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INTEGRATED MODULARIZATION OF PRODUCT AND SUPPLY NETWORK - A KEY ELEMENT FOR MASS CUSTOMIZATION

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Abstract

Manufacturers of complex investment goods face the challenges of individual customer requirements and increasing product variety. Subsequently, process complexity and thereby costs and delivery time rise.

Product modularization supports the achievement of Mass Customization benefits. Existing modularization methods incorporate customer requirements and technical solutions. Additionally, the presented approach covers product specific, cost and time-consuming manufacturing processes as well as flexibility of network partners. As product modularization requires measures for the estimation of network partners' flexibility, it has to be part of consideration in the course of design and configuration of supply networks.

The concept of integrated configuration developed enables enterprises to determine the most adequate product and network set-up in order to meet customer demand on the basis of product modularization and network flexibility estimation.

Key Words: ***Modularization, Product Design, Supply Network Flexibility, Configuration***

1. INTRODUCTION

Manufacturers of complex high quality investment goods face the challenges of individual customer requirements and increasing product variety. In addition to functionality, quality and price, the delivery time of the products plays a decisive role for the customer. High product variety causes turbulences in the processes of the OEM (Original Equipment Manufacturer) as well as in the entire production network. The consequences are long lead times and high costs in direct, e.g. assembly and manufacturing, and indirect, e.g. purchasing, processes.

There are different approaches to reduce product variety or to minimize its impact on production processes and network. Measures like product modularization, modular sourcing or postponement in logistics are frequently used, but as we will show, they are not yet adequate for the manufacturers in consideration here. Enhancements are necessary to cover the particularities of complex investments goods, which are manufactured to a specific order. In this regard, product complexity and the dependence on specialized suppliers already working at their capacity limits require an analysis of the entire production network.

Network particularities have to be considered in product modularization. Only when the needs of the entire production network are taken into account, the potential of improved flexibility in enterprise specific and cross enterprise processes can be exploited. Therefore, the suppliers' capability in research and development, in manufacturing and in pre-assembly has to be regarded within modularization.

Any bottleneck on the critical path within the production of a consumer-specific module results in a production delay of the final product. The product designer should be aware that a multitude of suppliers with frequent delivery problems, which represent additional bottlenecks for the different components of one module, are adverse to short lead times. Delays sum up and cannot be counterbalanced.

Depending on the customer needs, the network planner has to adapt the network to new situations. He must be able to change the network configuration based on predefined scenarios. An immediate modification of the network for a newly developed customer-specific module is hardly possible, since the expected delivery times are mostly shorter than the time necessary to choose and qualify a new supplier. In case of frequent and extensive changes of the product or in case of exceptional combinations of modules, alternative suppliers can be chosen to improve efficiency. Therefore, suppliers with different performance attributes have to be available to the OEM.

2. THE FLEXIBLE SUPPLY NETWORK

Supply network flexibility is an issue of Supply Chain Management that has not yet been exhaustively investigated [1]. It is, however, a capability required for economic success, because of competition among supply chains and the increasing importance of reduced delivery time for customer satisfaction [2]. Work on flexibility of the supply chain originates in survey and description of manufacturing flexibility, which reflects the ability of a system to properly and rapidly adjust production of goods according to internal or external changes [3]. In the course of reducing the real net output ratio, i.e. the fraction of production processes performed by the OEM himself compared to the total value added, it becomes crucial to equally highlight the flexibility of supply relations and the entire supply network [2][4].

According to the literature review of *Duclos et al.* including strategic and manufacturing flexibility, six components of supply chain flexibility can be defined [4]: operation system flexibility, logistics flexibility, supply flexibility, organizational flexibility, new product flexibility and information systems flexibility.

The supply network can be considered as consolidation of several linear supply chains [5]. This extends the understanding of flexibility by the possibility of shifting production to different sites of the supply network. From the viewpoint of a single company that aims at estimating the flexibility of a single supplier, only the supplier's ability to shift production is of interest. Thus, we will refer to production shift flexibility as the suppliers' ability to choose another site for production in the following. Hence, as the supply network consists of several supply chains in our approach, the flexibility components of the above mentioned authors are extended by the production shift aspect.

In order to deal with the challenge of increasing product variety and ensuing process complexity, it is vital to arrange the supply network in face of flexibility. Thus, supply network flexibility has to be considered within network design and planning. Alternative network set-ups are required in order to benefit from a flexible network. These alternative set-ups will be employed in the course of network configuration according to the customer's requirements (see chapter 5).

According to the findings on flexibility stipulated above, we consider the following flexibility components to be relevant for product modularization:

- Operation system flexibility,
- Logistics flexibility,
- Organizational flexibility,
- New product flexibility,
- Information systems flexibility,
- Production shift

Operation system flexibility refers to manufacturing flexibility as it comprises product mix and product volume changing ability and capacity at network nodes. Obviously, it is one of the most important components of flexibility and subsequently a determinant of product modularization. Product modules have to be easily replaceable with others in the manufacturing processes and have to be usable in a wide range of product variants in order to perfectly meet the flexibility requirement.

Logistics flexibility implies both supply and distribution flexibility. In the context of product modularization, logistics flexibility is an input parameter that comprises the capability of network partners to switch from one procurement process to another, e.g. direct delivery to milk runs.

Organizational flexibility refers to workforce assignment to processes, organizational structures and business practices that are appropriate to guarantee responsiveness at the different network sites [4]. Flexibility means that alternative business processes are defined, which can be easily applied, or that well educated and qualified staff is available that can react flexibly to new situations.

New product flexibility describes the capability to integrate newly designed products or components into the order processing and manufacturing processes. New product flexibility makes demands on product architecture in terms of manufacturing techniques required and comprehensive documentation provided. Only if the modules can be manufactured with common methods and tools, it is possible to switch to concurrent suppliers.

Information systems flexibility comprises information sharing within the network and data interfaces between the network partners. The ability of the network to react and to adjust its structure depends on the ability to integrate network partners case-specifically without lengthy adaptation. The integration relies on data processing and exchange that is conducted with support of information systems.

Unlike the former components, information system flexibility is not strictly linked to product modularization endeavors. More precisely, information systems will not be of major concern in the process of product modularization, because in this case flexibility of the network is not directly correlated with the respective product.

Production shift flexibility as described above poses demands on product architecture. Furthermore, the capabilities of production sites and relevant suppliers have to be kept in mind accurately in the course of product modularization.

For the modularization approach presented, it is vital to identify network-related determinants for product modules as well as functional and process related ones.

As these network-related determinants for modularization include flexibility, a further detailed understanding of flexibility is required to operationalize the approach. Also, it is indispensible to develop a rough estimation of network partners' flexibility as a base for the definition of viable alternative network structures, which can be applied to meet customer demand.

In practice, planning and administration effort have to be considered in any attempt to boost flexibility within the network. Only if there is demand for flexibility, attention should be paid to its enhancement. Suppliers of replaceable low-cost components do not need to be very flexible for example. So, in a preliminary step of flexibility estimation, the network's elements relevant for flexibility consideration have to be identified.

In the following chapter we will describe a framework for the evaluation of network flexibility.

3. EVALUATION OF NETWORK FLEXIBILITY

Similar to network flexibility, scientific work on the measurement of flexibility is scarce. As *Stevenson et al.* state, “literature that attempts to measure supply chain flexibility remains in its infancy” [6]. Regarding flexibility and its integration in processes of decision-making, the theoretic concepts of network flexibility have to come down to relations between supplier and customer. For practical implementation, the measurement or the estimation of flexibility must refer to a certain supplier and a defined part or product component. However, the definition of figures on a numeric scale seems inadequate and not feasible because of the dynamic behavior of relations [7] and the interdependencies of relations within the network. Flexibility of a certain network partner, e.g. supplier, thus is dependent on the respective network partner within a bilateral supply relation, e.g. customer. Consequently, flexibility is an attribute of a one-to-one relation between one supplier and one customer. However, as each supplier maintains relations to several customers, flexibility and capacity have to be subdivided. Nonetheless, it is indispensable to measure or at least to estimate the flexibility of suppliers in order to find the appropriate network out of a range of applicable alternative supply structures. Therefore we propose an interval scale of flexibility estimation as introduced by *Garavelli*. For the sake of simplicity and manageability *Garavelli* differentiates the flexibility categories ‘no flexibility’, ‘limited flexibility’ and ‘total flexibility’ [3]. As these three categories are a very rough approximation and thus insufficient to represent the potentials of product modularization, we map the above mentioned flexibility components on five flexibility categories (see table 1). These categories allow evaluating flexibility more detailed because interdependencies between influencing factors are considered within each category.

In our approach we assume that network flexibility is one parameter of product modularization. One subsequent implication is the pretension that successful modularization permits the leap to an upgrade level, i.e. category, of flexibility.

The five generic flexibility categories we assess are ‘no flexibility’, ‘partial flexibility’, ‘limited flexibility’, ‘extensive flexibility’ and ‘total flexibility’. Table 1 displays the characteristics of the flexibility categories related to flexibility components.

The flexibility framework cannot be consolidated to a single index or figure, but must be evaluated per product module and network partner respectively. A supplier, for instance, who is able to raise output volume of a certain product, but cannot adapt the supply process, is not comparable by figures to another supplier, who can deliberately process a wide range of new products, but is not able to standardize the new production process, due to the lack of organizational flexibility.

Measuring flexibility in five clusters is a simple approach to estimate the extent to which suppliers can adapt their operational system, logistics, organization, new product integration, information systems and production site. However, the approach seems appropriate for our practical intentions. The flexibility estimation of single suppliers and specific parts or modules consolidates in the network to a product-specific flexibility map. Using this map, the flexibility demand, the flexibility offer and the resulting gap can be

Table 1: *Framework for the Evaluation of Supplier Flexibility*

Flexibility Components / Flexibility Categories	Operation System Flexibility	Logistics Flexibility	Organizational Flexibility	New Product Flexibility	Information System Flexibility	External Production Shift
No Flexibility	No adaption of product volume and mix possible	Fixed supply process (direct relation)	No adaption of workforce assignment and business processes	No processing of new products	No data interfaces and information sharing	No shift of production to alternative sites
Partial Flexibility	Limited adaption of product volume OR mix	Supply processe including service provider (3rd party)	Limited adaption of workforce assignment OR business processes	Processing of products with scaled geometry	Specific uni-directional data interfaces and limited information sharing	Production shift to one alternative site with high investment
Limited Flexibility	Total adaption of product volume OR mix	Supply processes affecting other partners (milkrun)	Total adaption of workforce assignment OR business processes	Processing of products with new manu-facturing techniques	Standard uni-directional OR specific bi-directional data interfaces and limited information sharing	Production shift to one alternative site with mean investment
Extensive Flexibility	Total adaption of product volume OR mix and ltd. adaption of volume OR mix resp.	Supply processes with advanced time sensitivity (JiT)	Limited adaption of workforce assignment AND business processes	Processing of products with new design effort	Standard bi-directional data interfaces and limited information sharing	Production shift to one alternative site without investment
Total Flexibility	Total adaption of product volume AND mix	Supply Processes with additional services (sequencing etc.)	Total adaption of workforce assignment AND business processes	Processing of any new product including prototyping	Standard bi-directional data interfaces and full information sharing	Production shift to multiple alternative sites without investment

determined. If necessary, measures can be taken to reduce the gap, e.g. supplier qualification.

4. PRODUCT MODULARIZATION

Product design determines the greatest part of costs and times required for the production processes of customer-specific products within the network [8]. Applying modularization, it is expected that a wide range of products can be produced without variant-specific efforts. Modularization means to build a product from mostly standardized components, so that a high number of final products can be achieved by combining different components, i.e. modules. The aim is to divide the product into modules while minimizing interconnections between modules and maximizing dependencies between different parts of one module [9].

Since modularization is an important prerequisite for Mass Customization, an optimized product structure for complex investment goods must be identified. Especially for long product life cycles and products covering a considerable market share and market growth respectively, modularization seems to be efficient. Else wise costs are too high to compensate the efforts of modularization [10].

As a product's structure and therewith its modules cannot be changed easily and quickly, a multitude of influencing factors has to be taken into account within modularization in order to design a product structure that lasts over the product lifecycle. As mentioned above, these factors are functionality and process as well as network and flexibility related aspects.

Furthermore, modularization has to represent future requirements of customers, processes and network partners. Thus, it is necessary to forecast customer demand in order to deduce product variants and quantities. Product modules have to be classified according to their variety distinguishing invariant modules from those with foreseeable frequent and extensive changes.

Scenarios have to be developed representing probable future requirements. These scenarios must contain for instance information about possible changes of customer requirements, new technical design demands, new production technologies and new suppliers in the network. Using methods like the Quality Function Deployment as a basis (see figure 1), product modules, which undergo extensive changes, can be deduced.

We have developed the simple index 'level of change' in order to identify products and modules, which undergo extensive changes. The index is a multiplication of the expected number of changes over the life cycle and the expected costs per change at involved partners. This level of change is sufficient for an efficient evaluation of possible changes. It is of importance for the integration of flexibility into modularization.

A. Flexibility and Network Requirements

The modules' demand for flexibility is characterized by the highest demand for flexibility of any module component. A module that consists of many simple components like screws, clamps and levers and one complex component, e.g. engine, demands the flexibility of the most challenging component, i.e. the engine, for example. Thus, parts of minor relevance for flexibility are not regarded in the applied method in order to limit modularization efforts.

In the following, the above mentioned flexibility components (see table 1) will be regarded in order to identify flexibility and network requirements for modularization.

Following the definition of operational system flexibility, parts with high flexibility requirements should be pooled together to one module in order to reduce flexibility requirements within one module. In case of modular sourcing only one supplier is affected then.

The module structure should allow the production of different module variants with virtually the same technologies. Thus, the variants of a module should have similar technology, quality, measuring and testing equipment and capacity requirements. Furthermore, the automation level of module variants should be similar to the variant with the highest production volume in order to level flexibility demand within a module.

Since technical capabilities of suppliers normally do not change fundamentally within a considerable timeframe, the module components should require only a limited number of technologies. Obviously, this applies especially to modules that probably will be changed during product life cycle.

Within product modularization, logistics flexibility refers to logistic parameters, e.g. dimensions and weight, of module variants as well as their loading device. Parameters and loading device should be standardized in order to allow switching between alternative suppliers and module variants respectively.

The organizational flexibility as defined above is only of importance when specific knowledge or competences are necessary for the production of different module variants. The production of a module should therefore demand similar skills and level of experience in order to enhance flexibility.

These modularization requirements have to be weighted for each supplier regarded and taken into account by the applied modularization method.

B. Suitability of Existing Modularization Methods

Several modularization techniques are available in scientific literature and practice. It is the aim to use and enhance existing techniques wherever possible within this work. Therefore it is necessary to examine, which method is applicable according to their characteristics.

One of the best known modularization techniques is the Modular Function Deployment (MFD) method [11]. The user defines modules by using predefined module drivers. A module driver is an experience-based criterion for modularization which represents similar requirements that a module has to fulfill. Module drivers result predominantly from one functional area of the enterprise, e.g. assembly [12].The comprehensible structure and the multitude of influencing factors considered are the advantages of this method. However, influencing factors resulting from flexibility and network considerations are not included.

Another technique for modularization is the Design Structure Matrix [13]. An existing product is decomposed into modules by considering only interfaces of complex components. Only customer related, physical and a few strategic requirements are regarded.

The Modular Product Development method [14] is based on the functional decomposition of the product and on functional trees, while criteria for designing different modules are not given explicitly. Network aspects and flexibility requirements are not considered.

The Function Structure Heuristic method uses functional decomposition block diagrams of product functions as well as material, energy and information flows between the components [15]. *Stone et al.* separate modules from a single product's function structure by finding the 'dominant flow', 'branching flows', or 'conversion-transmission' pairs. Since these flows between modules can hardly express flexibility and network requirements, this method is not integrated in the presented approach.

Modular structures can also be defined using Dendrograms [16]. Since this is another possibility of representing and defining the modular structure that covers functional aspects only, the method will not be pursued further.

Dynamic Modularization [17] is another method to modularize a product using cause and effect diagrams for individual modularization causes. This method is considered as being too complex to integrate flexibility and network aspects because of interdependencies between the regarded causes.

The method House of Modular Enhancement also takes life cycle costs into account [18]. The shortfalls of this method are the difficulties to calculate life cycle costs for complex industrial goods and the lacking possibility to weight the influencing factors of modularization within the method.

Since the existing modularization methods consider neither network nor flexibility requirements, a new approach has to be developed or the existing methods have to be enhanced. The MFD method is the most advantageous of the methods presented, because it corresponds to different requirements, it allows the weighting of module drivers and it is proven and commonly accepted. Subsequently, it will be used as a basis for our approach.

C. An advanced Product Modularization Method

As mentioned above, variants and future product requirements have to be determined as input parameters for modularization (see figure 1). Product classes can be defined, if high efforts are necessary to determine the impact of future customer preferences, technical developments and network parameters. Each product class represents different products with similar modularization requirements.

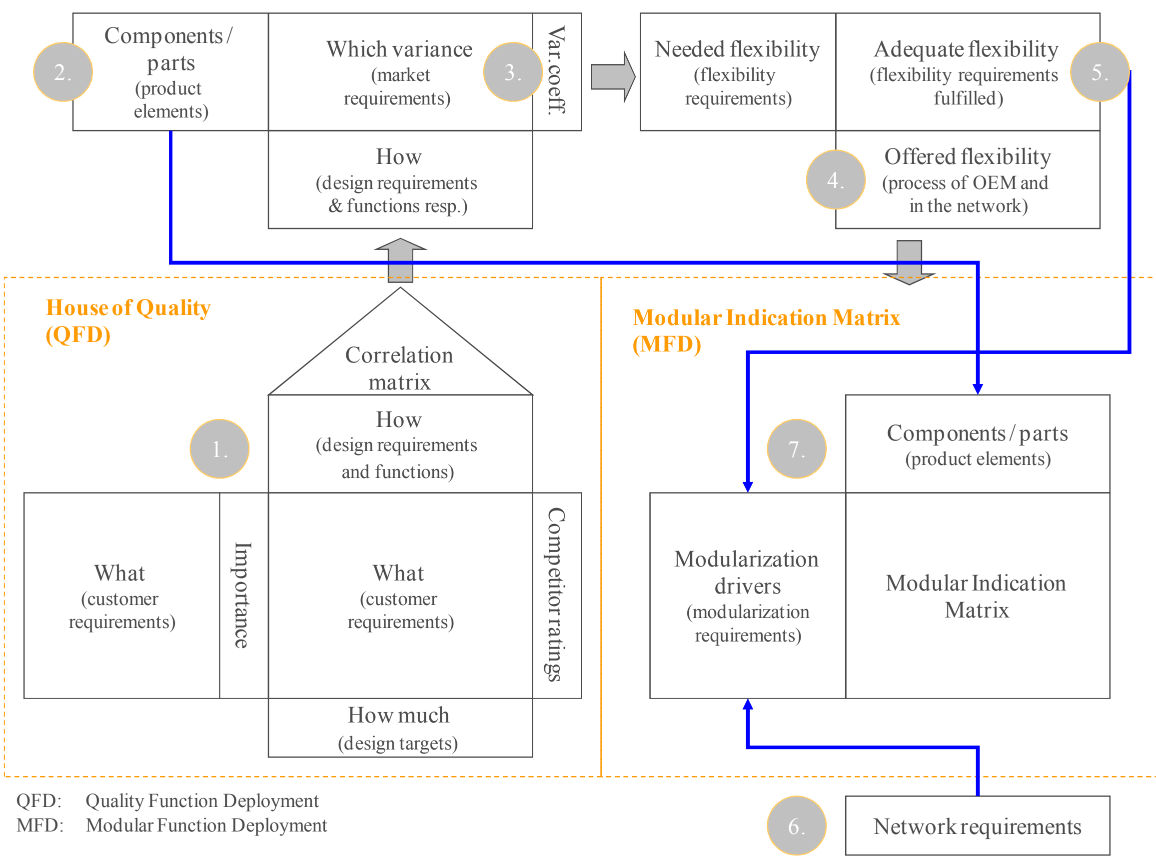

Figure 1: *Integrating Network and Flexibility Aspects into Modularization*

Then, demand forecast has to be surveyed in order to define the importance of functionalities, i.e. product modules, for the customer. The aim is to prioritize modularization endeavors according to forecast volume.
The next step within modularization contains the determination of suppliers and product components that pose important requirements. These requirements have to be integrated into the modularization technique. In the case of a newly developed product, which is not yet in series production, the supplier's capability to produce the number of variants within the required cost and time frame has to be estimated.
Within modularization, the flexibility and network requirements of any part must be compared with the requirements stated by customer, functionality and processes. Using an ordinal scaled measure, which is based on the results of standardized questions to the modularization team, this comparison can take place. As figure 1 shows, requirements for modularization can be summarized in the Modular Indication Matrix of MFD. The aim is to develop a modular structure that is adequate for all product variants since otherwise this structure has to be optimized for many single product variants.
Given the modular structure of the product family, which fulfills the most important requirements including flexibility and network requirements, the resulting product variants have to be managed efficiently. As we will show in the next chapter, the configuration of the product and the network is a viable approach to cope with product variety.

5. THE INTEGRATION OF PRODUCT AND NETWORK CONFIGURATION

The use of software-based product configurators is widely spread in businesses that follow the Mass Customization approach. The configuration of the supply network and the consideration of network flexibility in contrast have not yet been described in detail [19].
In this work we aim at combining product and network configuration within an integrated concept while taking network flexibility and the result of product modularization as described above into account.
When configuring the product, the foremost goal is to obtain a Bill of Material (BOM) and a working plan that is suitable to generate a product according to the customer demand [20]. A secondary goal is to establish configuration software as a data base for expert knowledge [21]. There are various approaches how to technically implement this aim ranging from case-based to constraint-based methods (see [22] for an overview).
Within network configuration two distinctive use cases have to be distinguished: First, the concealed, automated configuration in the background while the customer customizes a product. Second, the obvious configuration when the network designer or supply chain manager, who has access to the available information, configures the most adequate network, e.g. for a set of customer orders. While the first case originates in an immediate customer requirement, the latter's trigger is a planning task. The differences in the cases concern the different goals of operation, the diverse knowledge of the user and the scope of data, which is available or visible to the user.
The purpose of configuration as regarded in this work meets the second of these two cases. Practically, the configuration will be performed in order to analyze the impact of new or changed products, modules or specific features or to define the most adequate network to deal with a bulk order.
When configuring, a data base of the subject has to be available covering its components and their combinability. The result of the configuration process is a set of components, which meets preliminary stipulated functional requirements, general rules and specific directives, e.g. minimize costs or maximize product performance (similar: [23]).
The resulting set of components needs to be described in a modality that is usable within further business processes, i.e. a Bill of Material and preferably working plans in case of product configuration. This is especially of importance in the course of integrating the configuration concept into existing or newly developed software tools. Consistent business processes then allow coping with high product variety.
Our approach of integrating modularization and configuration emphasizes the correlation of both aspects by including the supply network and flexibility within modularization and within configuration. Based on the modular product and flexible supply network structures we aim at configuring both aspects in a single working environment and with a common data base.
As displayed in figure 2, the configuration process originates in a conceptional planning task. Within this step, the user has to define the requirements, which the product has to fulfill, as well as his preferences regarding costs, time of delivery and flexibility that are required for network configuration.
The result of integrated configuration is a specific product and network set-up. In the following, the product configuration, network configuration and data base according to figure 2 are described.

A. Product Configuration

Product modularization is a prerequisite for configuration. The product configuration in the sense of composing a product set-up is only possible on the basis of a product model, which includes the compatibility of product components.
Based on the product modules that have been defined within the modularization process as described above, on the rules and constraints, which constitute the modules' combinability, and on optional directives, product configuration is performed. According to *Ladeby et al.* the following data-sets are required for product configuration [23]:

- A fixed, pre-defined set of components, where a component is described by a set of properties
- Ports / interfaces for connecting it to other components
- Constraints at each port that describe the components that can be connected to this port
- Other structural components

In other words, these data sets comprise the product modules, their combinability and properties. Additionally, the configuration process uses directives, which are used to evaluate the quality of a solution (see figure 2). Core functionality of configuration is to match the initially posed requirements with the module properties. In this process the modules' combinability defines the constraints that have to be fulfilled. Finally, the best out of a set of possible solutions is identified by application of the optimization directives. The most obvious optimization directive in product modularization is minimizing the costs of the configured product.

Result of the product configuration step is a comprehensive description of the configured product, i.e. a Bill of Material with the selected modules. Furthermore, it is advisable to provide working plans for manufacturing and assembly of the product and the modules respectively. This however requires working plans stored in the data base in addition to the above mentioned elements.

Within the consecutive step, the network configuration, the resulting product set-up is used as input for computation.

B. Network Configuration

Similar to the product configuration step, we search a network set-up that optimally meets previously stated requirements, rules and directives within network configuration. Requirements refer to the previously defined product and to customers' preferences, rules state the interdependencies between network segments and directives define how to detect the best out of a set of possible solutions. Obviously, the result of the previous step, i.e. the configured product is incorporated into the network configuration process. Thus, the solution space of permitted network segments is limited to those that are applicable to the previously configured product and its modules.

While product configuration relies on a product model, network configuration requires a network model containing combinable segments (see figure 2). The combinability of the segments has to be described in the network model to ensure that the solution is both complete and feasible. Equally to the product model, the network model contains interfaces between the segments and constraints describing combinability, i.e. which segments can be connected to the respective interface.

Network segments include the supply relation, i.e. supplier and customer, the assigned product module and properties, like transportation and stock policy. Flexibility according to the framework of components and categories (see table 1) is a property of network segments within network configuration as well. The flexibility property is used as an input parameter in the course of network configuration: Depending on the user preferences, some network segments are more or less adequate for network set-up.

The optimization directives in network configuration cover logistic costs, the resulting time of delivery of the

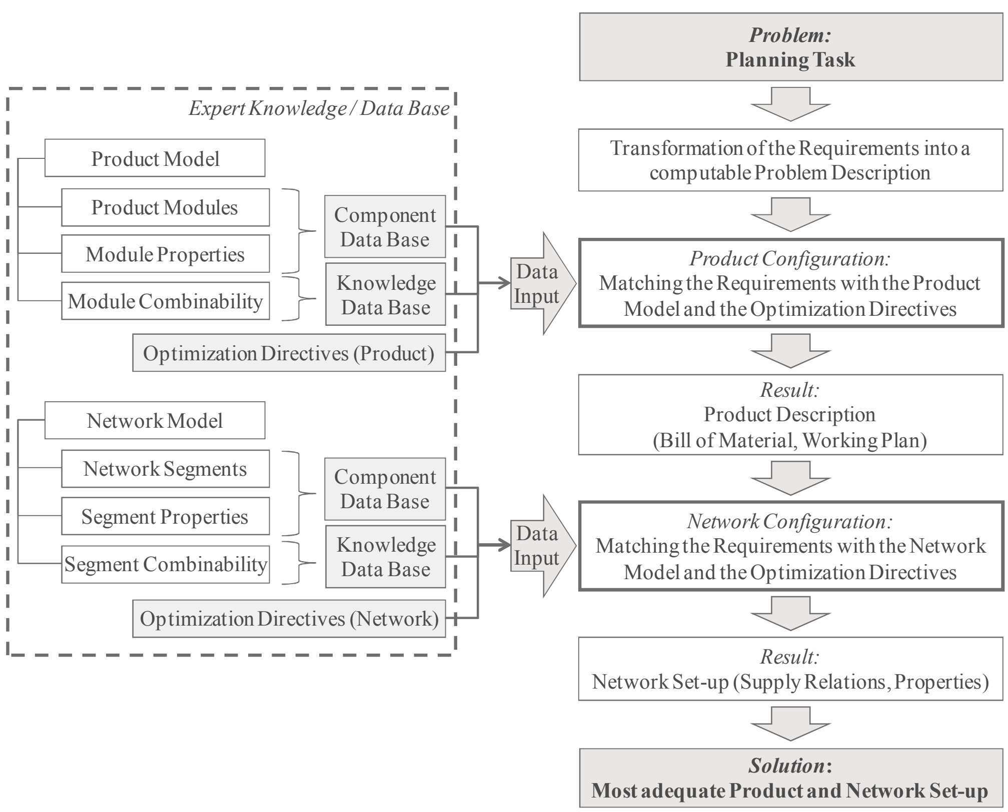

Figure 2: *Data Base and Process of Integrated Configuration*

product and required network flexibility. The user preferences concerning these dimensions are incorporated into the configuration process.
The result of the network configuration step is a complete network that matches requirements, rules and directives and that allows the adequate productions of the previously configured product.

C. Data Base and Software Tool Requirements

As figure 2 displays, the configuration of product and network can be performed without support of information technology (IT) on basis of expert knowledge. Actually, this is the daily task of product designer and supply chain manager. However, in order to manage product variants and alternative networks, a digital data base and the support of computer software is advisable.
As shown in the product and network configuration sections, integrated configuration requires a model of product and network respectively that consists of components, i.e. modules and segments, their combinability and properties. In conclusion, we propose a data base that contains the elements 'component data base', 'knowledge data base' and 'optimization directives'. The component data base covers product modules and network segments respectively and their specific properties. The knowledge database comprises information about component combinability and optimization directives describe how to find the best out of a set of possible configurations.
The component data base of the product represents a list of all available modules and their properties, which are relevant for configuration. These properties include the interfaces available to other modules and their parameters as well as information on costs.
In the knowledge data base of the product, each interface, which has been listed in the component data base, is opposed to any other interface in a matrix. The cells of the matrix contain the bandwidth within the parameters may vary until the interfaces do not fit to each other anymore.
The component data base of the network contains available network segments. As described above, these segments consist of a supply relation, the assigned product module and properties. In detail, these properties are:

- Transportation: Means of transportation, capacity and loading device are defined here.
- Stock policy: Defines stock level and safety level at origin and destination.
- Flexibility: Defines the flexibility of the supply relation according to the framework in table 1.
- Cost and time information: Costs and lead time of the supply relation.

The knowledge data base of the network contains interfaces between network segments. These interfaces constrain combinability of network segments according to their origin (supplier), destination (customer) and properties, e.g. loading device.

Optimization directives for product and network are mapped within a dataset that contains a brief description of the directive and the stipulated constraints. As mentioned above, these optimization directives concern costs, time of delivery and network flexibility.
Further directives like mandatory service level or local content, i.e. the procurement of parts from local suppliers, can extend the proposed trias of directives. However, this requires further research endeavor on the influencing factors and the expected result.

The data base is an element of integrated configuration that allows a software tool to support product and network configuration. The configuration process of matching requirements and available components, i.e. product modules and network segments, can only be performed by an automated software routine, if a consistent data base is available.
As a result of the integrated configuration process described, a software tool, which can perform the integrated configuration, has to provide the following core elements:

- A data base, which consists of component data base and knowledge data base for both product and network.
- Search algorithms, which allow identifying possible solutions by matching requirements and combinable components.
- Analyzing algorithms, which allow identifying the most adequate out of possible solutions according to stated optimization directives.

Since the presented approach of integrated configuration is complex and innovative, these rough requirements to software are a first estimation that has to be refined in consecutive work.

6. CONCLUSION

Customer expectations regarding costs and time of delivery and high product variety affect production processes as well as the value creation network. Mass Customization is a promising approach to cope with these challenges, because a modular product structure and customized products enhance order processing. Thereby, costs and time of delivery can be reduced.
As manufacturers of complex investment goods depend on specialized suppliers, a flexible network is crucial in order to satisfy individual customer demands. Thus, network and flexibility requirements have to be considered in modularization endeavors. A method was developed approving the integration of network and flexibility aspects into product modularization.
As networks change frequently, network flexibility has to be considered continuously. The concept of integrated configuration of product and network incorporates network flexibility as input parameter into the configuration process. It has been shown, that this concept enables companies to determine the most adequate product and network set-up in order to meet customer demand.

Computer software for the integrated configuration has to map product modules and network segments as well as their combinability and properties in order to implement the concept.

Further developments and advancements of the modularization and configuration concepts presented are advisable. The modularization method must be refined with the aim to measure and integrate all important flexibility components accurately. The modularization technique then has to be supported by software products. The integrated configuration concept has to be enhanced and detailed in order to develop a software tool that supports the automated configuration.

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