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APPLYING AXIOMATIC DESIGN TO SUPPLY CHAIN MANAGEMENT

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ABSTRACT

This paper outlines the application of Axiomatic Design to supply chain management (SCM). After an overview of SCM, the supply chain design decomposition SCDD is presented, which is developed using Axiomatic Design. Because the SCDD systematically relates means to objectives of SCM at different levels of abstraction, higher-level objectives can be made actionable step-by-step. Using a structured procedure, the SCDD can be utilized to develop a supply chain strategy that is in alignment with corporate strategic goals and the context and the environment of the enterprise. Moreover, it can be used for an analysis of cause-and-effects and for a sustainable implementation of SCM concepts. A short case study illustrates the application of the methodology.

Keywords: Supply Chain Management (SCM), Axiomatic Design, Supply Chain Design Decomposition

1 INTRODUCTION

Supply chain management (SCM) is a widespread and successful concept for the co-operation of enterprises in the area of logistics by connecting, aligning and coordinating processes in supply chains as well as flows of materials and information between suppliers and customers. "Supply chain management is the coordination of a strategic and long-term cooperation among co-makers in the total logistics network for the development and production of products, both in production and procurement and in product and process innovation" (Schönsleben, 2003).

On an operational and tactical level of SCM, there exists a multitude of concepts and best practices of SCM such as vendor managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR). Their application and the design of objectives and means should be aligned with corporate strategy so that all activities of SCM contribute to the success of the company. This way, companies are able to realize improvement potentials of SCM: more efficient logistics processes, better customer service, and cost reduction.

In order to achieve a good design of objectives and means of a supply chain and to align all SCM activities, Axiomatic Design could be applied. Axiomatic Design was developed by Nam P. Suh at the Massachusetts Institute of Technology (MIT) as a design method for products, systems, and processes with the goal of making the field of design scientific (Suh, 1990; Suh, 2001). Consequently, the research objective of this paper is to apply Axiomatic Design to SCM in order to generate a supply chain design decomposition, which can be used for the design of objectives and means of SCM.

The research described here was conducted under the framework of a large-scale international research project, ProdChain (IST-2000-61205), which was funded by the European Commission. Three European academic research institutes as well as ten industrial partners participated in ProdChain. The research methodology follows the principles of action research according to Greenwood and Levin (1998). The research process consists of five consecutive steps and this paper is organized accordingly: First, requirements and issues in theory and practice relating to SCM were identified by means of literature reviews and surveys (sec. 2). In a second and third step, Axiomatic Design is applied to SCM, yielding a decomposition of SCM, the supply chain design decomposition (SCDD), that was validated together with industrial partners during the ProdChain project (sec. 3). In a fourth step, the SCDD is applied to identify and align objectives and means of SCM (sec. 4). Subsequently, the application is illustrated by means of a case study (sec. 5). In sec. 6 and 7, we discuss the results, give an outlook for further research and draw some conclusions.

2 RESEARCH BACKGROUND

SCM has a significant impact on company objectives. The general target areas of SCM are quality (meeting higher customer requirements), delivery reliability (punctuality), delivery lead time (delivery times, availability), flexibility (responsiveness, managing changes and uncertainties), assets (inventories, infrastructures), and costs (Schönsleben, 2003). In a supply chain strategy, these target areas are prioritized and operationalized and have to be aligned with corporate strategy (Schnetzler et al., 2006).

Current literature of SCM is summarized and reviewed for instance by Chen and Paulraj (2004) and Power (2005). In the view of the topic of this paper, the following areas of relevant research can be identified: strategy orientation and value orientation. Strategy orientation refers to fundamental supply chain decisions and objectives. Many authors point out that alignment of the supply chain strategy (objectives and means) with corporate strategy ('strategic fit') is crucial (see, e.g., Evans and Danks, 1998; Gattorna, 1998; Chopra and Meindl, 2004; Cohen and Roussel, 2004). Value orientation means gearing all activities towards maximization of the enterprise (Copeland et al., 2000). No longer is SCM regarded as a cost driver, but rather as a value driver for high customer satisfaction and high business success. However, the adoption of value orientation to logistics and SCM is in an early stage yet. Some concepts related to SCM have been developed that identify value drivers of SCM (see, e.g., Lambert and Burduroglu, 2000; Chopra and Meindl, 2004). In particular, relationships between objectives and means of SCM are not analyzed in detail. As a consequence, the impacts of SCM on business objectives are not considered in a holistic way.

As a conclusion, the issue is to design a supply chain in terms of objectives and means so that all activities are aligned with corporate strategy (strategy orientation) and geared towards value creation (value orientation).

In the area of design of products, processes, and systems, the aforementioned Axiomatic Design was developed as a scientific approach for the generation and selection of good design solutions and has been successfully applied in a large number of examples (Suh, 1990; Suh, 2001). It focuses on the identification of functional requirements (FRs) (objectives: 'what to achieve'), and the selection of means for achieving them, i.e., design parameters (DPs) ('how to achieve'). Two design axioms provide a rational basis for generating good designs and identifying the best design of proposed solution alternatives (Suh, 2001). The independence axiom says that the independence of the FRs must be maintained. This means that in an acceptable design, a DP can be adjusted to satisfy its corresponding FR without affecting the other FRs. The information axiom requires the information content to be minimized: Of the alternative designs that fulfill the independence axiom the best design has the minimum information content (i.e., maximum probability to fulfill the DPs). The mapping of relationships between FRs and DPs can be represented by a design matrix (for details, see Suh, 2001). The design matrix can be evaluated using the two axioms in order to determine whether the design is good.

By decomposing the design into several levels of objectives-means-combinations, a hierarchical causal model is created showing the connections of an objective (FR) and the appropriate means (DP). In doing so iteratively, high level objectives and means are decomposed and concretized into lower level objectives and means (design process). This systematic approach has two main benefits (Duda, 2000): The separation of objectives and solutions helps to clarify the logic and to focus on what is to be achieved prior to thinking about solutions. Furthermore, the systematic decomposition enables to concretize high-level goals systematically on lower levels.

Axiomatic design was applied to manufacturing systems, yielding the Manufacturing Systems Design Decomposition (MSDD) (Cochran et al., 2001). The top-level objective in the MSDD is to maximize long-term return on investment, which is further decomposed into maximizing sales revenue, minimizing production costs, and minimizing investment over production system lifecycle. The MSDD incorporates means according to lean manufacturing and comprises more than 70 pairs of FRs and DPs. It has been used for the design and evaluation of production systems, development of production strategies as well as for linking performance measurement.

3 SUPPLY CHAIN DESIGN DECOMPOSITION (SCDD)

Within the framework of the research project mentioned in sec. 1, we applied Axiomatic Design to SCM. The result is the Supply Chain Design Decomposition (SCDD). It was developed systematically based on the latest research and validated with the cooperation of partners in the industry (Schnetzler, 2005; Schnetzler et al., 2006). SCDD is systematically structured (see Figure 1): The upper levels of SCDD incorporate value orientation and are structured according to the concept of EVA (economic value added, see Ehrbar, 1998). The highest, general corporate objective is to achieve a high EVA, a measure that represents business success. In simplified form, EVA can be calculated as the difference between net operating profit after taxes (NOPAT) and capital charge, which is dependent on the total invested capital and weighted average cost of capital (Ehrbar, 1998; Copeland et al., 2000).

Subsequently, the SCDD is horizontally subdivided into the target areas of SCM, i.e. quality, delivery reliability, delivery lead time, flexibility and further into assets (inventories, work in progress, infrastructure) and operational costs. The sequence follows path dependency, which can be empirically well supported through the 'sand cone' model (see below). From this point on, only the impact of SCM on these target areas is considered. At the fourth level, the decomposition is continued according to the generic processes of 'source', 'make', and 'deliver' (SCOR, 2005).

Next, the production factors (or resources) are considered: capacities, information, and materials. FRs and DPs are identified by using so-called inhibitors according to lean manu-facturing that prevent optimum efficiency of the supply chain: waste (over production, waiting, transportation, unsuitable production methods, excess inventories, quality defects etc.) (Ohno, 1988) as well as fluctuations, and inflexibility.

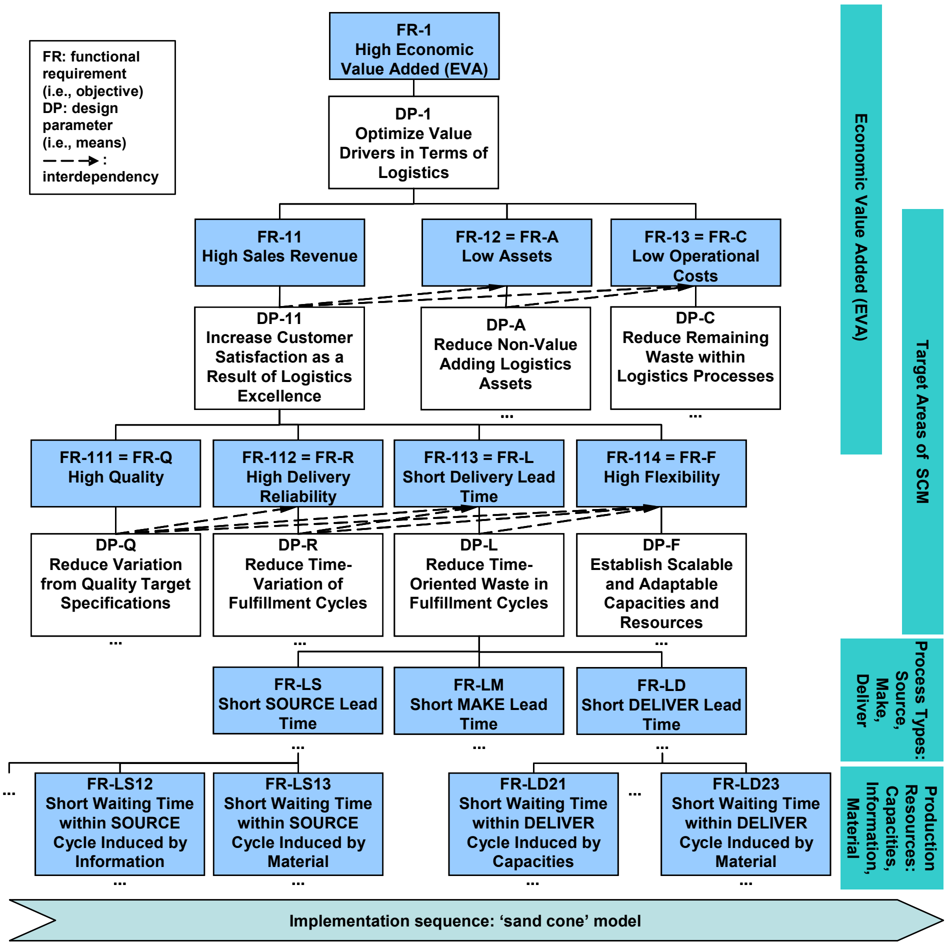

Figure 1. Setup and upper levels of the SCDD

The sequence of the target areas follows the so-called ‘sand cone’ model (Ferdows and De Meyer, 1990). It states that an appropriate quality is a precondition for the optimization of reliability; next, lead time and flexibility should be improved, and finally costs. The rationale behind is that compromising on quality would induce serious problems while optimizing reliability and lead times. If a certain degree of reliability is established, then lead times and subsequently flexibility can be optimized, since it is inefficient to optimize processes that are not well controlled towards speed and flexibility. This is the prerequisite for reducing assets and costs. Reducing them first could cause serious problems regarding quality, reliability and availability. This sequence reflects the logical order of decisions and implementation of measures. In the terminology of Axiomatic Design, this path dependency due to the mutual influences among the target areas (depicted by dotted arrows in the SCDD) is reflected in a partially coupled design. Because assets and costs are impacted by all other target areas, a different sequence would violate the independence axiom of Axiomatic Design and therefore result in a coupled, and thus poor, design. Mutual influences have to be analyzed carefully in the specific context.

The SCDD consists of more than 250 objectives and means of SCM and is described in detail in Schnetzler (2005) and Schnetzler et al. (2006). Figure 1 shows a small excerpt of the SCDD. A remark regarding the notation: Functional requirements and design parameters are noted as FR-xyz and DP-xyz, respectively, with x = Q, R, L, F, A or C for the target areas quality, delivery reliability, delivery lead time, flexibility, assets, and operational costs, y = S, M or D for 'source', 'make' or 'deliver' in the corresponding target area, and z = hierarchical number for the further decomposition. (Exceptions are the high level objectives and means FR/DP-1 and FR/DP-11).

The target of a high EVA (FR-1) is achieved by means of the optimization of its value drivers in terms of logistics (DP-1). Therefore, DP-1 is decomposed into the value drivers high sales revenue (FR-11), low assets (FR-A), and low operational costs (FR-C). As a means for FR-11, increasing customer satisfaction (DP-11) is identified, which is further decomposed into the objectives of high quality (FR-Q), high delivery reliability (FR-R), short delivery lead times (FR-L) and high delivery flexibility (FR-F). For each of these objectives, appropriate means are identified with respect to the state of the art of SCM and lean manufacturing principles, as mentioned above. These elements are further decomposed into objectives and means over several levels.

High quality (FR-Q) is achieved by reducing deviations from quality requirements on the customer's side. Only a small over-achievement is allowed (otherwise, it is waste). When quality is ensured, delivery reliability (FR-R), i.e., punctuality, can be optimized by minimizing time deviations and delays of 'source', 'make', and 'deliver' processes. In particular, supply chain risk management and process control as well as supply techniques such as continuous replenishment can be employed. Next, with a high reliability as a prerequisite, delivery lead time (FR-L), i.e. availability and time to delivery, can be optimized by reducing any kind of time waste, for example, avoidable waiting times. Measures are, for instance, just in time techniques, better synchronization, co-ordination and harmonization of processes, seamless flows of materials and information, set-up time reduction and optimization of capacity utilization. Processing time may be reduced by elimination, parallelization, integration or acceleration of process steps or by a change in sequences. Furthermore, information technology can help accelerating the flow of information (order processing etc.). High flexibility (FR-F) relates to the capability to cope with changes of order patterns and order due dates as well as uncertainties of demand. Means for this purpose are scalable and adaptable capacities.

Assets (FR-A) can be optimized by reducing investments in non value-adding current (inventories, work in process etc.) and fixed assets (infrastructure), as far as possible. This can be achieved, for instance, through optimizing lot sizes and order cycles, smoothing of demand variations, inventory management, reduction of inventory levels, outsourcing, and the reduction of added value profile. Furthermore, it is essential to optimize safety stock and to prevent the bullwhip effect (Lee et al., 1997), which describes the phenomenon that demand variance is amplified upwards the supply chain resulting in inefficiencies such as surplus and fluctuating stocks as well as long lead times. This can be reduced through sharing of information about end-customer demand and forecasts throughout the supply chain, as well as inventory control. Furthermore, measures for short lead times (DP-L) have a positive impact on low assets.

Fixed assets can be reduced, for example, by outsourcing non-core processes, e.g., warehousing. Since costs are influenced by all target areas discussed so far, cost reductions (FR-C) are not sustainable unless all prerequisites are met. Any kind of waste in processes related to the flow of material and information as well as related to management and warehousing has to be eliminated systematically. In particular, information technology can facilitate this objective by automating exchange and processing of information and also by employing, e.g., barcoding, track & trace, radio frequency identification (RFID), electronic procurement etc.

4 APPLICATION

There are many applications of the SCDD (Schnetzler, 2005; Schnetzler et al., 2006): First of all, the SCDD can be framed into a decision making process in order to develop supply chain strategies that are in alignment with corporate objectives. Since the SCDD systematically connects objectives and means, a supply chain strategy can be developed by starting in the SCDD at the strategic priorities given by corporate strategy and following the decomposition. In doing so, the strategic objectives are made tactical and operational, and, moreover, appropriate means (methods, techniques, best practices of SCM) can be identified. In the SCDD, an operationalized supply chain strategy represents a path that begins at the strategic priorities and consists of FR-DP-pairs. Therefore, all SCM activities are aligned and strategic SCM projects can be defined in order to implement them. This idea can be embedded into a procedure for the development and implementation of a supply chain strategy that comprises an intelligence, design, choice, and implementation/review phase (Schnetzler et al., 2006).

Furthermore, improvement potentials can be realized by identifying appropriate objectives and means in the SCDD. In particular, it can be analyzed whether prerequisites are fulfilled, which effects on other target areas should be taken into consideration and what are the root causes.

There are more applications, for instance: Supply chain due diligence analyzes strengths and weaknesses of a supply chain design in a systematic way based on the SCDD. In order to better meet customer needs, supply chains can be segmented so that they have different priorities, objectives, and means. Appropriate best practices and measures can be selected for each supply chain segment.

5 CASE STUDY

In this section, the application of the SCDD in a short case study is illustrated (source: Schnetzler et al., 2006). In a company, inventories of a specific product family are too large in the long term; moreover, they increased unplanned. Delivery reliability is also sub-optimal. Therefore, a supply chain strategy is needed that will lead to a lasting reduction of inventories, but without adversely affecting customer satisfaction. Based on an additional analysis of strengths and weaknesses as well as opportunities and threats it was decided that the strategic priorities are reducing inventories and maintaining a defined level of availability with the help of improved delivery reliability.

In a first step, the SCDD was used to identify root causes and to analyze prerequisites of high inventory levels by identifying objectives and means that influence inventory (FR-Ax1 with x = S, M, D for 'source', 'make', and 'deliver'). Since high improvement potential has been identified in 'source', the lever was applied there first. The most important influence was located at delivery reliability in 'source' (FR-RS), i.e. particularly reliable supply and planning, while high quality (FR-QS) has already been ensured enough (see Figure 2). Then, the objective of low 'source' disturbances induced by information (FR-RS212) by means of a reliable procurement planning (DP-RS212) with the prerequisite of information management in 'source' (DP-QS2, i.e., high data quality and information technology, for instance) was prioritized.

These elements are prerequisites for low working capital (inventories, work in process) in 'source' (FR-AS1). The means for this purpose is optimizing of inventory levels of raw materials and components (DP-AS1). Sub-objectives are low cycle stocks (FR-AS11) and low safety stocks (FR-AS12). For this, analyses are initiated that examine the actual inventory situation more closely with a view to integrated optimization. Based on the SCDD, potential conflicts of objective and synergistic effects were analyzed in order to prevent the inventory levels reduction at the expense of sales revenue and customer satisfaction (due to reduced availability). Thus, the operationalized supply chain strategy was to increase delivery reliability through improving procurement reliably and a more reliable procurement planning in order to create the prerequisites for reducing inventory levels in a lasting way.

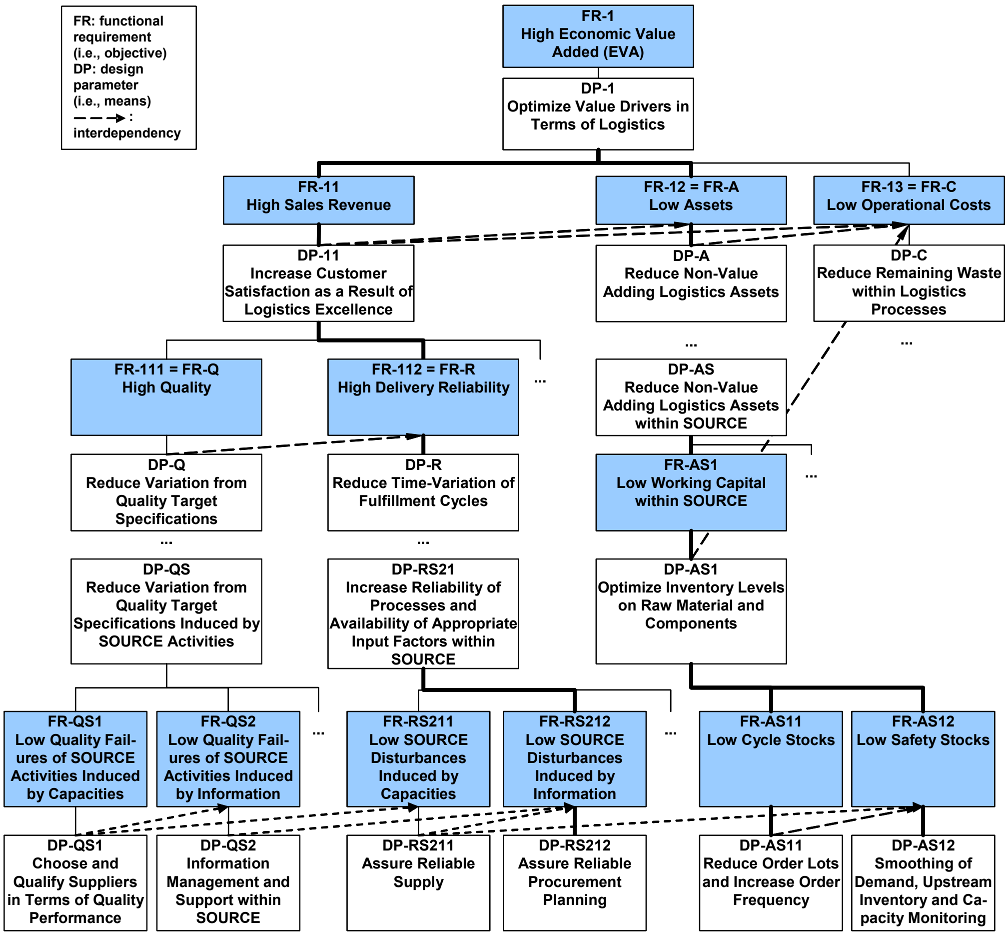

Figure 2. Case study (excerpt).

Consequently, three bundles of measures were developed: assuring reliable supply (sourcing strategies and supplier management), reliable procurement planning (blanket orders with sales companies, exchange of forecasts and requirement figures), and inventory control. Moreover, implementation has been initiated and a performance measurement system set up.

6 DISCUSSION AND OUTLOOK

In addition to the case study described above, additional case studies have been conducted during the ProdChain project. The benefits of the methodology are, in particular, that objectives and means can be operationalized and, besides, appropriate measures can be identified and symptoms, e.g., high inventory levels as in the case study, can be distinguished from root causes, e.g., lack of reliability and planning, due to the modeling of causes and effects in the SCDD (Schnetzler et al., 2006). Most companies were not aware of the proposed implementation sequence according to the 'sand cone' model. The SCDD enables a profound understanding of how objectives and means of SCM should be designed.

However, the application of the SCDD requires a structured procedure since the decomposition is complex and extensive. The SCCD has to be interpreted in view of the specific context of the company and the supply chain. In general, the mutual influences between objectives and means cannot be quantified, and they depend on the context as well. As an outlook for further research, the information axiom of Axiomatic Design can be applied to the SCDD and SCM. Furthermore, the aspect of functional periodicity (Suh, 2005) is interesting to investigate. Moreover, the principles of Axiomatic Design and the ideas of the SCDD could be applied to other management issues. In particular, further aspects such as information, technology, and innovation management, human resources and marketing, social aspects, environmental responsibility as well as sustainability can be incorporated in order to develop an 'Enterprise Design Decomposition' for a good design of an enterprise.

7 CONCLUSION

The SCDD is a systematically structured system of objectives and means of SCM that is developed according to the principles of Axiomatic Design. It can be used to design the objectives and means of SCM. Through this, a supply chain strategy can be developed that is in alignment with corporate strategy and its environment. Strategic priorities can be operationalized and measures such as best practices of SCM identified.

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