

Alignment of manufacturing strategies to customer requirements using analytical hierarchy process

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The purpose of this paper is to provide new insights in the field of operations management decision-making. It aims to combine manufacturing strategies with the service dominant logic in order to connect customer satisfaction. An analytic hierarchy process (AHP) is developed and applied within two case companies. A sensitivity analysis revealed that the manufacturing strategy selection changes when customer requirements vary. The sensitivity of manufacturing strategy alteration towards changing customer requirements is dependent on distinct product characteristics. The presented AHP offers an opportunity to define those customer requirements predominantly affecting manufacturing strategy selection. The paper provides a helpful generic framework that could serve as starting point to develop appropriate supply chain differentiation approaches.

Keywords: analytic hierarchy process (AHP); customer decoupling point (CDP); make to order production (MTO); manufacturing strategy; supply chain differentiation

1. Introduction

Today, customers are becoming more and more sophisticated in terms of demand and are asking for customised and individualised goods and services. At the same time, technological progress is shortening product life cycles and globalisation is severing competition in most markets. This highly competitive, sophisticated and dynamic current economic environment is calling for innovative, flexible, adaptive and differentiated business models. In the context of operations management, this challenging starting situation requires adequate strategies exhibiting minimal cost levels as well as maximal customer and quality focus coincidentally. In parallel to the latter requirements, companies increasingly consider the differentiation opportunity given through the optimisation of manufacturing settings in order to enhance customer satisfaction. Key issues in this context are manufacturing strategies focussing on individual solutions for customers through “make to order” and “postponement” (Olhager, 2003) as well as “the interaction with customers” that directly influence operations settings (Etgar, 2008).

When striving for customer satisfaction, companies should focus on customer requirements and become customer responsive (Hilletoft, 2009). Customer requirements, however, are neither static nor equal for all potential customers. Hence, there does not exist one single adequate strategy given for all customers (Beck, Hofmann, & Stölzle, 2012) but rather a continuum of manufacturing strategies that need to be

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focused on several markets or customer segments (CS) exhibiting distinct and dynamic requirements.

The task at this point is to connect such dynamic and market-specific customer requirements to manufacturing strategies in order to support the adequate operations management decisions reacting on distinct and dynamic demand patterns. The scientific literature so far provides several helpful frameworks and models providing information about strategic opportunities for operations management. Some of them focus on strategy settings with regard to product characteristics (Fisher, 1997). Others emphasise supply chain flexibility and agility as well as several competitive priorities with regard to customer requirements (cf. for e.g. Mason-Jones, Naylor, & Towill, 2000). A magnitude of scientific research focuses on manufacturing strategy implications like postponement, customer decoupling point (CDP) setting or mass customisation (cf. for e.g. Da Silveira, Borenstein, & Fogliatto, 2001; Hilletoft, 2009; Mikkola & Skjøtt-Larsen, 2004). Finally, literature even provides findings about the customer's direct influence on the manufacturing process (Etgar, 2008).

However, although the literature describes comprehensive data regarding relevant decision criteria to focus the manufacturing process on customer requirements, there does not yet exist an integrated approach that allows dynamic detection of changes in operations settings in dependence of altering customer requirements. Thus, the following question arises:

How can operations management decision-finding be structured in order to effectively react on market specific and dynamic customer requirements?

Regarding to manufacturing strategies, the decision problem could be framed as follows: to reach customer satisfaction, which manufacturing strategy or CDP setting (Hilletoft, 2009) is an adequate solution for a certain market represented by several requirements of customers allocated to the respective market or segment? A promising approach to support such a multi-criteria decision-finding problem is offered by the so-called analytic hierarchy process (AHP) (Saaty, 1996). This method is especially helpful in situations with several dependent variables (decision alternatives) and independent variables (decision criteria) and thus might be a potent tool in the context of customer related operations management decision-finding.

The paper is structured as follows: Sections 2 and 3 will collect potential decision alternatives – dependent variables – regarding to operations settings literature review and structure them with respect to their link to customer requirements – independent variables – within a new framework. Section 4 will transfer the defined independent and dependent variables into an AHP and apply it to real case examples thereby providing insights into the sensitivity of manufacturing strategy alignments with respect to altering customer requirements. In Section 5, our results are discussed. The paper closes with a brief conclusion and outlook (Section 6). Notably, the respective research question is focusing on effectivity aspects – meaning the value proposition for the customer – rather than efficiency and hence cost aspects of manufacturing strategies as well as the influence on prices are, at the moment, only marginally considered. The latter, however, is justified since it allows a better understanding of the overall complexity at a certain aspect and provides the first step of an incremental understanding about the whole picture, starting with the question how to deliver maximal value for the customer.

2. Literature review

In the context of customer responsive operations strategies, the literature offers several approaches providing potential decision alternatives (dependent variables) regarding the above-described decision problem:

- Responsive and effective supply chains (e.g. Fisher, 1997).
- Supply chain agility (e.g. Agarwal, Shankar, & Tiwari, 2007; Christopher & Towill, 2002; Lee, 2002; Lin, Chiub & Chub, 2006; Van Hoek, Harrison, & Christopher, 2001; Yusuf, Gunasekaran, Adeleye, & Sivayoganathan, 2004).
- CDP approaches (e.g. Agarwal, Shankar, & Tiwari, 2006; Amaro, Hendry, & Kingsman, 1999; Christopher, Peck, & Towill, 2006; Hallgren & Olhager, 2006; Hilletoft, 2009; Naim & Gosling, 2010).
- Postponement strategies (e.g. Kumar & Wilson, 2009; Manson-Jones & Towill, 1999; Pagh & Cooper, 1998; Van Hoek, 1998; Zinn & Bowersox, 1988).
- Mass customisation (e.g. Da Silveira et al., 2001; Ernst & Kamard, 2000; Jiao, Ma, & Tseng, 2003; Mikkola & Skjott-Larsen, 2004; Tu, Vonderembse, & Ragu-Nathan, 2001).
- Competitive supply chain priorities (e.g. Ketchen, Rebarick, Hult, & Meyer, 2008; Zhang, Vonderembse, & Lim, 2002, 2003, 2005, 2006).
- Market oriented supply chain segmentation (e.g. Davis, 2010; Davis & MacDonnell, 2011).
- Logistical service level differentiation (e.g. Bottani & Rizzi, 2006; Franceschini & Rafele, 2000; Mentzer, Flint, & Hult, 2001; Rafele, 2004; Van Amstel & D'hert, 1996; Zhang et al., 2002).
- Process of customer co-production (e.g. Etgar, 2008).
- Product associated services (e.g. Geng, Chu, Xue, & Zhang, 2011; Mont, 2002; Oliva & Kallenberg, 2003; Raddats & Easingwood, 2010; Yoon, Kim, & Rhee, 2012).

Companies striving for customer satisfaction through targeting customer requirements obviously will be able to differentiate themselves from competitors regarding to a certain market or customer segment (Beck et al., 2012). Differentiation is “when a firm [...] outperforms [...] in the provision of a feature(s) such that it faces reduced sensitivity for other feature” (Sharp & Dawes, 2001, p. 739). When talking about differentiation in the context of operations management, it is necessary to detect the respective factors (features) that need to be considered for this purpose. As a consequence of what is understood as differentiation, the respective factors need to be directly perceptible for customers. Obviously, product features themselves play an important role for the customer and also have several implications for operations management decisions and the manufacturing process (cf. Fisher, 1997). Another opportunity to demarcate the crucial customer perceptible operations management decisions is the CDP that can simply be interpreted as the point from which the supply chain becomes customer sensitive and reacts on individual orders through customer pull (Manson-Jones & Towill, 1999; Razmi, Rahnejat, & Khan, 1998). Upstream of the CDP, supply chains are forecast-driven and downstream of the CDP, supply chains are demand-driven (Olhager, 2010). Demand-driven production means that production starts after customer order placement (Murakoshi, 1994). Hence, the whole supply chain downstream of the CDP can be interpreted as directly perceptible for the customer. Furthermore, processes

downstream the CDP need to be agile while processes upstream the CDP should be as lean as possible (Christopher et al., 2006).

While product features and CDP settings mainly influence the manufacturing process and thereby the manufacturing strategy (Hilletoft, 2009), there exist several other operations management settings directly perceptible by the customers. The latter are predominantly linked to factors defining the logistical service level as well as many product-associated services.

3. Framework

3.1. *Criteria of customer requirements*

To capture potential customer requirements – independent variables – it is necessary to frame the comprehensive data provided by the literature. Therefore, the criteria relevant to define the adequate operations settings – the dependent variables – are structured on different levels in relation to their direct connection to customer requirements:

- Level 1: a first level includes all classical activities that are necessary to assure product allocation (cf. for e.g. Rafele, 2004). They are needed to ensure disposability for the customer and thus the respective independent variable is the magnitude of “product availability” required by the customer.
- Level 2: a second level is associated with differentiation options considering all relevant product service options. When considering the independent variables defining settings on this level, they are connected to customer requirements that support the customer in application and utilisation of the product, like “installation support” or “utilization support” that can be either product or user process oriented as described by Oliva and Kallenberg (2003).
- Level 3: a third level encompasses activities that directly influence the product features as well as the manufacturing process. When considering the influence of the customer on the physical product, one can identify customer requirements like “product variety” (static amount of product features) and “product variability” (seasonal changes of product features) (cf. Childerhouse, Aitken & Towill, 2002). The possible decision alternatives on this level are different CDP settings directly influencing the agility and customer responsiveness of the production process.

The defined independent variables – customer requirements – do directly influence operations activities and settings on the respective level. However, their influence is not restricted to this level, since of course the different levels are connected. For example, the requirement “availability” will also influence the CDP-setting and hence the manufacturing strategy and high product “variety” as a result of a huge amount of product features could also lead to a requirement of “utilisation support”.

3.2. *Customer satisfaction as decision goal*

Next it is necessary to find a way that links customer requirements (independent variables) to potential decision alternatives (dependent variables) in relation to the decision goal: customer satisfaction.

To do so, we refer to the co-production framework of Etgar (2008) since it provides an opportunity to link different operations management relevant phases of the value chain

(design, source, make, deliver and product utilisation) directly with customer satisfaction through the term customisation. Customisation in this context is understood as matching the individual preferences of customers as precisely as possible with the sold product or service in order to reach maximal customer satisfaction. Additionally, Etgar (2008) argues with the completely customer-centred concept of “Service Dominant Logic” (SDL) that defines the customer as a value co-creator (in the wider sense) and as a co-producer (in the narrow sense) within the value chain (Vargo & Lusch, 2008a, 2008b). Through acting as a co-creator during the value creation process, the customer starts influencing the value creation process. He tries to contribute to enhance customer-specific value generation or, in other words, to customisation (Etgar, 2008) and the higher the need for customisation, the higher the need for co-creation. The maximal amount of customer co-creation is reached as soon as the customer becomes part of the production phase as co-producer, at least for physical goods (Etgar, 2008; Vargo & Lusch, 2008b). However, not all customers require the same extend of co-creation and hence the crucial challenge is to find an adequate setting for all customers at the same time.

The most important implication regarding the SDL in the context of operations management is that the amount of customer satisfaction is dependent on the adequate extent of customer integration into the value creation process. As a consequence, different degrees of co-creation, or in other words, different degrees of customer influence on the value creation process, should determine operations settings with regard to how extensively and in what manner the customer needs to be integrated into the value creation process. Obviously, the higher the need for co-creation, the sooner upstream along the value creation process the customer needs to be integrated. Thus, the most important operations decision regarding how to integrate the customer into the value creation process – thereby focussing on the goal of customer satisfaction – is the CDP setting and the manufacturing strategy since the latter determines where the manufacturing process starts becoming customer perceptible and hence where customisation starts. Furthermore, the CDP setting represents a crucial decision since it determines the point from where on the supply chain becomes customer responsive and agile (Christopher et al., 2006).

3.3. *Manufacturing strategies as dependent alternatives*

The SCL implications lead to focus strategic operations decisions by defining manufacturing strategies regarding to the requirements of different CS that need to be supplied. It is, therefore, important to define value additions underlying the generic logic of manufacturing processes and the manufacturing strategies determined through a certain CDP setting (cf. Hilletoft, 2009). A prerequisite is to subdivide the manufacturing process of several planning points (cf. Olhager, 2003). Such a manufacturing process then is described as follows figured: the process starts with the formation of several product intermediates (INM). After product assembly (FPA), several packaging steps might follow: primary packaging and secondary packaging. Differences between packaging steps only concern different components of the package that, for example, fulfil different functions. Importantly, packaging also determines the selling unit of products. The framework for customer-oriented manufacturing strategy selection is presented in Figure 1.

The first CDP setting is called make to order (MTO). In this case (marked with number 1), all relevant components are sourced upstream the CDP and subsequent

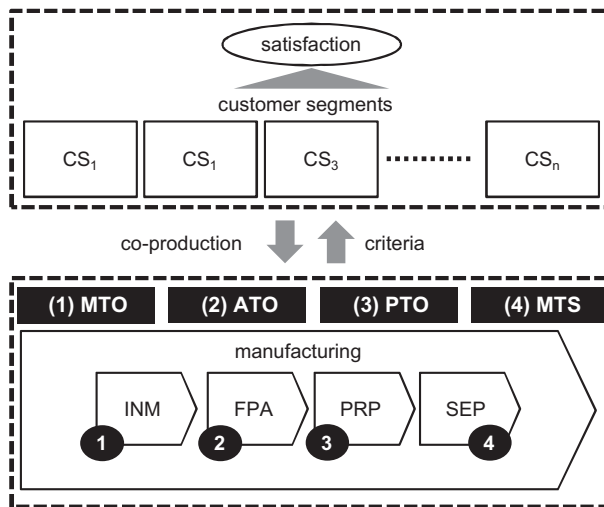


Figure 1. Framework for customer-oriented manufacturing strategy selection.

manufacturing activities are postponed until customer order placement. For MTO products, customisation or higher value adding activities start at the very beginning of the manufacturing process. One could imagine the manufacturing of a watch considering many customer-specific details that need to be included very early in the manufacturing process. Importantly, MTO does not allow the pre-manufacturing of modules since customisation starts already very early during the production of intermediates. MTO can also be an option if no customisation is necessary. However, highly volatile demand in combination with the inability of pre-manufacturing low value intermediates exhibits a severe challenge for the company.

The second possible CDP setting is marked with number 2 and represents the assemble-to-order (ATO) strategy. A classical example of ATO is the assembly of customised cars by utilisation of pre-manufactured modules or systems. The difference to MTO is the possibility of utilising pre-manufactured low-value intermediates. In this case, final assembly activities are postponed until order placement. However, ATO is strongly dependent on the application of mass customisation and product modularisation that allow efficient and fast assembly processes allowing creating variability with lead times much shorter than compared to MTO.

The third CDP-setting option (number 3) refers to different package to order (PTO) options and is important in terms of customisation with regard to the selling unit or package function. An illustrative example of different selling units could be highly customer-specific dosages of certain drug within the pharmaceutical industry.

The last option – a make to stock (MTS) strategy – is forecast-driven. This approach represents all other opportunities where postponement option is chosen.

It still remains unclear how the manufacturing strategies and customer satisfaction are interconnected within a decision process. The next section will now derive the AHP model that connects independent and dependent variables above and structures them in order to support operations management decisions regarding accurate selection of CDP and manufacturing strategies.

3.4. Efficiency constraints and target costs

As already mentioned, the goal of the paper is to provide one certain aspect – effectivity – of how manufacturing strategy selection is dependent on customer requirements. Nevertheless, efficiency aspects cannot be faded out when taking the decision for a certain manufacturing strategy since obviously the manufacturing strategy will influence manufacturing, logistics and distribution cost. For example, an ATO strategy requires the respective applications to handle variability (Bley, Avgoustinov, & Franke, 2002). The latter again will influence the price of the final product, another customer requirement. The overall goal addressed to the selection of the adequate manufacturing strategy hence is to create a positive net added value for the customer.

On the other hand, from a business model point of view, the price is completely relative and depends on how precisely the customer's problem or requirement is addressed through value proposition (Johnson, Christensen, & Kagermann, 2008). Now, each manufacturing strategy will address customer requirements differently and add different value what will lead to a different price acceptance of the customer as long as the net added value will be constant or increase. Consequently, a model focusing on dependent and independent variables is not feasible anymore since the result – the selected manufacturing strategy – will influence through negative or positive feedback the independent variable “price”. Variables then require to be rather interdependent what finally will increase complexity. To prevent that, another approach could be to first focus on effectivity and “how to best solve the customer's problem” and in a second step analysing the cost aspects through a target costing approach (Cooper & Slagmulder, 1999).

4. Decision-finding model

4.1. Backdrop of AHP

To simplify the complexity of a decision problem, it is necessary to structure it. The crucial foundation of structuring is several relative pair-wise comparisons of two decision elements with respect to a third decision element (Saaty, 1996). Relative pair-wise comparisons are either made between two criteria with respect to their importance for decision-finding (criteria prioritisation) or between alternatives with respect to their fulfilment of each decision criteria (evaluation of alternatives). Importantly, the higher the experience and knowledge of a person with respect to a certain decision problem, the higher the quality of each relative pair-wise comparison (Saaty, 1996, 2004).

All together, solving a decision problem finally requires the following procedure called AHP (Saaty, 1996): first: hierarchical problem structuring on at least three levels: goal, criteria, sub-criteria (if necessary) and alternatives, the latter represent the decision options. Ideally, the selected criteria that are not influencing each other and the alternatives are mutually exclusive. Second: definition of several pair-wise comparisons enabling the consideration of experience and knowledge of the decision maker. Third: definition of numbers to measure the relative preferences of the experienced decision maker. Fourth: synthesis of all results from the pair-wise comparisons to prioritise the decision alternatives.

The AHP is a common approach of multiple criteria decision-making in operations management (Beck & Hofmann, 2012). Beside this multi-attribute utility approach, others – like multi objective mathematical programming (e.g. data envelopment analysis) or fuzzy set methods – exist (e.g. Wallenius et al., 2008). We have chosen the AHP as a “pragmatic” means to structure and analyse the choice of manufacturing

strategies in accordance to customer requirements pair-wise. A main advantage of this method is to overcome ad hoc decisions of managers which are often based on experiences or feelings (Partovi, Burton, & Banerjee, 1990).

To numerically measure the results of the pair-wise comparisons in an AHP, Saaty (1996) suggests ratio scales since it is neither meaningful nor necessary to measure preferences on an absolute scale with respect to decision-finding. The respective scale (so far validated through a great number of practical applications) used to capture relative pair-wise comparisons is called fundamental scale and reaches from 1 (equal importance) to 9 (extreme preference of one element over the other) and reciprocals, respectively. The questions to be answered for each pair-wise comparison are the following (Saaty, 1996): either: which of the two criteria is dominant over the other with respect to the decision goal (or superior criterion in terms of sub-criteria) and how much is it dominating the other one on the fundamental scale. Or: which of the two alternatives is dominant over the other with respect to one decision criteria and how much is it dominating the other one on the fundamental scale. Importantly, to apply the fundamental scale, the chosen elements need to be homogeneous. This implies that the dominance of the largest element should not be more than nine times the smallest element (Saaty, 1996, 2004).

To synthesise the numerical results of all pair-wise comparisons, several linear algebraic mathematical applications are necessary. The first goal is to find a relative priority list of the applied criteria on hierarchy level two with respect to the decision goal (Saaty, 1996). Next, the alternatives need to be evaluated relatively with respect to each criterion. Finally, through multiplying and summarising criteria priorities and alternative priorities with respect to each criterion, a holistic priority list for all alternatives emerge that can be normalised (Saaty, 1996). To calculate relative priorities from pair-wise comparisons on each hierarchy level, the formation of reciprocal square matrices is necessary (Saaty, 1996). The priority vector is calculated by solving an eigenvalue problem (cf. Saaty, 1996). The necessary mathematical proofs are comprehensively illustrated in the literature (cf. Saaty, 1996, 2004). Importantly, the decisions need to be assessed with respect to consistency. Consistency becomes important as soon as more than two elements need to be compared on the fundamental scale. The overall consistency of a reciprocal square matrix can be represented through its consistency ratio (CR) that needs to be less than .1. Otherwise, the resulting priority vector cannot be accepted (Saaty, 1996, 2004).

An interesting feature of the AHP is the so-called sensitivity analysis that can be achieved through computation as soon as the pair-wise comparisons were completed by an expert and the basic priority vectors are known (Saaty, 1996, p. 8). To do so, one rating of a single pair-wise comparison is modified along the fundamental scale from 1/9 to 9 while all other ratings are left equal to the original judgement. Through changing single ratings, the overall priorities of the alternatives are shifted with respect to their sensitivity towards the modified criteria relation (cf. Agarwal et al., 2006, p. 220 f.). However, a huge number of different criteria and alternatives reduces the sensitivity of the model towards individual criteria. Thus, there exists a certain trade-off between the comprehensiveness of the model and its applicability for sensitivity analysis.

4.2. AHP in the context of manufacturing strategy selection

The task at the beginning is to define an adequate decision hierarchy. The most accurate manufacturing strategy and CDP setting results in high degree of fulfilment for a certain

customer segment and thus the overall goal should be formulated as to reach the most positive impact on customer satisfaction.

The different manifestations of the dependent variables are used as the decision alternatives. These alternatives need to be connected with the goal of customer satisfaction through several meaningful criteria. The latter obviously should be the several independent variables that represent the customer requirements directly influencing the CDP setting. Within the methodology of the AHP, these criteria on the one hand need to be prioritised with respect to the goal. On the other hand, the alternatives need to be assessed with respect to their appropriateness for each criterion. The criteria thereby operate as connectors between customer satisfaction and the manufacturing strategy alternative. This procedure needs to be repeated for each customer segment identified within the target market.

The outcome of the AHP is the most adequate CDP setting described in Figure 2. The option MTS represents the alternative where no manufacturing postponement option is chosen. Importantly, independent variables of other operations levels that are influencing the CDP setting only indirectly are included on the criteria level to take account to the interdependency of the operations management levels defined.

The proposed decision hierarchy within Figure 2 leads to a total amount of 40 pair-wise comparisons. The questions that need to be answered with respect to the fundamental scale are as the following examples:

- *For criteria prioritisation:* how much more (or less) important with respect to customer satisfaction is product variety when compared to product variability on the fundamental scale?
- *For alternative accuracy with respect to each criterion:* how much more (or less) appropriate for product variety is “make to order” when compared to “assemble to order” on the fundamental scale?

4.3. Application of the AHP

The next step is to test the applicability of the proposed AHP in practice. To do so, operations managers from different companies were asked to apply the model for on

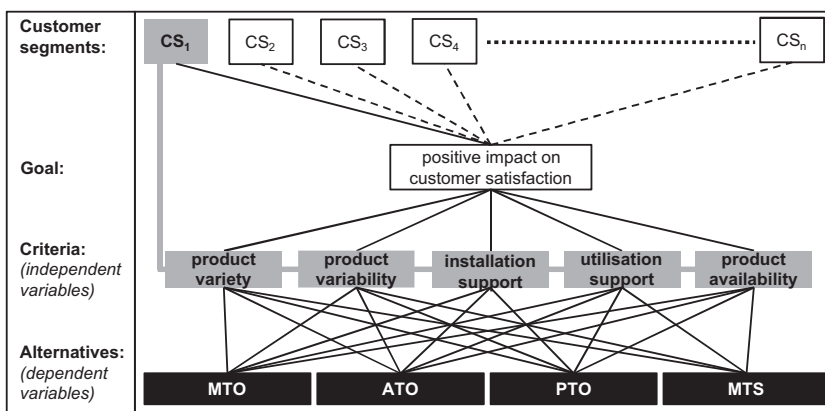


Figure 2. The AHP to support decision-finding regarding to manufacturing strategy selection.

selected product only. In addition, a sensitivity analysis was computed that revealed the changes in alternatives prioritisation with respect to the altering relative importance of single criteria. This approach finally allowed detecting required changes in manufacturing strategies (dependent variables) with respect to the prioritisation of customer-relevant criteria (independent variables).

To test the model, two products from different European-based chemical and pharmaceutical companies with internationally located manufacturing plants were chosen. The companies were selected with respect to industry similarity. To further detect potential differences with respect to product characteristics, the chosen products exhibit different complexity levels regarding manufacturing techniques and functional utilisation characteristics as well as manufacturing strategy characteristics. The candidate-companies both claimed to remain anonymous and thus are named company X/product X and company Y/product Y in the following. An overview of the companies can be found within Table 1.

Company X represents a large European agrochemical manufacturer with customers around the globe. The candidate product line X contains a variety of sophisticated and customised plant-protection chemicals applied in the farming and crop industry. The agrochemicals exhibiting generally high product variety are produced through execution of a “make to order” approach. The company offers installation support, products are distributed directly. The responding operations manager of company X is a member of the company’s strategic supply planning division.

Company Y on the other hand represents a middle-class European pharmaceutical company mainly focusing on consumer drugs with production plants located in different European countries. The chosen product lines exhibit less heterogeneity when compared to company X and are produced to stock without specified services. Products are sold through wholesalers with focus on high availability. The company’s representative is head of operations management for one European country.

Both respondents were asked to do the respective pair-wise comparisons of the model for their products with regard to the customers in general or with regard to one popular customer segment. The priority vectors were computed as described within Appendix 1. The respondents were asked to prioritise the criteria and alternatives under the requirement of a maximally allowed value for the consistency ratio of .1. For each pair-wise comparison block the consistency ratio was indicated with a code. To support

Table 1. Overview of case companies.

Company	Main products	Sales (2011) <i>Mio. Dollars</i>	EBIT (2011) <i>Mio. Dollars</i>	Employees (worldwide)	Head office	Locations
Company X	Agro-chemicals and plant protection	ca. 10,000	ca. 3000	ca. 15,000	Europe	• Africa • Asia • Europe • America
Company Y	Pharmaceuticals and drugs	ca. 200	< 1	ca. 2000	Europe	• France • Germany • Switzerland

respondents during the questionnaire, the answering process was accompanied by a telephone interview.

4.4. Computation of priority vectors for two different products

The AHP for the more sophisticated product line X revealed a clear dominance of the criteria “product variety” while for product Y criteria “product availability” turned out to be most important for customers (cf. Figure 3).

The grey fields within Figure 3 represent the pair-wise comparisons that were answered by the respondents. The white fields are reciprocals. Importantly, the common AHP procedure would require further answering of the black fields through the respondent. However, to allow overall consistency during the later sensitivity analysis, it was necessary to derive the relative values within the black fields through computation. Mathematically this is possible since basically the comparison of criterion “product variety” with all others is sufficient. The relations among the others than can be calculated easily as a result of comparing their priorities with respect to “product variety”. This reduces the influence of the respondent’s expertise on the final outcome and might lead to a certain distortion. On the other hand, it makes the sensitivity analysis more significant since consistency can be maintained when changing the importance of one criterion over another.

After prioritisation of each criterion, the respondents had to compare each alternative with other alternatives with respect to their relative appropriateness for each criterion. For the criterion “product variety”, this is illustrated within Figure 4. Again, the grey fields represent the pair-wise comparisons considered by the respondents.

For product X, MTO turned out to be the preferred alternative with respect to the criteria “product variety” and “product variability”, where ATO slightly dominates the other alternatives regarding to “installation support” and “product availability”. Since company X does not offer utilisation support, the influence of this criterion on alternatives became subordinate what is expressed by equal relative appropriateness of each alternative under the criterion installation support (cf. Appendix 2).

For product Y, PTO dominates other alternatives with respect to criteria “product variety” and “product variability” while MTS is the preferred option under criterion “product availability”. Since company Y does offer neither installation nor utilisation support, the influence of these criteria became subordinate. The respective priority vectors resulted in equal appropriateness of each alternative under the respective (cf. Appendix 2).

criteria priorities product X	variety	variability	installation support	utilisation support	availability	priority
variety	1.00	5.00	7.00	8.00	2.00	0.51
variability	0.20	1.00	1.40	1.60	0.40	0.10
installation support	0.14	0.71	1.00	1.14	0.29	0.07
utilisation support	0.13	0.63	0.88	1.00	0.25	0.06
availability	0.50	2.50	3.50	4.00	1.00	0.25

criteria priorities product Y	variety	variability	installation support	utilisation support	availability	priority
variety	1.00	7.00	8.00	4.00	0.13	0.21
variability	0.14	1.00	1.14	0.57	0.11	0.04
installation support	0.13	0.88	1.00	0.50	0.11	0.04
utilisation support	0.25	1.75	2.00	1.00	0.11	0.06
availability	8.00	9.00	9.00	9.00	1.00	0.66

Figure 3. Priority vectors of criteria with respect to the goal.

product variety product X	MTO	ATO	PTO	MTS	priority
MTO	1.00	6.00	6.00	8.00	0.66
ATO	0.17	1.00	3.00	4.00	0.19
PTO	0.17	0.33	1.00	3.00	0.10
MTS	0.13	0.25	0.33	1.00	0.05

product variety product Y	MTO	ATO	PTO	MTS	priority
MTO	1.00	0.25	0.20	0.25	0.06
ATO	4.00	1.00	0.25	2.00	0.21
PTO	5.00	4.00	1.00	5.00	0.58
MTS	4.00	0.50	0.20	1.00	0.15

Figure 4. Priority vectors of alternatives with respect to product variety.

product X	product variety 0.51	product variability 0.10	installation support 0.07	utilisation support 0.06	availability 0.25	priority
MTO	0.66	0.47	0.26	0.25	0.18	0.46
ATO	0.19	0.23	0.38	0.25	0.43	0.27
PTO	0.10	0.25	0.32	0.25	0.34	0.20
MTS	0.05	0.05	0.04	0.25	0.05	0.06

product Y	product variety 0.21	product variability 0.04	installation support 0.04	utilisation support 0.06	availability 0.66	priority
MTO	0.06	0.30	0.25	0.25	0.04	0.08
ATO	0.21	0.25	0.25	0.25	0.11	0.15
PTO	0.58	0.39	0.25	0.25	0.16	0.27
MTS	0.15	0.06	0.25	0.25	0.68	0.50

Figure 5. Overall priority vectors for the alternatives.

Finally, the synthesis of criteria prioritisation and alternative fulfilment with respect to each criterion resulted for product X in a clear dominance of the MTO strategy, while for product Y the MTS strategy exhibits the highest priority value (cf. Figure 5).

4.5. Sensitivity analysis

As already introduced above, the sensitivity analysis in this case allows detecting changes of the CDP-setting priority with respect to altering criteria priorities representing the customer requirements. The sensitivity analysis derives the susceptibility of the overall priority vector for changes in single relative pair-wise comparisons. Therefore, one needs to alter, for example, the importance of “product variety” when compared to “product variability” from 1/9 to 9 when all other relative comparisons including the criterion “product variety” are kept constant. The consistency ratio of the criteria pair-wise comparison matrix needed to remain below .1 when altering values of single pair-wise comparisons for “product variety”. As aforementioned, the crucial prerequisite, therefore, was to determine several pair-wise comparisons between criteria other than “product variety” mathematically through a computed function instead of deducing them from intuitive answers by the respondents (see Appendix 1).

The results of the sensitivity analysis for the more heterogeneous product X revealed that changes in the importance of “product availability” when compared to “product variety” lead to a substitution of the originally prioritised alternative MTO by the alternative ATO (cf. Figure 6, *left panel*). Furthermore, the prioritized CDP-setting also changed from MTO to ATO with respect to the importance of criterion “installation

support” when compared with “product variety” (cf. Figure 6, right panel). The overall sensitivity, however, remained low since the substitution of the generally preferred MTO strategy by ATO needed at least a strong dominance of either criterion “product availability” or criterion “installation support” over criterion “product variety”. The latter is indicated by the substitution points between .2 and .3 on the *X*-axis for both sensitivity analyses, respectively (cf. Figure 6). Changing the relative importance of the other criteria when compared to “product variety” did not result in the substitution of MTO by other alternatives.

Regarding product Y, the sensitivity analysis also revealed a substitution of the generally preferred MTS strategy by PTO when “product variety” becomes more important with respect to “product availability” (cf. Figure 7, left panel). Notably, the sensitivity of the respective alternative substitution towards altering relative importance of the respective criteria pair is significantly higher for product Y. This is indicated by the fact that as soon as “product variety” becomes slightly more important than “product availability” (changes on the *X*-axis from 1 to values marginally above 1), MTS is substituted by PTO. The same can be observed vice versa (cf. Figure 7, left panel).

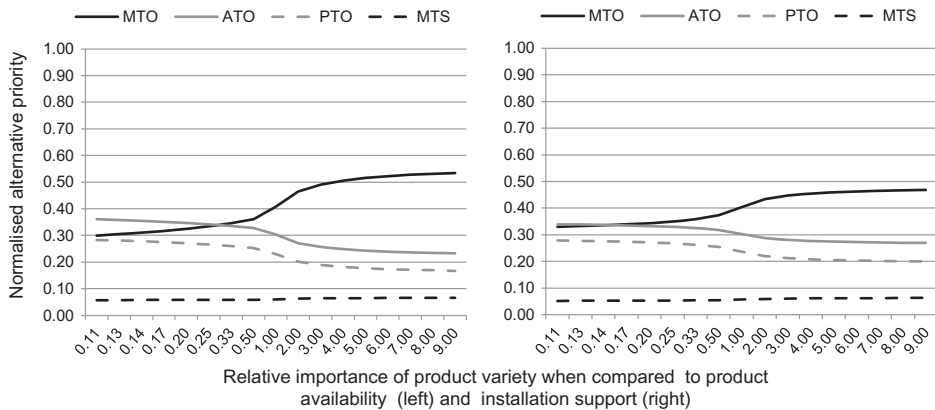


Figure 6. Results of the sensitivity analysis for criterion product variety, product X.

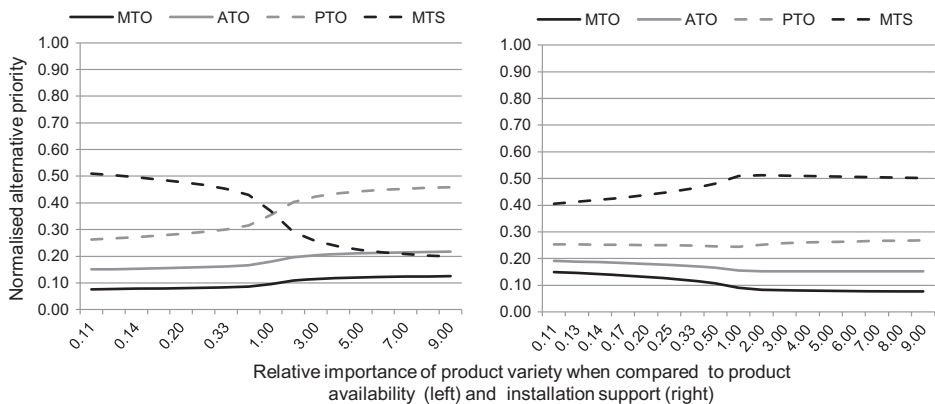


Figure 7. Results of the sensitivity analysis for criterion product variety, product Y.

Changing the relative importance of the other criteria when compared to “product variety” did not result in the substitution of MTS by other alternatives.

5. Discussion

5.1. Interpretation of results

The developed AHP model was used to derive the manifestation of the “CDP-setting”. For this purpose, independent variables of distinct operations management decision levels were used as criteria for the AHP decision structure. This kind of criteria selection finally allowed to simultaneously connect on the one hand the decision goal (customer satisfaction) with the alternatives (CDP-settings) as well as on the other hand the different decision levels with each other.

The AHP then was applied to two product lines from different firms exhibiting distinct functional complexity levels. The respondents – represented by operations managers of the respective companies – were asked to consider the pair-wise comparisons in general, without focusing on one specific customer segment. The potential alternatives differences with regard to changing customer requirements were then derived through sensitivity analyses. This finally allowed determining those customer requirements that could be used as segmentation criteria to allocate customers to the accurate segments regarding the differentiated manufacturing strategy applied to supply the respective segments.

For the more sophisticated agrochemical product line of company X, the MTO CDP setting turned out to be most preferable in general, meaning an acceptable basic or trade-off strategy for all customers. This makes sense since the respective products normally need to be specified for each customer, indicated by the high importance of the criteria product variety (cf. Figure 3, left panel). With respect to single criteria, the MTO alternative turned out to be most appropriate with respect to “product variety” and “product variability”. ATO is dominating regarding to “installation support” and “product availability” (cf. Appendix 2). This is reasonable since high product availability for the customer is connected with short lead times. Components of the respective agrochemicals thus are pre-manufactured and mixed (the latter can be interpreted as “assembly”) as soon as the customer orders the product to ensure minimal order lead times. Here, it is important to state again the importance of short assembly lead times in order to overcome the bottleneck of manufacturing (cf. part 0). In this case, the mixing of pre-manufactured substances requires to be achieved much faster than the manufacturing of each of the single substances. The ATO strategy reduces the lead time but limits product variety (customisation and product heterogeneity) on the other hand. The results of the sensitivity analysis for product X confirm these findings since they revealed that for customers that massively prioritise “product availability” over “product variety” the ATO substitutes the MTO as the most preferable CDP setting alternative. A similar substitution of MTO by ATO can be observed when “installation support” becomes more important with respect to “product variety”. This demonstrates the influence of installation support on the production process. Hence, regarding the agrochemicals, this would indicate that when customers require high installation support, ATO is the dominating strategy. For such customers, the installation process, here for example mixing of several chemicals directly at the customer’s location, is preferred over customisation and “product variety” and thus the MTO strategy required to ensure high “product variety” becomes less important. The overall findings for product X are that indeed changing priorities of customer requirements are calling for distinct CDP

settings. The criteria “product availability” and “installation support” appear to be the crucial customer requirements influencing the prioritized CDP setting with respect to customer satisfaction. One possible interpretation could be to segment customers with respect to “product availability” or “installation support” and to execute different manufacturing strategies with different CDP settings for the resulting CS with the overall goal of reaching higher customer satisfaction.

The results gathered for the rather standardised product line Y are slightly different. The dominant CDP setting in general is the MTS strategy. This makes sense since the relative importance of product variety is low and products are more homogeneous. The predominating criterion or customer requirement is “product availability” what correlates well with the MTS strategy where the order lead time is minimal. Interestingly, however, as soon as “product variety” becomes slightly more important when compared to “product availability”, the generally preferred MTS strategy is substituted by the PTO strategy (cf. Figure 7, *left panel*). This is meaningful because the variety for product Y – consumer drugs – mainly is a result of different packaging or dosage units. The latter was confirmed by the company’s respondent. The respective variety is achieved predominantly during the packaging process. The slight loss of product availability through execution of PTO instead of MTS can be interpreted as acceptable. The results demonstrate that company Y might be forced to segment their customers with respect to their need for product variety and hence execute a PTO strategy for those customers next to the conventional MTS strategy in order to reach maximal customer satisfaction.

Interestingly, the substitution of MTS by PTO with regard to product Y is much more sensitive towards changing customer requirements when compared with the respective MTO substitutions by ATO in terms of product X. The reason, therefore, most probably has to do with the fact that customers demanding product X generally prefer high product variety while customers demanding product Y (a rather homogeneous product) are focusing predominantly on high product availability. Now, the negative impact on product variety when changing from MTO to ATO in terms of product X is probably much more severe than the slight lead time elongation (equal with a loss of product availability) resulting from the substitution of MTS by PTO in terms of product Y. These results suggest that for product Y, the prioritized CDP setting is much more sensitive towards altering customer requirements than for the rather complex product X exhibiting high product variety. Hence, the need for customer segment distinct manufacturing strategies is higher in terms of the less complex product Y. The latter, however, is simply due to the fact that the substitution of MTS by PTO can generate more variety without dramatically elongating order lead time. A higher need for differentiated manufacturing strategies hence cannot be generalised for standardised products since as soon as variety requires more than distinct packaging, the resulting lead time elongation is too high as to result in a substitution of MTS by either ATO or MTO. A generalisation for complex products on the other hand is also not meaningful since the lead time reduction through changing from MTO to ATO for customers requiring high product availability is dependent on the specific severity of product variety reduction as a result of the alternatives substitution. In this case, factors like product modularity and mass customisation constitute considerable factors since they reduce the loss of product variety when executing an ATO strategy instead of a MTO strategy.

In summary, the results so far do not allow any general statements. The data revealed that changing customer requirements might require altering manufacturing strategies (represented by distinct CDP-settings) and that the sensitivity of strategy changes towards altering customer requirements depends on specific (not general)

product characteristics. Nevertheless, it is quite surprising that the selection of the prioritized manufacturing strategy even in terms of rather homogeneous standard products exhibits significant sensitivity towards altering customer requirements.

5.2. *Limitations*

Of course the chosen AHP approach exhibits several limitations and weaknesses that either are common systemic problems of the AHP in general or specific limitations related to the field of application that turned out during the interview sessions.

One important systemic limitation of the AHP in general is the prerequisite for independency of criteria from other criteria or alternatives from other alternatives. Thus, the AHP requires the assumption of criteria independency. In the case of the independent variables serving as criteria, the respective assumption indeed can be seen as crucial limitation. This problem could be addressed by introducing a decision network and through application of an Analytic Network Process (ANP) (cf. Saaty & Vargas, 2006).

The most obvious model-specific limitation of the approach is the trade-off between the complexity and the practicability of the AHP decision hierarchy that was chosen in this case. As soon as several additional criteria or alternatives are included or if any further sub-criteria level is added, the amount of required pair-wise comparisons increases while the sensitivity of the alternative priority vector towards single criteria decreases. On the other hand, the approach of using the minimally required amount of criteria and alternatives increases the abstractness level of the decision structure and thus makes it difficult to apply the model to practical cases. Indeed, the respondents addressed this issue as a crucial limitation of the overall approach. Furthermore, the fewer criteria and sub-criteria are available for the responding expert, the less support is offered through the problem structuring framework of the AHP. Hence, the respondent has to consider intuitively all those sub-criteria that were abandoned in order to keep the complexity level of the decision hierarchy on a minimal level. The latter of course reduces the reliability of the single pair-wise comparison assessments achieved by the responding expert.

One other specific limitation is a result of the mathematical functions that were applied to reduce the amount of pair-wise comparisons during the criteria prioritisation step in order to optimise consistency during the sensitivity analysis (see Appendix 1). The respective changes reduced the influence of the responding expert on the final result and thus make the results slightly less credible.

Finally, it has to be realised that the model so far excluded cost aspects of the decision process. The focus lays on effectiveness and customer satisfaction through the maximal value proposition. This is also due to the close contextual connection to the SDL. Factors like cost efficiency should be included into a meaningful decision process in order to strive for maximal customer's net added value.

6. *Conclusion*

6.1. *Scientific impact*

The AHP model developed within this paper offers an opportunity to structure the comprehensive multi-criteria decision-finding problem emerging when customer requirements are linked to manufacturing strategy. It could be demonstrated that the AHP indeed turned out to be well applicable to detect changing CDP settings regarding to different relative manifestations of several customer requirements.

The AHP model thus offers a tool that allows structuring operations management relevant decision options described in the literature. It allows connecting them with customer requirements in order to select the adequate operations setting required to reach customer satisfaction for each segment.

The applicability of the AHP model could be proven within two illustrative cases. The results of the application in practice revealed the sensitivity of the dependent variables towards the independent variables and thereby demonstrated how manufacturing strategy decisions may alter with respect to changing customer requirements. Overall, the sensitivity of manufacturing strategy decisions towards customer requirements revealed that it could be crucial to segment customers with respect to criteria exhibiting the highest impact on manufacturing strategy changes in order to keep all customers satisfied.

6.2. Managerial implications

Evaluating customers with respect to their need for co-creation actually may help to detect the crucial location along the overall value chain where customer specification should take place. Furthermore, the application of AHP models in the context of operations settings offers the opportunity for decision-makers to assess single CS with respect to the adequate manufacturing strategy. Additionally, the sensitivity analysis allows deriving the customer requirements – the criteria within the AHP decision hierarchy – exhibiting the most significant impact on manufacturing strategy changes. Hence, companies might apply such models to define the crucial customer segmentation criteria and to effectively segment their customers with respect to operations management considerations. Sensitivity analysis moreover might help to define or at least suggest the right amount of different manufacturing strategies needed to supply customer with a distinct product since they indicate changes in the preferred operations setting with respect to changing customer requirements.

Above all, the implications for decision-makers in praxis are as follows:

- A single “one size fits all approach” is not appropriate to satisfy all customer requirements. Different CS need different manufacturing strategies and these – in turn – different supply chains.
- The alignment of manufacturing strategies to customer requirements is an appropriate starting point for supply chain differentiation. Supply chain differentiation itself is based on the criteria “value of availability” (level 1), “value in use” (level 2) and “value co creation” (level 3).
- In order to attain “management attention”, the alignment of manufacturing strategies should be made on board resp. executive level. Within such a top-down approach, the necessary changes (especially process adaptations) in the supply chain can be initiated.
- The AHP model developed within this paper is an appropriate decision support instrument. Determined decisions have to be evaluated regarding cost of implementation (efficiency constraints).

6.3. Future research

As already suggested, to overcome the problem of criteria interconnection, one could try to further develop an ANP instead of the classical AHP. The ANP can be seen as an advancement of the AHP (cf. Saaty, 1996, 2005). The systematic difference lies in the introduction of feedback network structures next to simple hierarchies as well as the

formation of super matrices next to the priority vectors that evaluate the influence of each element on all other elements with respect to the goal. The procedure of super matrix formulation is described extensively in the literature (cf. Agarwal et al., 2006). But, the practicability of the ANP is limited since the requirement of super matrices raises the amount of necessary pair-wise comparisons to a rather large number even when only a small amount of criteria is used to structure the decision problem. An increasing amount of pair-wise comparisons also reduces sensitivity of the alternative priority vector towards single criteria. Furthermore, the ANP might exhibit the risk of so-called cyclic matrices that impair the mathematical resolvability massively (cf. Saaty, 1996).

As cost aspects so far were excluded when considering customer satisfaction as prior goal of the decision-finding process, the model presented here is focusing on effectivity and value proposition. To further include cost and price aspects, the following approaches could be added to the current model (cf. part 3.4): first, one simply could combine the here presented decision-finding model with a target costing approach. That way, the current model can deliver the most adequate manufacturing strategy – the one leading to the best value proposition or added value for the customers. Through assessing the price acceptance of the customer for the respective value propositions the company can identify the target price and hence the target costs for applying the selected manufacturing strategy. Second, price and crucial cost aspects – like processing cost, material cost or transportation and inventory cost – could be included on the criteria level of the decision hierarchy. However, the latter will require the model to capture feedback connections of criteria and alternatives and hence would definitely necessitate the application of an ANP with its overall much higher level of complexity. How the decision hierarchy of such an ANP could look like is illustrated within Figure 8.

One of the crucial strengths of the AHP is that it tries to profit from the personnel experience of the respondent. This, however, makes the method somehow subjective and probably susceptible for human misinterpretation. To overcome this problem, one could enhance the decision power of the model through integration of more than one experienced respondent. These could for example be additional operations managers; but also marketing and customer relationship management specialists. The final priority vector then could be derived as a mean value of the pair-wise comparison achievements of all involved respondents.

Another potential methodical extension in the context of subjectivity is the so called fuzzy approach (cf. Ayag & Özdemir, 2009; Geng et al., 2011; Yücenur, Vayvay, & Demirel, 2011). In this case, the respondent is not forced to set his choice for one fix

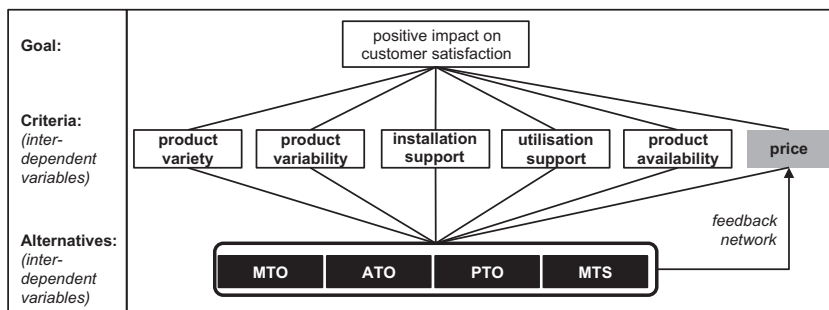


Figure 8. ANP decision hierarchy illustration including price feedback network.

number on the fundamental scale with respect to the single judgements. The respondent rather can determine a “fuzzy” range of importance what finally offers a certain manoeuvring room for the final alternative prioritisation.

A potent limitation of the suggested basic model is given by its high abstractive level. To overcome this limitation, one could simply add additional criteria and sub-criteria to further specify the model. This in fact would increase complexity and reduces sensitivity towards single criteria. On the other hand, further sub-criteria offer the opportunity of enhanced structuring and thus reduce the model’s susceptibility to human error. When considering, for example, the criteria product variety, several potential sub-criteria become obvious since product variety itself depends on many other factors like, for example, functional product characteristics, production technologies, process characteristics as well as the customer’s ability and will to actively act as co-producer (cf. Childerhouse et al., 2002; Etgar, 2008; Olhager, 2003). Such sub-criteria could also be added for the other criteria. However, the trade-off between complexity and practicability (or sensitivity) remains.

The suggested decision-finding model so far only utilised the AHP method with regard to manufacturing strategy decisions. But, of course the application of AHP/ANP models is not limited to this decision level. One could include several more single AHP/ANP hierarchies and networks to further determine manifestations of other dependent variables from other operations management decision levels.

Additionally, the proposed AHP structure is thought to be applicable in general and does not focus on single industries or products. Hence, it might make sense to adapt the basic structure to single product, process or industry specifications. This would not be limited to criteria but might also be practicable for the alternatives. The amount of CDP setting options, for example, is not limited to the ones proposed within the basic model. In fact, potential CDP depend on the production process and the amount of planning points (cf. Olhager, 2003).

All together, we offer several new insights regarding the connection of customer requirements and operations management decisions. Nevertheless, some weaknesses of the chosen approach call for further advancement. The future offers some promising opportunities with regard to the approach presented here. Most notably, to alleviate the weaknesses that emerged during the development and application of the AHP model, it is necessary to develop single models that are able to address distinct industry characteristics as well as single product features more accurately. The rather generic approach presented could be used as starting point and as source of inspiration for later investigations on the way to supply chain differentiation.

References

- Agarwal, A., Shankar, R., & Tiwari, M. K. (2006). Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach. *European Journal of Operational Research*, 173, 211–225.
- Agarwal, A., Shankar, R., & Tiwari, M. K. (2007). Modeling agility of supply chain. *Industrial Marketing Management*, 36, 443–457.
- Amaro, G., Hendry, L., & Kingsman, B. (1999). Competitive advantage, customisation and a new taxonomy for non make-to-stock companies. *International Journal of Operations & Production Management*, 19, 349–371.
- Ayag, Z., & Özdemir, R. G. (2009). A hybrid approach to concept selection through fuzzy analytic. *Computers and Industrial Engineering*, 56, 368–379.

- Beck, P., & Hofmann, E. (2012). Multiple criteria decision making in supply chain management – Currently available methods and possibilities for future research. *Die Unternehmung – Swiss Journal of Business Research and Practice*, 66, 181–214.
- Beck, P., Hofmann, E., & Stölzle, W. (2012). One size does not fit all: An approach for differentiated supply chain management. *International Journal of Services Sciences*, 4, 213–239.
- Bley, H., Avgoustinov, N., & Franke, C. (2002). Towards feature-based intelligent assembly. *Production Engineering*, 9, 97–100.
- Bottani, E., & Rizzi, A. (2006). Strategic management of logistics service: A fuzzy QFD approach. *International Journal of Production Economics*, 103, 585–599.
- Childerhouse, P., Aitken, J., & Towill, D. R. (2002). Analysis and design of focused demand chains. *Journal of Operations Management*, 20, 675–689.
- Christopher, M., Peck, H., & Towill, D. R. (2006). A taxonomy for selecting global supply chain strategies. *The International Journal of Logistics Management*, 17, 277–287.
- Christopher, M., & Towill, D. R. (2002). Developing market specific supply chain strategies. *The International Journal of Logistics Management*, 13(1), 1–14.
- Cooper, R., & Slagmulder, R. (1999). Develop profitable new products with target costing. *Sloan Management Review*, 40, 23–33.
- Da Silveira, G., Borenstein, D., & Fogliatto, F. S. (2001). Mass customization: Literature review and research directions. *International Journal of Production Economics*, 72(1), 1–13.
- Davis, M. (2010). *Case study for supply chain leaders: Dell's transformation journey through supply chain segmentation*. Gartner research ID number G00208603. Retrieved April 17, 2012, from <http://www.gartner.com/id=1468717>
- Davis, M., & McDonnell, W. (2011). *The seven steps of the supply chain segmentation journey*. Gartner research ID number G00210319. Retrieved March 10, 2012, from <http://www.gartner.com/id=1537017>
- Ernst, R., & Kamrad, B. (2000). Evaluation of supply chain structures through modularization and postponement. *European Journal of Operational Research*, 124, 495–510.
- Etgar, M. (2008). A descriptive model of the consumer co-production process. *Journal of the Academy of Marketing Science*, 36, 97–108.
- Fisher, M. L. (1997). What is the right supply chain for your product? A simple framework can help you figure out the answer. *Harvard Business Review*, 75, 105–116.
- Franceschini, F., & Rafele, C. (2000). Quality evaluation in logistic services. *International Journal of Agile Management Systems*, 2, 49–53.
- Geng, X., Chu, X., Xue, D., & Zhang, Z. (2011). A systematic decision-making approach for the optimal product-service system planning. *Expert Systems with Applications*, 38, 11849–11858.
- Hallgren, M., & Olhager, J. (2006). Differentiating manufacturing focus. *International Journal of Production Research*, 44, 3863–3878.
- Hilletofth, P. (2009). How to develop a differentiated supply chain strategy. *Industrial Management & Data Systems*, 109, 16–33.
- Jiao, J., Ma, Q., & Tseng, M. M. (2003). Towards high value-added products and services: Mass customization and beyond. *Technovation*, 23, 809–821.
- Johnson, M. W., Christensen, C. C., & Kagermann, H. (2008). Reinventing your business model. *Harvard Business Review*, 86, 50–59.
- Ketchen, D. J., Rebarick, W., Hult, G. T. M., & Meyer, D. (2008). Best value supply chains: A key competitive weapon for the 21st century. *Business Horizons*, 51, 235–243.
- Kumar, S., & Wilson, J. (2009). A manufacturing decision framework for minimizing inventory costs of a configurable off-shored product using postponement. *International Journal of Production Research*, 47, 143–162.
- Lee, H. L. (2002). Aligning supply chain strategies with product uncertainties. *California Management Review*, 44, 105–119.
- Lin, C.-T., Chiub, H., & Chub, P.-Y. (2006). Agility index in the supply chain. *International Journal of Production Economics*, 100, 285–299.
- Manson-Jones, R., & Towill, R. D. (1999). Using the information decoupling point to improve supply chain performance. *The International Journal of Logistics Management*, 10, 13–26.
- Mason-Jones, R., Naylor, B., & Towill, D. R. (2000). Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, 38, 4061–4070.

- Mentzer, J. T., Flint, D. J., & Hult, G. T. M. (2001). Logistics service quality as a segment-customized process. *Journal of Marketing*, 65, 82–104.
- Mikkola, J. H., & Skjott-Larsen, T. (2004). Supply-chain integration: Implications for mass customization, modularization and postponement strategies. *Production Planning & Control*, 15, 352–361.
- Mont, O. K. (2002). Clarifying the concept of product-service system. *Journal of Cleaner Production*, 10, 237–245.
- Murakoshi, T. (1994). Customer-driven manufacturing in Japan. *International Journal of Production Economics*, 37, 63–72.
- Naim, M. M., & Gosling, J. (2010). On leanness, agility and leagile supply chains. *International Journal of Production Economics*, 131, 342–354.
- Olhager, J. (2003). Strategic positioning of the order penetration point. *International Journal of Production Economics*, 85, 319–329.
- Olhager, J. (2010). The role of the customer order decoupling point in production and supply chain management. *Computers in Industry*, 61, 863–868.
- Oliva, R., & Kallenberg, R. (2003). Managing the transition from products to services. *International Journal of Service Industry Management*, 14, 160–172.
- Pagh, J. D., & Cooper, M. C. (1998). Supply chain postponement and speculation strategies: How to choose the right strategy. *Journal of Business Logistics*, 19, 13–33.
- Partovi, F. Y., Burton, J., & Banerjee, A. (1990). Application of analytical hierarchy process in operations management. *International Journal of Operations & Production Management*, 10, 5–19.
- Raddats, C., & Easingwood, C. (2010). Services growth options for B2B product-centric businesses. *Industrial Marketing Management*, 39, 1334–1345.
- Rafele, C. (2004). Logistics service management: A reference framework. *Journal of Manufacturing Technology Management*, 15, 280–290.
- Razmi, J., Rahnejat, H., & Khan, M. K. (1998). Use of analytic hierarchy process approach in classification of push, pull and hybrid push-pull systems for production planning. *International Journal of Operations & Production Management*, 18, 1134–1151.
- Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*. Pittsburgh, PA: RWS-Publications.
- Saaty, T. L. (2004). Decision making – The analytic hierarchy and network process (AHP/ANP). *Journal of Systems Science and Systems Engineering*, 13(1), 1–35.
- Saaty, T. L. (2005). Making and validating complex decisions with the AHP/ANP. *Journal of Systems Science and Systems Engineering*, 14(1), 1–36.
- Saaty, T. L., & Vargas, L. C. (2006). *Decision making with the analytic network process: Economic, political, social and technological applications with benefits, opportunities, costs and risks*. Boston, MA: Springer.
- Sharp, B., & Dawes, J. (2001). What is differentiation and how does it work? *Journal of Marketing Management*, 17, 739–759.
- Tu, Q., Vonderembse, M. A., & Ragu-Nathan, T. S. (2001). The impact of time-based manufacturing practices on mass customization and value to customer. *Journal of Operations Management*, 19, 201–217.
- Van Amstel, R. P., & D'hert, G. (1996). Performance indicators in distribution. *The International Journal of Logistics Management*, 7, 73–82.
- Van Hoek, R. I. (1998). Reconfiguring the supply chain to implement postponed manufacturing. *The International Journal of Logistics Management*, 9, 95–110.
- Van Hoek, R. I., Harrison, A., & Christopher, M. (2001). Measuring agile capabilities in the supply chain. *International Journal of Operations & Production Management*, 21, 126–147.
- Vargo, S. L., & Lusch, R. F. (2008a). From goods to service(s): Divergences and convergences of logistics. *Industrial Marketing Management*, 37, 254–259.
- Vargo, S. L., & Lusch, R. F. (2008b). Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science*, 36(1), 1–10.
- Wallenius, J., Dyer, J. S., Fishburn, P. C., Steuer, R. E., Zionts, S., & Deb, K. (2008). Multiple criteria decision making, multiattribute utility theory: Recent accomplishments and what lies ahead. *Management Science*, 54, 1336–1349.
- Yoon, B., Kim, S., & Rhee, J. (2012). An evaluation method for designing a new product-service system. *Expert Systems with Applications*, 39, 3100–3108.

- Yücenur, G. N., Vayvay, Ö., & Demirel, N. C. (2011). Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment. *The International Journal of Advanced Manufacturing Technology*, 56, 823–833.
- Yusuf, Y. Y., Gunasekaran, A., Adeleye, E. O., & Sivayoganathan, K. (2004). Agile supply chain capabilities: Determinants of competitive objectives. *European Journal of Operational Research*, 159, 379–392.
- Zhang, Q., Vonderembse, M. A., & Lim, J.-S. (2002). Value chain flexibility: A dichotomy of competence and capability. *International Journal of Production Research*, 40, 561–583.
- Zhang, Q., Vonderembse, M. A., & Lim, J.-S. (2003). Manufacturing flexibility: Defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management*, 21, 173–191.
- Zhang, Q., Vonderembse, M. A., & Lim, J.-S. (2005). Logistics flexibility and its impact on customer satisfaction. *The International Journal of Logistics Management*, 16, 71–95.
- Zhang, Q., Vonderembse, M. A., & Lim, J.-S. (2006). Spanning flexibility: Supply chain information dissemination drives strategy development and customer satisfaction. *Supply Chain Management: An International Journal*, 11, 390–399.
- Zinn, W., & Bowersox, D. J. (1988). Planing physical distribution with the principle of postponement. *Journal of Business Logistics*, 9, 117–136.

Appendix 1. AHP computations

MS Excel® computations were all performed using the add-in PopTools (<http://www.poptools.org/>). The respective add-in allows calculating eigenvalues and provides several functions for matrix calculations. To ensure consistency during the sensitivity analysis, it was necessary to pre-calculate several pair-wise judgments instead of using values derived through intuitive judgments of the respondent. This is the prerequisite for proper application of the sensitivity analysis described in Figures A1, A2 and A3.

Questions: Importance for customer satisfaction	Score from 1/9 to 9	
How much more (or less) important is product variety when compared to product variability ?	1.00	Filled in by the respondent
How much more (or less) important is product variety when compared to installation support ?	1.00	
How much more (or less) important is product variety when compared to utilisation support ?	1.00	
How much more (or less) important is product variety when compared to product availability ?	1.00	
How much more (or less) important is product variability when compared to installation support ?	1.00	➡ =WHEN((C9/C7)<1/9; 1/9; WHEN((C9/C7)>9; 9; C11/C7))
How much more (or less) important is product variability when compared to utilisation support ?	1.00	➡ =WHEN((C11/C7)<1/9; 1/9; WHEN((C11/C7)>9; 9; C11/C7))
How much more (or less) important is product variability when compared to product availability ?	1.00	➡ =WHEN((C13/C7)<1/9; 1/9; WHEN((C13/C7)>9; 9; C11/C7))
How much more (or less) important is installation support when compared to utilisation support ?	1.00	➡ =WHEN((C11/C9)<1/9; 1/9; WHEN((C11/C9)>9; 9; C11/C7))
How much more (or less) important is installation support when compared to product availability ?	1.00	➡ =WHEN((C13/C7)<1/9; 1/9; WHEN((C13/C7)>9; 9; C11/C7))
How much more (or less) important is utilisation support when compared to product availability ?	1.00	➡ =WHEN((C13/C11)<1/9; 1/9; WHEN((C13/C11)>9; 9; C11/C7))

Figure A1. Special MS Excel® calculations for criteria assessment with respect to the AHP goal. The indicated formulas contain cell coordinates C7, C9, C11, C13. The latter represent the cell content entered by the respondent (grey cells in the figure).

normalised sum of the appropriateness ratings of the alternative
(each multiplied by the priority of the respective criterion)

	product variety	product variability	installation support	utilisation support	availability	
	priority vector of criteria assessment matrix					priority
MTO						
ATO	priority vector of alternatives appropriateness assessments with respect to each criteria					
PTO						
MTS						

Figure A2. Overall priority calculations within the AHP. Eigenvalues and eigenvectors were calculated using the respective functions provided by PopTools: Excel add-ins → PopTools → Matrix tools → Eigenanalysis (general square).

Questions: Importance for customer satisfaction	Score from 1/9 to 9	
How much more (or less) important is product variety when compared to product variability ?	1.00	➡ Varying from 1/9 to 9 while other values were kept constant: Results in sensitivity analysis for product variety vs. product variability
How much more (or less) important is product variety when compared to installation support ?	1.00	➡ Varying from 1/9 to 9 while other values were kept constant: Results in sensitivity analysis for product variety vs. installation support
How much more (or less) important is product variety when compared to utilisation support ?	1.00	➡ Varying from 1/9 to 9 while other values were kept constant: Results in sensitivity analysis for product variety vs. utilisation support
How much more (or less) important is product variety when compared to product availability ?	1.00	➡ Varying from 1/9 to 9 while other values were kept constant: Results in sensitivity analysis for product variety vs. product availability
How much more (or less) important is product variability when compared to installation support ?	1.00	➡ =WHEN((C9/C7)<1/9; 1/9; WHEN((C9/C7)>9; 9; C11/C7))
How much more (or less) important is product variability when compared to utilisation support ?	1.00	➡ =WHEN((C11/C7)<1/9; 1/9; WHEN((C11/C7)>9; 9; C11/C7))
How much more (or less) important is product variability when compared to product availability ?	1.00	➡ =WHEN((C13/C7)<1/9; 1/9; WHEN((C13/C7)>9; 9; C11/C7))
How much more (or less) important is installation support when compared to utilisation support ?	1.00	➡ =WHEN((C11/C9)<1/9; 1/9; WHEN((C11/C9)>9; 9; C11/C7))
How much more (or less) important is installation support when compared to product availability ?	1.00	➡ =WHEN((C13/C7)<1/9; 1/9; WHEN((C13/C7)>9; 9; C11/C7))
How much more (or less) important is utilisation support when compared to product availability ?	1.00	➡ =WHEN((C13/C11)<1/9; 1/9; WHEN((C13/C11)>9; 9; C11/C7))

Figure A3. MS Excel® procedure for the sensitivity analysis. The indicated formulas contain cell coordinates C7, C9, C11, C13. The latter represent the cell varied for the sensitivity analysis (grey cells in the figure).

Appendix 2. Computation results and numerical spreadsheets

criteria priorities product X	variety	variability	installation support	utilisation support	availability	priority
variety	1.00	5.00	7.00	8.00	2.00	0.51
variability	0.20	1.00	1.40	1.60	0.40	0.10
installation support	0.14	0.71	1.00	1.14	0.29	0.07
utilisation support	0.13	0.63	0.88	1.00	0.25	0.06
availability	0.50	2.50	3.50	4.00	1.00	0.25

n: 5; $\lambda_{\max}$: 5; μ : 0.00; C.I. for n = 5: 1.11; C.R.: 0

variety	MTO	ATO	PTO	MTS	priority
MTO	1.00	6.00	6.00	8.00	0.66
ATO	0.17	1.00	3.00	4.00	0.19
PTO	0.17	0.33	1.00	3.00	0.10
MTS	0.13	0.25	0.33	1.00	0.05

n: 4; $\lambda_{\max}$: 4.24; μ : 0.08; C.I. for n = 5: 0.89; C.R.: 0.09

variability	MTO	ATO	PTO	MTS	priority
MTO	1.00	3.00	2.00	6.00	0.47
ATO	0.33	1.00	1.00	6.00	0.23
PTO	0.50	1.00	1.00	6.00	0.25
MTS	0.17	0.17	0.17	1.00	0.05

n: 4; $\lambda_{\max}$: 4.12; μ : 0.04; C.I. for n = 5: 0.89; C.R.: 0.04

installation support	MTO	ATO	PTO	MTS	priority
MTO	1.00	1.00	0.50	7.00	0.26
ATO	1.00	1.00	2.00	7.00	0.38
PTO	2.00	0.50	1.00	7.00	0.32
MTS	0.14	0.14	0.14	1.00	0.04

n: 4; $\lambda_{\max}$: 4.19; μ : 0.06; C.I. for n = 5: 0.89; C.R.: 0.07

utilisation support	MTO	ATO	PTO	MTS	priority
MTO	1.00	1.00	1.00	1.00	0.25
ATO	1.00	1.00	1.00	1.00	0.25
PTO	1.00	1.00	1.00	1.00	0.25
MTS	1.00	1.00	1.00	1.00	0.25

n: 4; $\lambda_{\max}$: 4; μ : 0.00; C.I. for n = 5: 0.89; C.R.: 0

availability	MTO	ATO	PTO	MTS	priority
MTO	1.00	0.25	0.50	6.00	0.18
ATO	4.00	1.00	1.00	6.00	0.43
PTO	2.00	1.00	1.00	6.00	0.34
MTS	0.17	0.17	0.17	1.00	0.05

n: 4; $\lambda_{\max}$: 4.19; μ : 0.06; C.I. for n = 5: 0.89; C.R.: 0.07

Figure A4. Numerical spreadsheets for product X. Legend: n : number of criteria, $\lambda_{\max}$: principal eigenvalue of the $n \times n$ matrix, μ : consistency index, CI : corresponding random index for n and CR : consistency ratio. Consistency is given, when CR is below .1 (cf. Saaty, 2004, p. 23).

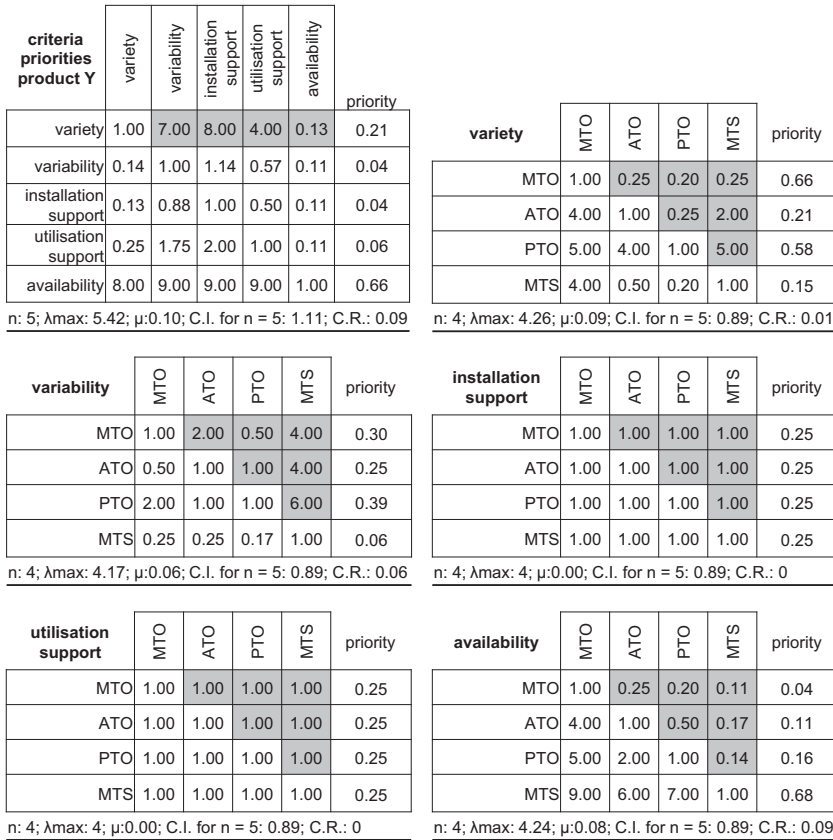


Figure A5. Numerical spreadsheets for product Y. Legend: n : number of criteria, $\lambda_{\max}$: principal eigenvalue of the $n \times n$ matrix, μ : consistency index, CI : corresponding random index for n and CR : consistency ratio. Consistency is given, when CR is below .1 (cf. Saaty, 2004, p. 23).