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THE APPLICATION OF AXIOMATIC DESIGN TO THE DESIGN OF THE PRODUCT DEVELOPMENT ORGANIZATION

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ABSTRACT

The following application of Axiomatic Design strives to provide a framework for the design of the organization of product development. It follows current research to expand the current theory of Axiomatic Design to complex systems, like software design [Suh (1999)] or the design of manufacturing system [Suh/Cochran/Lima (1998)], to name a few.

The development of new products has always been an essential challenge as it reflects not only the evolution of the needs and wants of the customers, but also the change of the entire corporate environment and of the company itself. Implications deriving from increased competition, more fragmented and demanding markets and an acceleration of technology change have alternated the approach towards designing and managing the product development function within a corporate entity [Clark/Fujimoto (1991)]. Whereas the initial intention of Axiomatic Design is to provide a general basis for the design process, the Product Development System Decomposition (PDS) strives to model the product development organization as a whole, consisting of individual information processes and overall organizational functionality and characteristics. However, the decomposition requires to clarify the context and linkage of the PDS within the corporate system.

In alignment to Axiomatic Design, the PDS is derived from top-level functional requirements (FRs) and design parameters (DPs), which reflect long-term decisions linked to corporate strategy and corporate system design. Due to the inconsistencies of current definitions it in addition appears necessary to redefine the scope and content of product development. The major FRs for the PDS are then linked to fundamental tasks within organizational theory, e.g. the provision of a sufficient level of functional expertise by differentiation and the continuing growth in productivity by aligning and adjusting the individual design activities by integration [Lawrence/Lorsch (1967), Sobek (1997)]. Beyond such high-level FRs the PDS is decomposed to a sufficient level which is necessary for a direct application and the continuous control of the product development system.

Keywords: Product Development System, Systems Design, Axiomatic Design, Corporate Design, Organizational Theory

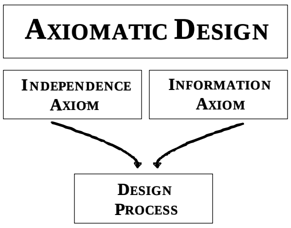
1 INTRODUCTION

The development of new products has always been an essential task for a corporate entity as it reflects the evolution of the environment and of the company itself. However, during the last years, the importance of product development has increased, as its impact on cost, quality, customer satisfaction, to name a few, became more significant. Three major driving forces behind the emerging importance of product development may be distinguished among several other influencing factors [Clark/ Fujimoto (1991), Wheelwright/Clark (1992)]. At first, the *intensity of international competition* has increased as the number of companies capable of competing in the international market and the level of performance has grown. Second, the *markets* have become more *fragmented and demanding*. Due to the increased customer sensitivity to the fulfillment of their needs by a total product concept, companies are forced to offer a broader variety of products, whereas the differentiation of a product goes beyond technical performance or superficial design features. Finally, the pace and diversity of the *technology changes* has gained speed. The variety and breadth of the enlarged set of technologies allows companies to create and offer new and customized products to the demanding and diverse market. These new implications have changed the approach towards designing and managing the product development function within a corporate entity. In former days, the way product development was managed derived out of the style products were designed, namely a more or less creative and unscientific process. Similar to manufacturing systems, several views are necessary to capture the characteristics of product development. The most obvious one is to refer to product development as a set of *processes*, determined by certain inputs and outputs. In addition, product development is a complex task requiring a sufficient level of *specialization* of the designers and engineers and of *integration* of the design tasks.

A framework for product development is therefore developed that provides a *systematic and complete guideline* to the design of the product development organization, similar to the existing manufacturing system design [Suh/Cochran/Lima (1998), Cochran (1999)].

2 AN INTRODUCTION TO AXIOMATIC DESIGN TO DESIGN COMPLEX SYSTEMS

To offer a methodology capable of solving design tasks regardless of their nature Suh's proposed the Axiomatic Design Methodology [Suh (1990)]. Defining the process of design as *"the creation of synthesized solutions in form of products, processes or systems that satisfy the perceived needs …"* [Suh (1990)], the area of application reaches from the design of physical entities to complex systems like product development systems.
Suh postulated several axioms that establish the guidance required to produce a good design and offer a basis for comparing and selecting design [Suh (1990)]. The two core axiom are as follows:
Axiom 1: The Independence Axiom
Maintain the independence of the functional requirements (FRs)
Axiom 2: The Information Axiom
Minimize the information content of the design.
Design in terms of Axiomatic Design maps the functional requirements FR_i to the design parameters DP_j guided by the axioms.



$$FR_i = A_{ij} \quad DP_j, \quad \text{with } i \in \{1,n\},\ j \in \{1,m\},\ A_{ij} = \partial FR_I / \partial DP_j$$

$$\begin{matrix} FR_1 \\ FR_2 \\ \dots \\ \dots \\ FR_n \end{matrix} = \begin{matrix} A_{11} & A_{12} & \dots & \dots & A_{1m} \\ A_{21} & A_{22} & \dots & \dots & A_{2m} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \dots & \dots & A_{nm} \end{matrix} \quad \begin{matrix} DP_1 \\ DP_2 \\ \dots \\ \dots \\ DP_m \end{matrix}$$

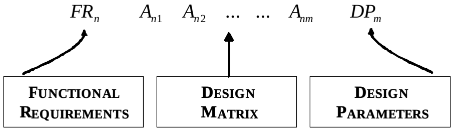
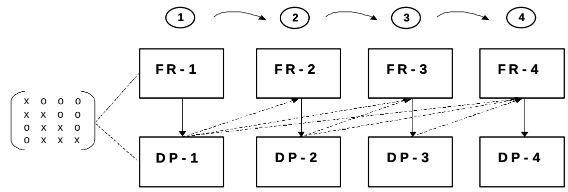


Figure 1. The Mapping process of Axiomatic Design

The set of FR_i and DP_j can be interpreted as two vectors FR and DP whereas the mapping instructions form a matrix as illustrated in figure 1.
The *Independence Axiom* ensures that within a design with more than two FRs the FRs have to be defined in the way that satisfying one FR doesn't affect the fulfillment of the other FRs. The second axiom, the *Information Axiom*, is based on the idea that the success of a design is determined by the probability associated with achieving the FRs. This probability decreases with the amount of information necessary to fulfill the FRs.
When applying Axiomatic Design to systems and organizational design, the nature of functional requirements and design parameters requires a more detailed description. In general, a functional requirement encompasses a requested functionality that a specific entity is obliged to fulfil. The requirement is stated in the nature of a function, mainly by defining an output and assuming that the entity will receive the necessary input.
However, this object to which a functional requirement can be referred to can be of different nature. A design parameter is more general than the term *Funktionsträger* which is used in the German design theory [Pahl/Beitz (1993), Ehrlenspiel (1995)] and solely embraces a physical entity. In Axiomatic Design, a design parameter is a closed entity, able to provide the requested FR, and free in its nature, therefore either of a physical or a conceptual nature. A top-level DP will encompass even conceptual and physical sub-systems, but when moving down the hierarchy towards more detailed systems, the DP mainly state physical solutions with the same class of elements, e.g. machinery, a CAD-system or human resources.
Concerning the *implementation* and *control* of a desired system design, Axiomatic Design provides some additional aspects. In alignment to properties which can be extracted of a design matrix, the two aspects cover the sequence of the implementation of the DPs and the tuning of the specific values of the FRs. The implementation and preparation of the operation of a system should be started with the one FR what is only dependent of its corresponding DP.



fix	-	DP-1	DP-2	DP-2, DP-3
variable	DP- 1	DP-2	DP-3	DP-4
Controlled FR	FR-1	FR-2	FR-3	FR-4

Figure 2. Sequence of implementation of DPs and FRs

In the case depicted in figure 2, the implementation will start with DP-1 since FR-1 is solely dependent on this DP. Within the same level, the other FRs can be installed one by one by implementing the related next DP and refining the specific DP until the desired value of the FR is obtained, as illustrated in figure 2. Having adjusted all DPs to obtain the requested system behavior on a hierarchy level within a decomposition, the subsequent higher level of DPs and FRs can be installed. The implementation of a complex system will therefore always start at the lowest level,, and move on level by level towards the initial FR.

3 CHARACTERISTICS OF PRODUCT DEVELOPMENT

Several views are necessary to capture the tasks related to the design of the product development organization. The most obvious one is to refer to product development as a set of *processes*, determined by certain inputs and outputs. Thus, the essential task is to arrange the single information processes in a way that the required *measures lead time* and *product quality* are achieved within the constraints of the existing facilities.
In general, the core lever to achieve the proposed measures is to *coordinate* and *overlap* the information processing activities, either

by integrating the content within or outside the regarded functional unit.

A manufacturing system is designed to make parts, or in other words, is an arrangement of *transformation processes directed to change the physical nature*, e.g. shape or structure, of the in- and out-flowing system elements. However, the essential activity on which product development is based is the *transformation of input information into output information* by using the knowledge, skills and gained experience of the designers in a process as illustrated in figure 3. Nevertheless are physical processes, e.g. building a prototype or a mock-up, part of product development, but serve merely as a supplementary activity to the information process.

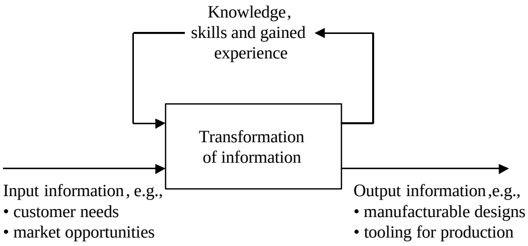


Figure 3. Product Development as an information processing activity

Using this model, the overall task of product development is a process in which it *"...transforms data on market opportunities and technical possibilities into information assets for commercial production. During the development process, these information assets are created, screened, stored, combined, decomposed, and transferred among various media, including human brains, paper, computer memory, software, and physical materials"* [Clark / Fujimoto (1991)].

In reference to the information process model, product development may be interpreted as a numerous set of individual information processing activities, which in their entirety fulfil the task stated above. However, the information process normally has to cope with *uncertainty* which is defined *"... as the difference between the amount of information required to perform a particular task and the amount of information already possessed by the organization"* [Galbraith (1973)]. Within a product development environment, this uncertainty can derive out of four major sources: (i) consumer uncertainty, relating to unrealized user requirements; (ii) technological uncertainty, relating to the lack of knowledge about technological solutions; (iii) competitive uncertainty, relating to the absence of information about competition; and finally (iv) the uncertainty related to the absence of information about the several resources required when designing new products [Moenart / Souder (1990)]. By transforming the input into output information, the *degree of uncertainty is gradually reduced*, whereas the transformation is determined by the amount and type of uncertainty as well as the knowledge and skills of the organizational unit.

One of the most challenging tasks of organizational design and management is the task of dealing with *differentiation* and *integration*. Differentiation in terms of product development covers not only the extent of specialization in distinguished functions, but also differences in behavior and work attitude. As a natural reaction to the increasing variety and amount of organizational tasks, integration as *"a state of high degrees of shared values, mutual goal commitments, and collaborative behaviors"* [Souder (1987)] heads to counteract the effects of differentiation. The *"differences in cognitive and emotional orientation among managers and people of different functional departments"* [Lawrence / Lorsch (1967)] due to the specific knowledge, skills, utility function and interest require instruments to minimize the losses through misalignment of individual activities, measurable in inflated lead time or unsatisfactory total product quality. The design of the product development organization is obliged to consider both aspects by installing several coordination and integration instruments.

4 A NEW CONCEPT OF CORPORATE SYSTEM AND SUB-SYSTEMS

A Corporate System embraces all elements and relationships required to achieve a marketable value. The value may be of a physical or informational nature, material or nonmaterial. It includes the activities to define and design this value, to produce the value and to distribute it to the market. The relationships may be arranged in corporate functions respectively sub-systems such as product definition, manufacturing and product distribution, which themselves inhibit additional subsystems. Furthermore, the elements comprise people, knowledge, information, machinery, and capital.

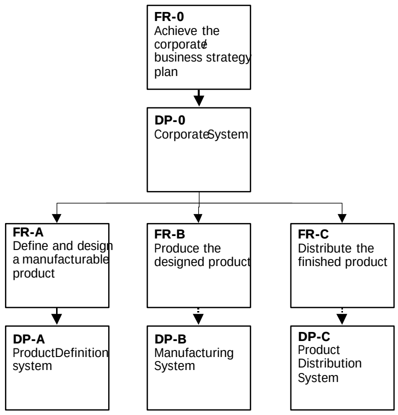


Figure 4. Decomposition of the Corporate System

A Product Development System (PDS) may be defined as *"an arrangement of elements (e.g. people, information systems, computer-based analytical tools, prototype manufacturing machines and equipment, hardware test equipment) to achieve a producible design by transforming information about market opportunities and technical possibilities into information assets for commercial production, and what can be characterized by the measurable parameters of the system design"* [Lenz 1999]. During the development process, value is added as the initial uncertainty of information concerning the product plan and concept is reduced and the level of detail increased.

The design of a PDS is challenged by the complexity and unpredictable behavior of people as the core design element. This difference due to other design objects fortifies also the diversity in the applied design principle. The design of a manufacturing system is regarded as a task related with systems theory, whereas the underlying nature of product development is seen in the field of organizational theory.

The marcation of the boundaries of a product development system requires to start the design at the strategic level within the corporate strategy, and concerning the design aspect, at the level of corporate design. It is therefore necessary to enlarge the scope of the design to the entire corporate, with the restriction to merely focus on product development. All corporate activities are assigned to one of the following, newly defined major corporate sub-systems. The first sub-system is called the *product definition system* as depicted in figure 4, and incorporates all activities which are based on the transformation of information. This information reflects the uncertainty of the market, which is reduced within the Product Definition System. The term *definition* corresponds to the activities starting with the recording from customer wants and needs, moves on to the statement of the product strategy and portfolio, includes the provision with the technology for the product design, executes the design task and finally delivers a producible design. The second sub-system is the *manufacturing system*. All activities, which are necessary to achieve the value of the product related to the physical attributes, are within the scope of this system. The third sub-system, the *product distribution system*, covers all activities which are linked to deliver the product from the point where is manufactured to the customer.

5 DECOMPOSING THE PRODUCT DEVELOPMENT SYSTEM

Applying Axiomatic Design to organizational design lacks the non-ambiguous mapping between the functional and the physical domain. In contrast to the design equations when decomposing for instance mechanical entities, the decomposition requires assumptions concerning the independence of functional requirements and design parameters. True, empirical studies support these assumptions, however the degree of interdependence of sub-systems and elements when dealing with human interaction is considerable. The decomposition is therefore based on relationships proven by research and common academic understanding in the field of product development. However, the underlying correlation and dependency of FRs and DPs may alternate due to new insights and improved design rules.

5.1 HIGH LEVEL DECOMPOSITION – FROM LEVEL 0 TO LEVEL 2

Within the Corporate System, the product definition embraces all activities linked to transform customer needs and market opportunities into a producible design. The exact definition is constituted as to “define and design a producible product” (FR-A), within the constraints of the restricted resources. In alignment to current research, which emphasizes the similarity of the underlying activities between marketing, brand management, product development and supporting functions, the product definition system covers the initial definition of the product (FR-A1), the provision of the required technology (FR-A2) and the design of the producible product (FR-A3) as shown in figure 5. The PDS (DP-A3) is stated to accomplish the design of the manufacturable product (FR-A3). Both preceding systems, DP-A1 and DP-A2, influence the design of the product as on the one hand, the product management system renders the initialization of the product with a rough outline, and on the other, the existing technologies determine the implementation of the functionality of the product. Although the definition of the product will be influenced by the Technology Development System (DP-A2) in the sense of a technology push, the task of defining the product and incorporating the customer needs is solely linked to the Product Management System (DP-A1).

$$\begin{Bmatrix} FR_{A1} \\ FR_{A2} \\ FR_{A3} \end{Bmatrix} = \begin{bmatrix} x & 0 & 0 \\ x & x & 0 \\ x & x & x \end{bmatrix} \begin{Bmatrix} DP_{A1} \\ DP_{A2} \\ DP_{A3} \end{Bmatrix}$$

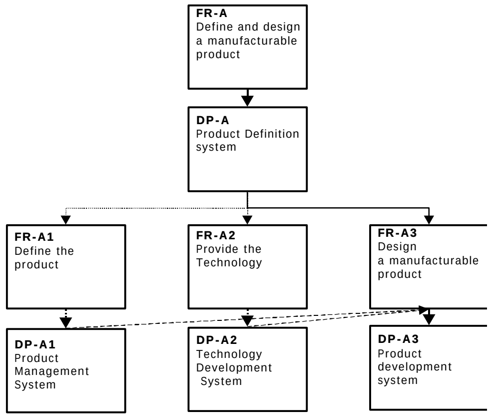


Figure 5. Decomposition and Matrix from level 0 to 1

In addition, elements of DP-A3 might have an impact on FR-A1, however Axiomatic Design refers to such restricting conditions as constraints, which solely reduce possible solutions to FR-A1. Additional analysis will be provided in the decomposition of DP-111 in section 5.3 .
In level 2 the PDS is decomposed by assigning the sub-systems and elements if they either contribute to the maximization of the sales revenue (FR-11), the minimization of development costs (FR-12) or the minimization of investment cost (FR-13).

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \\ FR_{13} \end{Bmatrix} = \begin{bmatrix} x & 0 & 0 \\ x & x & 0 \\ x & x & x \end{bmatrix} \begin{Bmatrix} DP_{11} \\ DP_{12} \\ DP_{13} \end{Bmatrix}$$

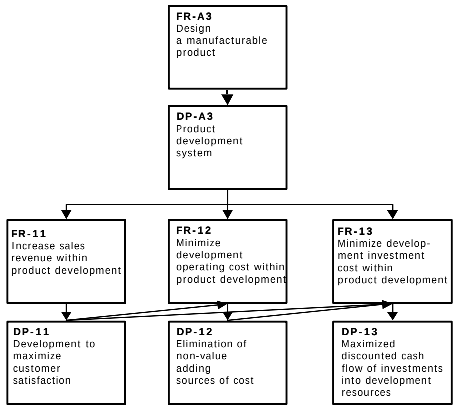


Figure 6. Decomposition and Matrix of FR-s and DP-s from level 1 to 2

The related design matrix exemplifies the close relationship between the DPs and FRs. Without ensuring a minimal customer satisfaction (DP-11), no sales (FR-12) nor investment (FR-13) activities have to be started. Furthermore, the elimination of non-value adding sources of waste (FR-12) allows to reduce the resources and therefore the investments (DP-13) demanded by the product development system.

5.2 MID-LEVEL DECOMPOSITION – FROM LEVEL 2 TO LEVEL 3

With DP-11 defined as the “maximization of customer satisfaction within product development”, all activities are addressed which provide any difference in the appearance and the perceived value at the customer. Two aspects form the customer satisfaction. The first one is related to *the degree* by which the *designed product* fulfills at a certain point in time the *proposed set of product attributes* or product FRs, whereas the second aspect stresses the necessity to *minimize the time lag* respectively to *minimize the permanently enlarging gap between needs and product*. Therefore FR-111 as to "maximize the product quality" ensures a PDS oriented to fulfil the stated product concept the best way it can, in contrast to FR-112, which aims to "minimize the development lead time" and reflects the continuous effort to align the products with the market and customer needs. In the case of a PDS, quality is obtained when all discrete design processes incorporate the restrictions that limit their scope and align as well as adjust their settings. The term that characterizes the extent of alignment and adjustment of organizational activities is referred to as *coordination*, therefore the degree of coordination has to be maximized (DP-111). In addition to the contextual alignment, a design process may be characterized by the start and finish time in reference to any other design process.

$$\begin{Bmatrix} FR_{111} \\ FR_{112} \end{Bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{Bmatrix} DP_{111} \\ DP_{112} \end{Bmatrix}$$

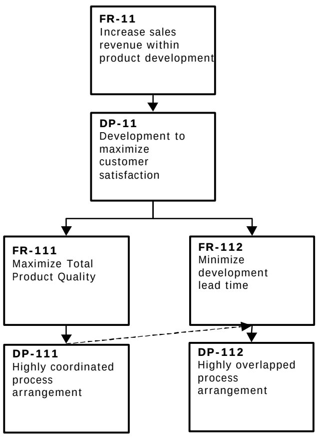


Figure 7. Decomposition and Matrix of FR11: from level 2 to 3

In the best case, the minimization of development time would lead to a process arrangement where all processes start at the same point in time and the duration of the development process is solely limited by the longest design activity. DP-112 claims to fulfil FR-112 by maximizing the *degree of overlap*, whereas the overlap is restricted by the dependency of design decisions. The coordination of design processes not only impacts the level of quality, but also the ability to overlap. When the design activities are increasingly aligned and adjusted, the necessity for subsequent corrections, e.g. by avoiding engineering changes due to unconsidered downstream restrictions, is reduced, and the time for development minimized.

Moving on to the minimization of development operating cost (FR-12), three leverages determine the extent by which non-value adding sources of cost (DP-12) may be eliminated. In general, the costs driven by development activities are differentiated into *direct labor*, *indirect labor* and *residual costs*. The referring objectives however depend on the nature of the activity. Referring to direct labor costs, the focus is set on "improving the efficiency" (FR-121), whereas indirect labor is regarded as in general superfluous and therefore should be avoided, as stated as "to minimize the amount of indirect labor"(FR-122). Finally, accruing residual development should also be minimized (FR-123). To increase the efficiency of direct labor, all activities, which do not add value to the design process, are to be eliminated (DP-121). As elucidated, indirect labor should generally be reduced, however the attributes and methods related to a possible DP are so various that DP-122 is common defined as "the reduction of indirect tasks". However, the corresponding DP-123 to FR-123 is chosen as the "substitution of testing and prototyping activities through virtual simulation and rapid prototyping". This DP stresses the long-term trend to move from costly physical test to cheap virtual tests by simulating real world behavior in a computer system.

$$\begin{Bmatrix} FR_{121} \\ FR_{122} \\ FR_{123} \end{Bmatrix} = \begin{bmatrix} x & 0 & 0 \\ x & x & 0 \\ x & 0 & x \end{bmatrix} \begin{Bmatrix} DP_{121} \\ DP_{122} \\ DP_{123} \end{Bmatrix}$$

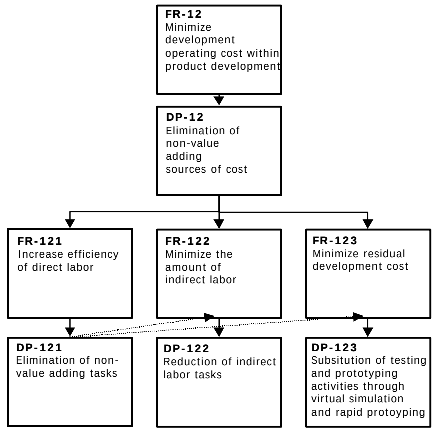


Figure 8. Decomposition and Matrix of FR12: from level 2 to 3

In the last branch concerning the minimization of development investment costs, the decomposition of DP-13 corresponds to the steps related to a normal investment decision.

$$\begin{Bmatrix} FR_{131} \\ FR_{132} \end{Bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{Bmatrix} DP_{131} \\ DP_{132} \end{Bmatrix}$$

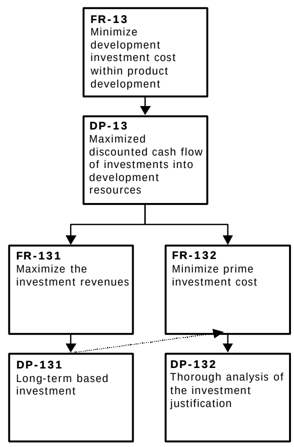


Figure 9. Decomposition and Matrix of FR-13: from level 2 to 3

Every investment consists of an *inpayment* and *outpayment* flow. Latter is characterized by a row of payments, where the prime costs form the dominant amount. Former in contrast are triggered by annual revenues over the whole investment period. Therefore FR-131 states to "maximize the investment revenues" and FR-132 to "minimize prime costs". Although the in- and outpayments inhibit additional aspects, FR-132 merely concentrates on the initial investment as the up-following costs depend mainly on the operating attributes stated in DP-11 and

DP-12. The fulfillment of FR-131 is defined as the installation of a “long-term based strategy” (DP-131). However, solely stressing long-term usage would overemphasize investments in capacity and functionality of machinery, equipment and training which are directed in the future. A thorough analysis of the investment decision (DP-132) by exactly matching the required functionality with the purchased good will serve as the counterbalance and optimize the investment decision.

5.3 LOW-LEVEL DECOMPOSITION – FROM LEVEL 3 TO LEVEL 6

Due to the complexity of the PDS System Design Decomposition, the following introduction to level 3 to 6 will be limited to the branch derived from FR/DP 111. However, a complete overview down to level 7 is provided in [Lenz (1999)].
The first FR related to total product quality (DP-111) describes the maximization of the design quality by the alignment of the internal design process with external requirements and restrictions (FR-E1). In general, the external attributes are normally synthesized into the product plan stated at the starting point of the design process by the Product Management System (DP-A1). However, the concept is incomplete and requires further interpretation during the refinement and iteration in product development. Furthermore, the customer needs and wants from which the product concept is derived alter during the development process, which may take up to 5 years. This reflects the basic understanding of product development as an information processing activity that reduces the degree of uncertainty as presented in section 3.

$$\begin{Bmatrix} FR_{E1} \\ FR_{I1} \end{Bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{Bmatrix} DP_{E1} \\ DP_{I1} \end{Bmatrix}$$

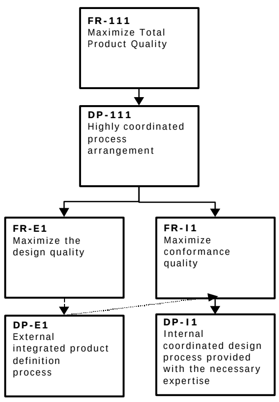


Figure 10. Decomposition and Matrix of FR-111: from level 3 to 4

Until now, the mechanisms to achieve such an external integration are various and normally assigned to the collaboration of marketing with the project manager of the product design. The generic statement of DP-E1 as “external integrated product definition process” reflects the close interaction with the product management system (DP-A1) and the ongoing nature of this DP throughout the entire design process.
The second requirement demands to “maximize conformance quality” (FR-I1) which is linked to the degree of integration within the PDS. Conformance quality is determined by the product design in the way that the *product design meets the constraints of the manufacturing system*, whereas the actual implementation is related to the production of the part. In alignment to DP-E1, DP-I1 is defined as an “internal coordinated design process [...]”, what is presented in figure 10.
Every integration process, regardless of the specific setting and context, requires to distribute the relevant information to the participating individuals. Therefore FR-E11 demands to “ensure the exchange of the coordination dependent information”.
Despite the knowledge of constraints and restrictions, a designer might still decide to pursue his initial solution. FR-E12 provides the sufficient condition to accomplish an integrated process by requiring to “ensure the alignment of the development activities”. Until now, the empirical research lacks the unambiguousness which is the requisite for a closer definition and a further decomposition of interfunctional integration. The DP-E11 provides the “information exchange mechanisms” for FR-E11 and DP-E12 encounters FR-E12 with a “task coordination system” as illustrated in figure 11.

$$\begin{Bmatrix} FR_{E11} \\ FR_{E12} \end{Bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{Bmatrix} DP_{E11} \\ DP_{E12} \end{Bmatrix}$$

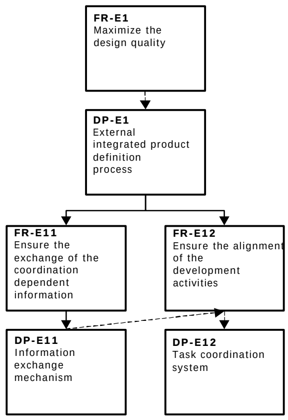


Figure 11. Decomposition and Matrix of FR- E1: from level 4 to 5

In alignment to the decomposition of the external integration, the *internal integration* requires the distribution of the relevant information and constraints (FR-I12) as well as the alignment of the different development activities (FR-I13). However, beyond these two basic FRs, the integration of the internal design activities is dependent on the provision of the designers and engineers with the necessary level of skills and knowledge to generally accomplish a design activity (FR-I11). This reflects the necessity of *differentiation* in the design of a organization as the counterpart to integration. Since design activities may be externalized, the constraints deriving from activities from outside suppliers have also to be integrated into the internal design process (FR-I14). To summarize, an internal coordinated design process demands the knowledge, the distribution of the constraints by the various design activities, the actual alignment of the design activities and the integration of external design activities as shown in figure 12.
The corresponding DP-I11 merely states the generic attribute of the PDS to provide the functional expertise by various methods like documentation and training. In analogy to the external integration, DP-I12 heads to fulfill the exchange of the required information by choosing to install a “information exchange mechanism”. In addition, DP-I13 summarizes the attributes related to a “task coordination system”. DP-I14 is not further decomposable as it depends on the scope of the design task delegated to the supplier.

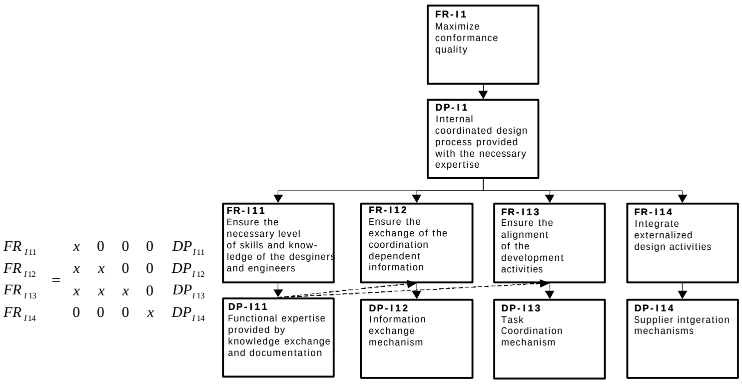


Figure 12. Decomposition and Matrix of FR-I1: from level 4 to 5

The DP is therefore defined as a "supplier integration mechanisms", summarizing all methods related to the integration of the supplier in dependence of the nature of the linkage. The corresponding matrix in figure 12 is decoupled and easily derived from the external integration. Before either the exchange of the relevant information (FR-I12) or the alignment can be ensured (FR-I13), the designers have to be provided with the necessary expertise by various methods (DP-I11). In the next step, the alignment of the development activities (FR-I13) is dependent on the information exchange mechanisms (DP-I12). The involvement of the supplier design activities can be implemented without the current DPs of level 5, depending however on the nature of the linkage. With a close relationship between supplier and manufacturer, the outside activities can be considered as equivalent design activities, and therefore FR-I14 would be influenced by DP-I11, DP-I12 and DP-I13. However, the general case of a loose linkage is regarded as default and therefore none or merely little dependency exists.

The first step when implementing an internal coordinated design process (DP-I1) was to provide the necessary knowledge and functional expertise (DP-I11). Skills and knowledge are related to the education and the experience of the designers and engineers in the development area. Furthermore, skills and knowledge are dynamic, and have to be continuously updated by on-the-job training and sharing of expertise.

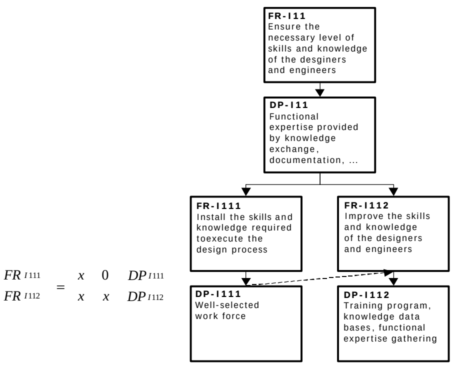


Figure 13. Decomposition and Matrix of FR-I11: from level 5 to 6

These insights are reflected in the two FRs related to DP-I11, and demand with FR-I111 to "install the skills and knowledge required to execute the [current] design process" as well as FR-I112 to "improve the skills and knowledge of the designers and engineers". Although the skills and knowledge evolve throughout the life-time of a person, the major impact is determined by the initial education. The core DP to obtain the necessary expertise is linked to the *selection* of the workforce (DP-I111). Beyond the initial selection, the ongoing improvement of the skills and knowledge can be provided by training programs, by knowledge data bases and by additional methods related to the gathering of functional expertise (DP-I112), as illustrated in figure 13.

Information assets are generated in various forms during the information processing activities, e.g. in clay models, in basic blue prints, in CAD-models or simply as ideas in the mind of the designers and engineers. These information assets have to be documented and stored (FR-I121). When somebody is interested in retracting information assets, the regarded system has to be accessible, no matter what kind of system the information storage or documentation is assigned to (FR-I122). Finally, the information relevant for the coordination will not only be retracted, but should also be actively distributed (FR-I123). The variety of types of information requires different types of systems for the documentation and storage as demanded in FR-I121. DP-I121 is related to the implementation of a work-flow integrated documentation system, which simplifies the tracking of the information assets due to the process-oriented setup of the information system. CAX-information systems like PDM- or EDM-databases belong also to this DP. Due to the second FR-I122, the systems have to provide a sufficient degree of accessibility within the development organization. The projected information in databases covers solely a small portion of the content required to design a product, it is rather stored in the minds of the designers and engineers, and is not captured in information systems. Due to the complexity and the detail of these information, they should not be part of the normal information system as stated in DP-I121, however be accessible.

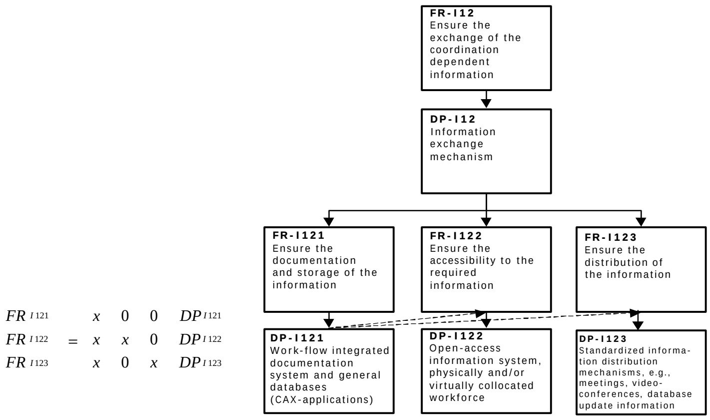


Figure 14. Decomposition and Matrix of FR I12: from level 5 to 6

This may be implemented by collocating the workforce either physical or virtual, what leads to less effort related to the exchange of information and increases the density of the information flow. Finally, the methods to ensure the distribution of the information (FR-I123) have to be installed. The corresponding DP-I123 has to provide *standardized distribution mechanisms*, with the possibility for refinements and feedback by the receiving units. Integration can be achieved by defining a strategy with long-term objectives and performance measures which incorporate different restrictions of the corporation and serve as a guideline for the different design activities and decisions (FR-I131). Contradicting objectives of the different functions and sub-systems are substituted by a consistent strategy framework (DP-I131) which is oriented to achieve the best performance for the entire system. But not only a extrinsic objective target can integrate a product development system, also the attitude and behavior of designers and engineers can be aligned (FR-I132). Sometimes this can rely on the same mindset and education, or on a common corporate culture (DP-I132). Yet this coordination is based less on the specific design decision than on the way the design processes is executed. To clarify the variance in this DP, one could think of the way product development is achieved at a traditional, high-end car manufacturer in contrast to the approach a dynamic software development company may choose to follow.

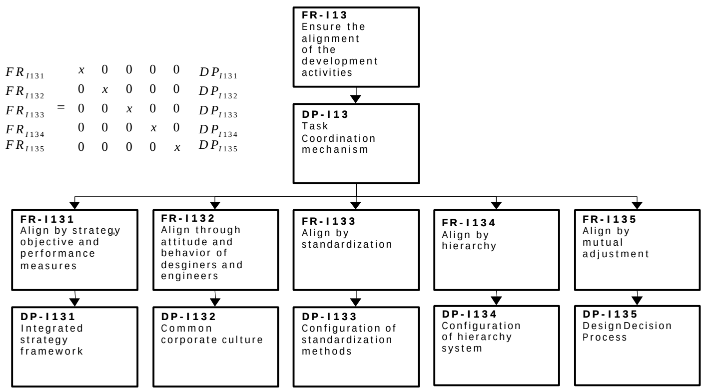


Figure 15. Decomposition and Matrix of FR-I13: from level 5 to 6

Furthermore, coordination can be obtained by standardizing the design task (FR-I133). Various methods exist to standardize a task, therefore DP-I133 is solely stated as "configuration of standardization methods". However, the most common technique for coordinating design activities is connected to the alignment by hierarchy (FR-I134). This embraces to install a project manager with more or less responsibility and power, who incorporates the various design information and makes a decision for the assigned team of designers. Or the design activities are pooled into specific groups, endorsing the exchange of information, but far more forcing a team member to consider and integrate the restrictions of the other team members. All these methods can be summarized into the choice concerning the configuration of the hierarchy system (DP-I134).

Finally, and most important, alignment takes place by mutual alignment (FR-I135). Such a coordination results from the everyday collaboration of the people within the product development system. In general, no specific measures are necessary to install this attribute, however the increasing differentiation of the specific work contents and size of corporations require specific methods to support mutual adjustment. Physical collocation may provide the information exchange, however it can not ensure that the designer will actually take the constraints into account. Mutual adjustment refers therefore mainly to the design of the decision process (DP-I135) as illustrated in figure 15. Note that the matrix is uncoupled, however the chosen DPs interact when they exceed a specific extent of coordination.

6 CONCLUSIONS

The decomposition of the Product Development System has provided an insight into the application of Axiomatic Design to organizational design. Furthermore, the PDS enables to undergo the continuous task of designing an organizational entity with a consistent framework, that in addition supports the implementation and control of the system.

7 ACKNOWLEDGMENTS

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