each level in the Axiomatic Design framework should result in, at least one, iteration between the product development function and the manufacturing development function. This provides the innovation process with a minimum of parallelism in order to gain a process that can be referred to as concurrent engineering.

The Development Phase: During the development phase, the design grows through three stages: preparation, development and validation.

In the *preparation* phase, the visions and the goals for the project are stressed. That is, the focus is on (expressed in Axiomatic Design terminology) the customer- and the functional domain. However, some conceptual ideas about how to fulfill the goals are normally also determined here. That is, the work in this phase does not directly address the design and process domain in Axiomatic Design, even though they are taken into consideration. Before passing tollgate 1 and moving on to the next phase, the following issues should have been determined: what the customers' demands are, which functional requirements they will trigger and which conceptual solutions that should be stressed further in the next phase.

In the *development* phase the detailed design is created. The work is conducted in all domains, both for the product design and the manufacturing system design. Synthesis and analysis are performed on each level in the whole design. The parallel way of working with the product design and the manufacturing system design are of special importance here. The development phase results in an open product model and an open manufacturing system model ready to function as controlling maps for the realization process. However, before using them in the realization phase there is a good idea to test them. This is done in the validation phase.

In the *validation* phase the whole system is analyzed, not only at one level at the time but at the whole system. The system, naturally, consists of both the products and the manufacturing system, which are tested in parallel. A useful tool for the system analysis is a full matrix, that is, a matrix with all levels in the design trees incorporated. Once the full matrix is set up, the first axiom in Axiomatic Design can be used to detect and evaluate couplings that might affect the control of the system. This is the last step in the development phase and when passing tollgate 3 the product model and the manufacturing system models will be frozen. This means that the project is ready to move into the realization phase.

The Realization Phase: In the realization phase, the design viewpoint is not used anymore. However, an exception to this is if something turns out to be wrong in the design, then the project has to go back to the development phase with the new experience and do a redesign. The focus in the realization phase is on the three sub-phases: source, make and deliver. Each of these sub-phases exists in the functions: manufacturing system realization and product realization. However, these sub-phases are not explicit expressed in the multi-viewpoint model since the focus in this model is on the development phase and on the concurrent

[5] Here is the analysis and synthesis in focus, confer *The Principles of Design* [Suh, 1990]

way of working. The result of the realization phase and, consequently, also of the whole innovation process, is a system ready to be put into a mass customisation phase.

5 DISCUSSION AND CONCLUSIONS

In this paper a multi-viewpoint model of the innovation process has been presented. The three viewpoints are the process centric view, the functional centric view and the design centric view. The process centric part of the model captures the different stages and toll-gates of the innovation process, whereas the function centric part of the model captures the functions of the innovation system in which the processes are executed. In addition, the design centric part of the model captures the detailed design process for the product and the manufacturing system.

A benefit of the multi-viewpoint model is an increased transparency of the operations of an innovation system. Furthermore, an increased understanding of the processes of an innovation system is also achieved.

The multi-viewpoint model has deliberately been limited to the innovation process and, hence, it does not consider the mass customization process. This process will, nevertheless, be executed by the customer specific configuration and the product realization functions, when the innovation process is finalized.

Another limitation is that the multi-viewpoint model has not been validated in a real innovation process. Thus, it is difficult to say how well it can support this process. It has also been difficult to validate it by comparing it to a well-known and accepted model described in literature, which confirms the uniqueness of the model.

However, the three constituent models of the multi-viewpoint model are compiled from several different models, from several different sources. The process centric model is a generalization and extension of similar models found in several theories [Andreasen and Hein, 1987] [Cooper, 1988 and 1993] [McGrath, 1996] [Ulrich and Eppinger, 2000], but also models found in industry [Ericsson, 2001] [Carlsberg, 1997] [Scania, 1998] [SCOR, 2001]. These models are all well known and widely accepted, for instance, more than 400 enterprises have been involved in the development of the SCOR-model.

Similar models to the function centric model can be found in literature [Sohlenius, 2000] [ISO10303-214, 2001] [Mårtensson and Fagerström, 2000]. However, they differ in granularity and terminology. In addition, whereas the functional model presented here and in *Productivity, Quality and Decision Theory Based Upon Axiomatic Design* [Sohlenius, 2000] covers both development and realization, the models in *ISO10303-214* [ISO10303-214, 2001] and *Product Function Independent Features in Axiomatic Design* [Mårtensson and Fagerström, 2000] cover development only.

Finally, the design centric model is based on Professor Suh's theories of Axiomatic Design [Suh, 1990] and, thus, is consistent with them. Nevertheless, Professor Suh has not considered the interaction between product development and manufacturing system development when they are performed in parallel. This is something that Professor Sohlenius is considering in [Sohlenius, 2000]. However, Professor Sohlenius' model differs in another aspect; it deals with six domains instead of eight. The reason for this is different purposes when putting up the models. As a result, the interaction between product development and manufacturing system development is not described in the same way.

A few matters have been identified for further research: a case study, or several, to validate the multi-viewpoint model, increase the scope of the multi-viewpoint model to include organization and company strategy design and a more thoroughly analysis of all the information flows in the function centric model.

The following conclusions have been made:

- The generic processes in an innovation system are the development phase and the realization phase.
    - The development phase can be divided into: preparation, development and validation.
    - The realization phase can be divided into: source, make and deliver.
- The functions in the innovation system are: product development, manufacturing system development, manufacturing system realization, customer specific configuration and product realization.
- The most important connections between the identified functions are the different models, which are constraining functions executed at a later stage.
- The constraints are generated by decisions, which impose limitations on the solution space for later decision.
- Most models, theoretical and practical, of the innovation process do not include the realization phase.
- Flexibility in the design solution space is obtained by a minimization of constraints in high-level decisions. This is especially evident when several systems are developed in parallel.

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Appendix A Processes in the Innovation System

	Development			Realization		
		P	L	A	N	
Basic Principles	**Preparation** -Investigate market need - Recognize need - Formalize requirement	**Development** -Concept synthesis - System synthesis - Detailed synthesis	**Validation** -Concept analysis - System analysis - Detailed analysis	**Source** - Supply chain execution	**Make** - Verify	**Deliver** - Verify
Andreasen & Hein	- Recognition of need - Investigation of need	- Product principle - Product design	- Production preparation	- Execution	- Execution	- Execution
Ulrich & Eppinger	- Planning	- Concept development - System design - Detailed design	- Testing and refine	- Production ramp up	- Production ramp up	- Production ramp up
McGrath	- Concept evaluation - Planning and specification	- Planning and specification - Development	- Test and evaluation	- Product Release	- Product Release	- Product Release
Cooper	- Preliminary investigation - Detailed investigation	- Development	- Test and validation	- Full product and market langue	- Full product and market langue	- Full product and market langue
Ericsson	- Pre study - Feasibility	- Specification - Design integration and verification	- System verification - Process verification	- Customer acceptance - Production ramp up	- Customer acceptance - Production ramp up	- Customer acceptance - Production ramp up
Carlsberg	- Idea evaluation - Preliminary study	- Development - Planning for launch	- Verification	- Production - Launch	- Production - Launch	- Production - Launch - Completion and follow up
Scania	- Initialization - Pre study	- Feasibility - Development	- Feasibility - Development	- Realization	- Realization	- Realization

Appendix B Functional Model of an Innovation System