Supply Chain Differentiation - A Multiple Criteria Decision Support Methodology

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The President:

Prof. Dr. Thomas Bieger

Vorwort

Die vorliegende Dissertation entstand im Rahmen meiner Forschungstätigkeit am Lehrstuhl für Logistikmanagement der Universität St.Gallen (LOG-HSG). Im Fokus dieser Arbeit steht die Entwicklung einer Methodik zur Entscheidungsunterstützung bei der Auswahl einer differenzierten Supply Chain Strategie. Die Motivation sich diesem Forschungsfeld zu widmen, entstand im Rahmen der Zusammenarbeit mit verschiedenen Unternehmen aus dem Schweizer Anlagen- und Maschinenbau, die mir die praktische Relevanz weiterer wissenschaftlicher Arbeit in diesem Forschungsgebiet verdeutlichten.

Mit diesem Vorwort danke ich allen Personen, die mich in meinem Dissertationsprozess begleitet und unterstützt haben.

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Ein weiterer ganz besonderer Dank gilt Prof. Dr. Erik Hofmann für seinen Zeiteinsatz und seine enge thematische Betreuung meines Dissertationsprozesses. Seine stets kreativen Ideen und seine strukturierte Herangehensweise an Problemstellungen haben meine Arbeit wesentlich beeinflusst.

Erfolgreiches wissenschaftliches Arbeiten in der Betriebswirtschaft setzt die Kooperation mit Partnern aus der Wirtschaft voraus. Daher bedanke ich mich an dieser Stelle bei allen Unternehmen, die meine Arbeit unterstützt und durch die Bereitstellung von Informationen erst ermöglichten. Speziell danke ich der Inova Management AG und der Reichle & De-Massari AG für die intensive Zusammenarbeit und den wertvollen Austausch.

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Zuletzt möchte ich meiner Familie für ihre bedingungslose Unterstützung danken, insbesondere meinem Bruder Denis Beck und meiner Mutter Elisabeth Frey.

Friedrichshafen im Juli 2013 Patrick Beck

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List of abbreviations

3PL	Third party logistics provider
3PRLP	Third party reverse logistics provider
AHP	Analytical hierarchy process
ANP	Analytical network process
AtO	Assemble-to-order
CG	Customer group
CI	Consistency index of the AHP
CR	Consistency ratio of the AHP
DP	Decoupling point
DEA	Data envelopment analysis
DtO	Deliver-to-order
EJOR	European Journal of Operational Research
ELECTRE	Elimination and choice expressing reality
IJPE	International Journal of Production Economics
IJPR	International Journal of Production Research
MACBETH	Measuring attractiveness by a categorical based evaluation technique
MAUT	Multi-attribute utility theory
MCDM	Multiple criteria decision making
MOMP	Multi-objective mathematical programming
MtO	Make-to-order
MtS	Make-to-stock
PC	Product cluster
PROMETHEE	Preference ranking organization method for enrichment evaluation
RI	Random index

RQ	Research question
SC	Supply chain
SCD	Supply chain differentiation
SCM	Supply chain management
SKU	Stock keeping unit
SMART	Simple multi attribute rating technique
StO	Source-to-order
TOPSIS	Technique for order preference by similarity to ideal solution
UTA	Utilities additives

Zusammenfassung

Das Supply Chain Management (SCM) muss heutzutage stark variierenden Kundenanforderungen innerhalb eines Marktes gerecht werden. Darüber hinaus sind Unternehmen meist teil mehrerer Supply Chains (SC), anstatt in nur einer SC einen Beitrag zu leisten. Diese Faktoren führen zu der Schlussfolgerung, dass klassische „One size fits all“-Ansätze nicht mehr zeitgemäss für ein modernes SCM sind.

Supply Chain Differenzierung (SCD) bedeutet den gleichzeitigen Einsatz mehrerer SCs nebeneinander, um verschiedenartige Kundenbedürfnisse in einem Markt effektiv zu befriedigen und somit aktuellen Forderungen an das SCM gerecht zu werden. Allerdings stellt die Entscheidung, ob aufgrund der Markterfordernisse mehrere SCs nebeneinander benötigt werden, ein komplexes Problem dar. Dieses Entscheidungsproblem bindet durch seine strategische Natur multiple qualitative, konfliktäre sowie unpräzise Kriterien ein. Dies erfordert die Nutzung einer speziellen Klasse der Entscheidungsunterstützung, Methoden der multikriteriellen Entscheidungsfindung.

Die vorliegende Dissertation entwickelt eine Methode der multikriteriellen Entscheidungsunterstützung, um Gestaltungempfehlungen für eine differenzierte SC abzuleiten. Der Forschungsansatz ist in drei Phasen untergliedert. (1) Die empirische Forschungsphase analysiert Entscheidungen in Bezug auf SCD durch Fallstudien und leitet ein SCD-Entscheidungsrahmenwerk ab. (2) Die Literaturanalyse gibt Aufschluss über bereits vorhandene multikriterielle Methoden der Entscheidungsunterstützung im SCM. (3) In der letzten Forschungsphase erfolgt die Integration des SCD-Entscheidungsrahmenwerks in ein SCD-Entscheidungsmodell. Aufgrund seiner besonderen Eignung im Hinblick auf das zugrundeliegende Entscheidungsproblem, kommt ein Analytical Hierarchy Process innerhalb des SCD-Entscheidungsmodells zum Einsatz.

Für Manager bietet die vorliegende Arbeit Unterstützung bei Entscheidungen bezüglich der Einführung einer differenzierten SC. Darüber hinaus offeriert die Literaturanalyse einen Überblick in Hinsicht auf vorhandene multikriterielle Methoden in der SCM-Literatur. Der Beitrag zur Wissenschaft liegt in der Vorstellung empirischer Ergebnisse für Entscheidungen zur Supply Chain Differenzierung. Ausserdem präsentiert die vorliegende Arbeit den ersten multikriteriellen Ansatz zur Generierung von Gestaltungsempfehlungen für eine differenzierte SC.

Summary

In the current business environment, supply chain management (SCM) has to deal with widely varying customer requirements even within one market. Additionally, companies tend to be part of several supply chains (SC) instead of only one. These facts lead to the conception that classic "one size fits all" approaches with respect to SCM are obsolete.

Supply chain differentiation (SCD), the concurrent operation of several SCs besides each other for satisfying differing customer needs in one market effectively, is one opportunity to tackle these momentarily emerging challenges for SCM. Yet, to decide whether a differentiated SC is the most suitable approach to deal with the requirements of the market is difficult. Managers and decision makers need support for decisions on SCD. Due to the strategic nature of this decision, multiple qualitative, conflicting and imprecise criteria have to be considered. This requires the application of a specific class of decision support methodologies, i.e. multiple criteria decision making.

The thesis at hand develops a multiple criteria decision support methodology for decisions on SCD. The research proceeding is divided in three phases. (1) The empirical research phase analyzes decisions on SCD by means of case studies and results in a SCD-decision framework. (2) The literature survey investigates, which decision or application areas in SCM are already covered by multiple criteria decision making approaches. (3) The last research phase integrates the SCD-decision framework in a multiple criteria decision making based SCD-decision model. Due to its convenience to SCD-decisions, an analytic hierarchy process is used as core of the SCD-decision model.

For managers this thesis offers support for decisions on SCD by means of the SCD-decision model and the integrated criteria and variables stemming from the SCD-decision framework. The literature survey gives managers an overview with respect to available support for decision problems in SCM. This thesis contributes to academia by presenting empirical research for decisions on SCD and by integrating these results in the first multiple criteria decision making approach for decisions on SCD. The literature review offers researchers guidance with respect to further research on multiple criteria decision making in SCM.

1 Introduction

In this section the practical and the theoretical relevance of decision support for SCD is discussed. Furthermore, the research objective and the research questions of this thesis are stated. Thereafter the research within this thesis is positioned in scientific theory. The last section states the structure of the thesis at hand. Note, this is a cumulative thesis. Therefore, the detailed research findings are presented in the three papers in the appendix of this thesis.

1.1 Managerial relevance of decision support for supply chain differentiation

Since Porter (1980) introduced differentiation as competitive strategy, companies seek to gain competitive advantage by delimiting their offering from other offerings in the market. As differentiation through product characteristics got more difficult, companies introduced differentiation approaches that are based on processes and value adding services, like logistics service level differentiation (cf. Fuller *et al.*, 1993). Subsequently, SCM in general has become a means for differentiation and developing a competitive advantage (cf. Hult *et al.*, 2007). Especially SCD has gained in importance (cf. Christopher *et al.*, 2009). In recent years there have been several reports on SCD, which stress the relevance of the approach to business practice. An earlier publication (Beck *et al.*, 2012), in which the author of this dissertation was involved, explains:

"A study of AT Kearney (Mayer et al., 2009) states that companies applying a differentiated SCM approach are more successful than their competitors using a "one size fits all" approach. Two-thirds of the companies that participated in the AT Kearney study have understood the importance of this approach and are implementing a differentiated SCM approach. Furthermore, Mayer et al. (2009) also find that 50% of European companies already differentiate their SC in some form or another.

McKinsey & Company (Malik et al., 2011) report that SCD "can help tame complexity, save money, and serve customers better." They present the example of a producer of consumer durables, located in the United States, who differentiates its SC due to highly volatile demand and large number of product variants.

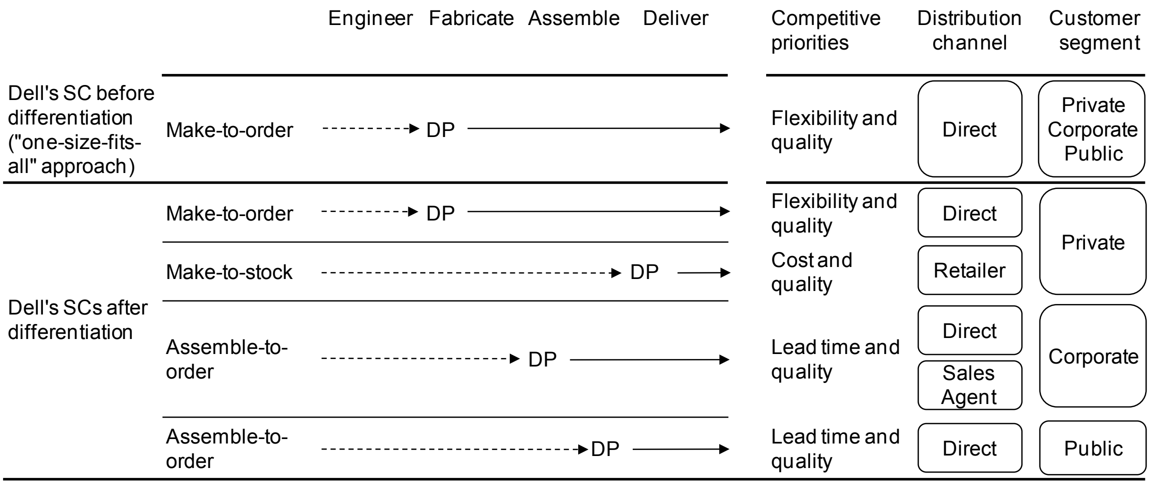

Figure 1: Basic principle of supply chain differentiation (Source: Beck *et al.*, 2012)

A further example for SCD is the computer manufacturer Dell, who was known for its negative cash-to-cash cycle, its direct distribution and its make-to-order manufacturing strategy (cf. Fugate and Mentzer, 2004; Gunasekaran and Ngai, 2005). However, the margins declined in recent years. Dell analyzed the problem and recognized that its make-to-order strategy implied high complexity, which not all customers require and value. The following insights are based on a case study report published by Gartner in November 2010 (Davis, 2010) and some concluding assumptions by the authors. Figure 1 illustrates possible configurations of Dell's SC before and after differentiation. The figure only includes aspects such as positioning of the decoupling point, competitive priorities (corresponds to SC strategy), distribution channels and customer segments. Certainly, SCD encompasses further issues, which are not depicted to reduce the complexity of the figure. Before the differentiation of its SC, Dell employed a "one size fits all" approach. All the customer segments were treated equally, disregarding their different requirements. The decoupling point was positioned upstream to ensure strong flexibility with respect to a broad product variation. The large number of product variants led to high complexity that implied unnecessary operational costs, since not all customers demand such a large variation of products. After the differentiation, Dell has been operating several SCs with different competitive priorities and varying positions of the decoupling point in the SC. Dell reports an increased customer proximity and lower operational costs (approximately $ 1.5 billion cost savings *from 2008 to 2010, relative to net revenues of $61 billion in 2009 and $53 billion in 2010), which was achieved due to SCD.*

Additional examples for SCD are the consumer goods manufacturers Nike, Adidas, and Oakley. All three firms operate a make-to-stock SC that produces their standard products, which are distributed through sport shops and several other channels. In recent years they implemented a make-to-order SC and offer their customers the opportunity to configure a product according to their wishes, which is distributed directly.

As these examples point out, SCD is a strong upcoming SCM trend in business practice."

Beck *et al.* (2012) demonstrate the practical relevance of SCD in general. Yet, this subsection aims at explaining the practical relevance of decision support for SCD. The basic argument here is that if the phenomenon SCD is relevant to business practice, decision support with respect to SCD should be relevant too. Besides the relevance of the decision problem's underlying phenomenon further factors indicate the practical relevance of decision support for SCD. Eisenführ *et al.* (2010) state, the more complex a decision problem, the more important is decision support for this problem as a means to transparently and systematically process information and factors relevant to the decision problem. Since SCD is basically a concept for setting up a differentiated SC design, decisions on SCD are not trivial and of a complex nature. The complexity of decisions on SCD is thoroughly elaborated within this thesis. Furthermore, decisions on SCD may come with a commitment to high investments for implementing SCD and are therefore most likely irreversible in the short run. Hence, misdeterminations with respect to SCD are at least costly or may even lead to the economic collapse of a company. Based on these arguments, managerial or practical relevance of SCD is assumed.

1.2 Theoretical relevance of decision support for supply chain differentiation

A differentiated or segmented SCM approach means to operate several SCs concurrently for serving one market, while each SC has a different strategic objective. Beside the fact that SCD aims at implementing multiple SC strategies besides each other for a differentiated customer approach, variables and criteria for decisions on

SCD stem mainly from academic publications on SC strategy (discussed in detail in Section A-3). Therefore, this section will state essential papers on SC strategy, before the research on SCD and SC segmentation is reviewed. Note, SCD is related to a number of research streams in operations management, e.g. logistics service level differentiation, mass customization and multiple sourcing approaches. These related research streams are briefly reviewed and explicitly delimited from SCD in Section 2.2.

1.2.1 Review of research on supply chain strategy

The "lean" body of thought was the first strategy adopted in SCM. Lean thinking is initially introduced to manufacturing (Krafcik, 1988; Womack *et al.,* 1990). Lean or efficient SCM is concerned with eliminating all the non-value-adding processes (waste) and thereby minimizing costs and cycle times (Hines and Rich, 1997; Hines *et al.,* 1998; Lamming, 1996; Levy, 1997).

Shapiro (1984) and Fisher (1997) introduce the discussion concerning physically efficient (lean) vs. market responsive (agile) SC strategies and their relation to product, demand and market characteristics. Further authors contributing to this area are Lee (2002), Li and O'Brien (2001), and Mason-Jones *et al.* (2000a).

Hybrid strategies regarding the application of decoupling points for the purpose of postponement were the next step of SC strategies mentioned in the literature. This concept dates back to Bucklin (1965), who applies it to logistics. Hoekstra *et al.* (1992) improve the early idea of Bucklin. Naylor *et al.* (1999) introduce how agile and lean SCs may be combined to create "leagile" SCs. Leagile SC strategies are discussed by further authors, e.g. Bruce and Daly (2004), Christopher and Towill (2001), Christopher (2000), Christopher and Towill (2002), Mason-Jones *et al.* (2000b), Mason-Jones and Towill (1999), Olhager (2003), Olhager (2010), Sun *et al.* (2008).

The articles in this section contribute to SCD since they offer various strategies for SCs and discuss criteria for the selection of an adequate SC strategy given certain product or market characteristics. In addition, the concept of decoupling points offers a further possibility for tailoring a SC strategy to customer requirements and combining lean and agile strategies. However, SC strategies are only a single part of SCD.

1.2.2 Review of research on supply chain differentiation and segmentation decisions

Childerhouse *et al.* (2002) present a case study of a UK lighting manufacturer that implements four SCs concurrently. They further introduce a framework for the development of “focused demand chains". The framework they use is the so called DWV^3 model and considers the criteria “product variety”, “demand variability”, “duration of product life-cycle”, “responsiveness of order cycle” and “product annual demand volume” for designing differentiated SC strategies. Aitken *et al.* (2003) uses the same case study and also investigates the DWV^3 model, yet, with an emphasis on the influence of the product life cycle on SC strategy. A segmented approach to SCM with the focus on collaboration is proposed by Barratt (2004). In his opinion strong collaboration should be limited to a small amount of customers and suppliers that are crucial to the company’s business. The article of Aitken *et al.* (2005) is based on the same case study and findings of Childerhouse *et al.* (2002) and presents seven different generic delivery-focused SC strategies.

Schnetzler *et al.* (2006) present a methodology based on axiomatic design decomposition for the development of a segmented SC strategy. In a later publication Schnetzler *et al.* (2007) focus on the derivation of a SC strategy applying the same methodology. The authors mention that segmentation of the SC should be possible using this approach. However, there is no example of a successful application. Hilletofth (2009) reports how two Swedish companies have employed differentiated SC strategies. He strongly focuses on manufacturing strategies in the SC context and considers some aspects of sourcing and distribution too. Christopher *et al.* (2009) summarizes publications within literature on the design of differentiated SC strategies. They find that the DWV^3 model delivers adequate results in today’s business environment. Stich and Meyer (2009) suggest an approach to SC segmentation based on hybrid systems theory. Even so, after introducing four generic SC strategies they give no advice on how a segmented SC should be designed and which aspects should be considered. Differentiation with respect to SC processes and their alignment with the SC strategy and product characteristics is studied by Stavrulaki and Davis (2010). However, with the focus on SC processes neglecting differentiated SC strategies, the authors’ framework lacks important aspects of SCD. Godsell *et al.* (2011) use the DWV^3 model for differentiating the SC of a fast moving consumer goods company. Hilletofth (2012) presents a framework for differentiating SC designs. Yet, he concentrates on describing a process for SCD rather than analyzing relevant criteria and variables relevant to decisions on SCD.

The papers on differentiated and segmented SC approaches contribute to the core research area of this thesis. The publications on the DWV^3 model offer variables and criteria, which should be considered in designing differentiated SC strategies. The DWV^3 model yields suitable results, according to authors that apply the model. To date, this model is the most investigated methodology for designing differentiated SC strategies. Note, the DWV^3 model integrated five different criteria and is therefore of multiple criteria nature.

1.2.3 Summary of the literature review and research gap

As we have seen, there is a vast body of literature with respect to fitting SC strategies to product characteristics, business unit strategy, demand as well as supply patterns, and sometimes even customer requirements.

As presented in Section 1.1, practitioners have an interest in SCD and, hence, a need for guidance with respect to SCD. Yet, the literature with respect to SCD is still scarce. Especially the SCD-decision is not investigated deeply enough and needs further research. Currently the only methodology available for supporting decisions on SCD is the DWV^3 model. The authors applying this model suggest that it delivers adequate results. Yet, at this time the DWV^3 model as presented by the authors above is a mere arithmetic framework for assigning products or stock keeping units (SKU) to different product clusters. Additionally, the variables and criteria of the DWV^3 model implicitly offer design suggestions for differentiated SCs (discussed in detail in Section A-4). Nevertheless, the model does not represent a decision support methodology in the classic sense. Therefore, several advantages that modern decision support methodologies offer are neglected. The thesis at hand tries to close this research gap and offers a support methodology for decisions on SCD, which will integrate the DWV^3 model. Since several criteria have to be considered in SCD-decisions, a decision support methodology from multiple criteria decision making (MCDM) has to be applied.

1.3 Research objective and research questions of the thesis

The main research objective of this thesis is to develop decision support for a transparent and structured approach to complex SCD-decisions. This target encompasses a managerial and theoretical research objective. The *managerial research objective* is to offer decision makers in SCM support for decisions on SCD. To achieve this goal three managerial sub-objectives are met. (1) The thesis provides a set of relevant variables and criteria decision makers have to consider in decisions on SCD and the thesis explains the influence these variables and criteria have on possible differentiated SC designs. Additionally, (2) the thesis gives an overview, which decision support for multiple criteria decisions in SCM is currently available for decision makers. Finally, (3) the thesis provides managers with a specific decision support methodology for decision on SCD.

Naturally, the *theoretical research objective* has a similar orientation, yet, it contributes to the further development of SCM research and decision support in SCM. Again, three theoretical sub-objectives are pursued. (1) The thesis delivers further empirical evidence with respect to relevant variables and criteria for decisions on SCD and their influence on possible differentiated SC designs. Furthermore, (2) the survey of currently available MCDM support for multiple criteria decision in SCM serves the purpose to suggest further fields for future research in decision support for MCDM problems in SCM in general. In conclusion, (3) the application of a MCDM methodology that integrates the previously evaluated set of variables and criteria for decisions on SCD represents an advancement of decision analysis in SCM.

By means of the above stated research objectives, the thesis aims at answering the *main research question:*

RQ: *How may companies decide whether or not they should differentiate their supply chain and how many supply chains they need by means of a suitable decision support methodology?*

This main research question encompasses different aspects of the overall research problem. For a better understanding of the research problem and a well-structured research approach the main research question is divided into six sub-questions. Sub-questions 1a to 1c are concerned with an empirical investigation of decisions on

SCD. The aim of these questions is to analyze the problem and find relevant criteria for SCD-decisions as well as finding hints in which cases a company should apply SCD. Especially, the requirements of SCD-decisions on a decision support methodology is investigated. This is the basis for the later following selection of an appropriate method for taking SCD-decisions and to prove that SCD-decisions are of multiple criteria nature.

RQ1a: *How can companies decide whether to differentiate their supply chain?*

RQ1b: *Which circumstances indicate that supply chain differentiation is meaningful for a company?*

RQ1c: *Which variables are relevant for SCD-decisions?*

Sub-question 2a and 2c present a survey of available multiple criteria decision support in SCM. Objective of these research questions is to analyze, which applications of MCDM methodologies already exist. It is identified, which application areas in SCM and which specific decision problems in these application areas are already covered by MCDM methodologies. The results of this step support the selection of a suitable MCDM method for SCD-decisions.

RQ2a: *Which supply chain management application areas are covered by suitable multiple criteria decision making approaches?*

RQ2b: *What multiple criteria decision making trends may develop in supply chain management?*

After the empirical investigation of the SCD-decision and the survey of existing MCDM applications on SCM, sub-question 3 selects an appropriate method for SCD-decisions. The selection is based on the information provided by the previous sub-questions. After the selection of an appropriate method, the method will be adapted to the SCD-decision and a decision model will be created on basis of the generated information to answer the previous sub-questions. The aim is to generate a generic decision model that is transferable to a high number of companies and industries.

RQ3: *How may a SCD-decision be supported by means of a multiple criteria decision making methodology?*

1.4 Positioning of research within scientific theory

Classical research in business administration often distinguishes between the meta-methodological, methodological and theoretical layer of research. The meta-methodological layer is concerned with the perception of the researcher regarding ontology, epistemology and human nature (cf. Burell and Morgan, 1979). The methodological layer describes the research approach for generating knowledge with respect to the underlying phenomenon. These research methodologies are categorized into inductive research for building theory by means of observation of the phenomenon or deductive research for testing already developed theory about the surveyed phenomenon (cf. Meredith, 1993). The theoretical layer of research states which already existing scientific theory or theories are integrated in the research approach for better describing, explaining or understanding the investigated phenomenon (cf. Creswell, 2009). Ulrich and Hill (1979) suggest that business research should be pragmatic and its results must support managers in their work. Nevertheless, this classic business research approaches are focused on generating or testing theory. Yet, the aim of this thesis is not purely to explore a phenomenon but to create decision support for business practice. Hence, another research approach is employed for this thesis, i.e. design science research.

Design science research originates from research on information systems and is devoted to creating innovative artifacts that support companies in business practice (cf. Hevner *et al.*, 2004). Holmström *et al.* (2009) argue that research in operations management should be more concerned with problem solving besides the generation and testing of theory. They postulate design science research as a means to establish research on problem solving in operations management rather than only explaining ex-post why the problem solving approach of a company was successful. An artifact in design science research may be a "construct, a model, a method or an instantiation" (Hevner *et al.,* 2004). Since the objective of this thesis is to create a decision model, the research approach in design science research is suitable. The so called design science research process according to Peffers *et al.* (2008) and Holmström *et al.* (2009) includes six steps.

(1) *Problem identification and motivation*: Design science research starts with a description and an investigation (on a low detail level) of the underlying problem and explains thereby the motivation for contributing to this problem. The motivation in this context is the academic as well as the managerial relevance of the problem.

(2) *Objectives of a solution*: This step provides a clear description of the research target in design science research. It must be provided, how the artifact that the research will provide, contributes to academia and to business practice.

(3) *Design and development*: After the relevance and the research objective have been stated, the actual design phase starts. This is the core of design science research, since it incorporates the detailed analysis of the underlying problem and the creation of a suitable solution for the problem.

(4) *Demonstration*: The demonstration of the designed artifact is conducted through the application of the artifact to the problem. It must be clearly shown that the designed artifact is suitable to solve the underlying problem.

(5) *Evaluation:* To evaluate the artifact, the solutions produced through the application of the artifact must be analyzed. As Hevner *et al.* (2004) states, this may be achieved through an experimental application of the artifact within a simulation.

(6) *Communication*: This step simply corresponds to disseminating the research results.

This thesis incorporates the above described design science research process. Since the design science research process correspond to the meta-research approach of the thesis, the detailed application is of the design science research process to develop a decision support methodology for SCD is explained in Chapter 3, which introduces the research methodology.

Besides the classification of the thesis within design science research, contentswise the thesis at hand belongs to the scientific field of decision theory. Decision theory comprehends two different schools, the normative (or prescriptive) decision theory and the descriptive (or positive) decision theory (cf. Laux *et al.,* 2012).

- Normative decision theory is concerned with providing decision support for complex and difficult decisions. Hence, normative decision theory offers quantitative approaches for making better decisions with respect to underlying rational of the decision maker. Unlike other theory in business research, normative decision theory does not offer an explanatory approach for a problem but a systematic approach for tackling complex decision problems (cf. Eisenführ *et al.,* 2010). In Anglo-American countries normative decision theory is also known as decision analysis and is often categorized as a subdomain of operations research and management science (cf. Keefer *et al.,* 2004).
- Descriptive decision theory investigates decision processes and the role of decision makers within the process. This research stream postulates that decision makers are not fully rational and analyzes how systematic mistakes of decision makers influence the outcome of decision processes (cf. Kahneman, 2003).

The research goal of this thesis is to analyze a specific decision problem, the SCD-decision, and to apply an appropriate decision support methodology to the problem. Therefore, the thesis contributes to normative decision theory. Within normative decision theory a number of different decision problems are classifiable. The main characteristics of different decision problems are the number of goals the decision maker integrates in the decision problem, the number of alternatives, and whether the decision is subject to certainty or uncertainty in its outcome (cf. Eisenführ *et al.,* 2010). Some authors differentiate with respect to uncertainty between the terms risk and uncertainty in a narrow sense (cf. Laux *et al.,* 2012). Furthermore, decision problems are classifiable with respect to the number of the involved decision makers (cf. Wallenius *et al.,* 2008).

For the thesis at hand the most crucial distinction between different classes of decision problems is the number of goals integrated in the decision problem. The goals are also often referred to as attributes or criteria the decision problem considers (cf. Dyer *et al.,* 1992). Since decisions on SCD are of multiple criteria nature, the decision support methodology applicable to this problem belongs to the family of MCDM. Hence, the thesis contributes to decision theory, more specifically to normative decision theory and decision problems with multiple criteria. *Figure 2* illustrates the explanation above.

1.5 Structure of the thesis

For a better understanding of the contents of the research at hand, this section presents the structure of the thesis.

Chapter 1 introduces the managerial and the theoretical relevance as well as the research gap this thesis aims at. Both, managerial and theoretical relevance use the argumentation line that decisions on SCD are relevant, if SCD is a relevant research field for academia and business practice. Having attested the general relevance of the thesis, the research objective and research questions tackled by this thesis as well as the position in scientific theory are stated.

Chapter 2 clarifies the term "supply chain differentiation" and "decisions on supply chain differentiation" as understood in this thesis. Therefore, this chapter discusses SCD beyond the background of current general trends in SCM research and shows that these trends foster the development of differentiated SC strategies instead of standing opposed to SCD. Furthermore, Chapter 2 distinguishes between SCD and other forms of differentiation, especially with respect to single function differentiation approaches in companies. Thereafter, decisions on SCD are charac-

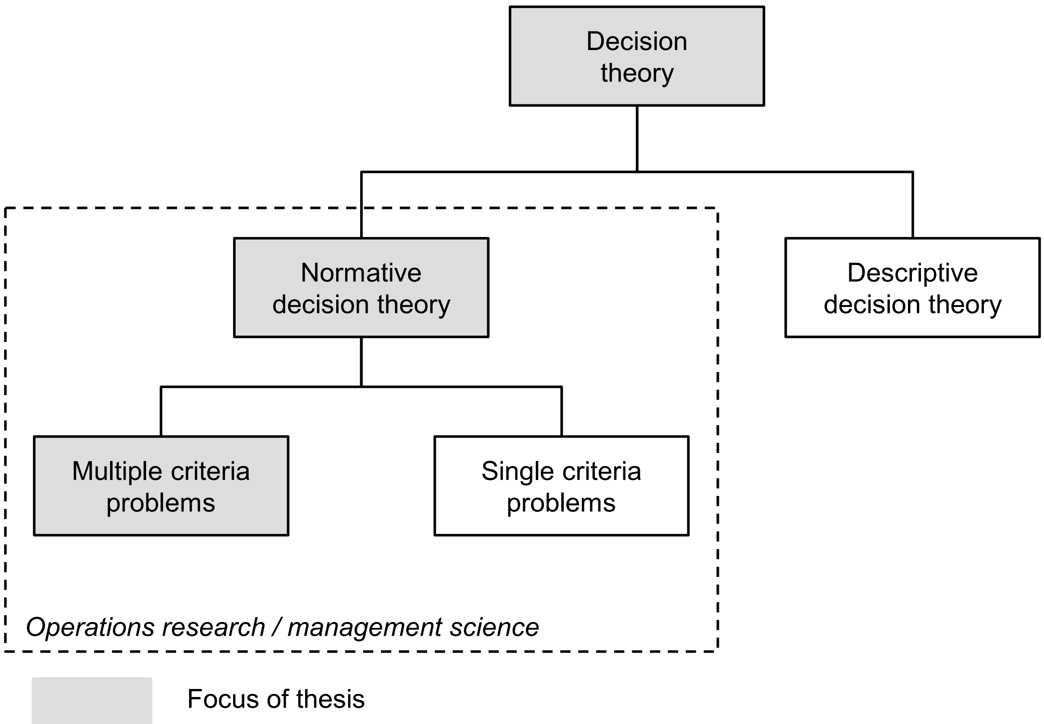

Figure 2: Position of the thesis in decision theory

terized by means of introducing different sub-decision areas within decision on SCD.

Chapter 3 states the research design of this thesis and the methodological principals of the multiple criteria decision support approach. Therefore, first the general research approach is stated. Then, the used research methods for tackling the single research sub-questions is discussed, i.e. empirical investigation of decisions on SCD and survey of available multiple criteria decision support in SCM. Additionally, the selection of the specific MCDM methodology for supporting decisions on SCD is stated and the method itself is explained.

Chapter 4 presents the key findings and the contribution of the thesis, structured according to the research phases of the thesis. The first section introduces a decision framework for decision on SCD. This decision framework encompasses relevant criteria and variables relevant to these decisions. Section 4.2 states the results of the literature review with respect to available MCMD methods in SCM. The last section in Chapter 4 states a decision model for SCD-decisions. This decision model integrates the framework from Section 4.1 and thereby all relevant variables and criteria for decision on SCD. The model is based on an analytic hierarch process (AHP).

Chapter 5 offers a conclusion of the thesis. It states the overall managerial as well as theoretical contribution of the thesis and discusses limitations and directions for future research.

In the appendix the detailed research findings are presented in form of three consecutive papers.

The structure of the thesis is illustrated in *Figure 3*.

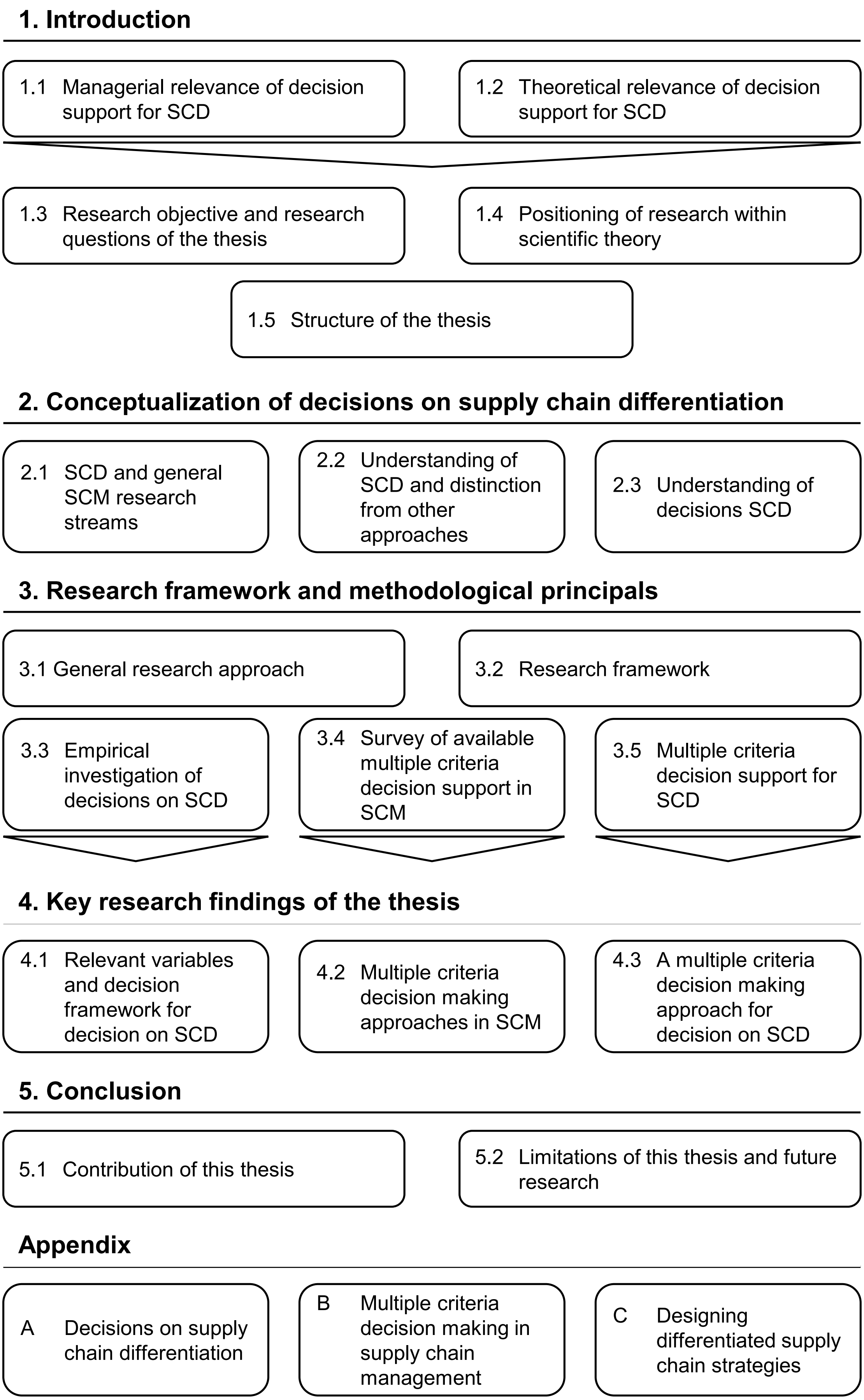

Figure 3: Structure of the thesis

2 Conceptualization of decisions on supply chain differentiation

SCD and decisions on SCD are a very complex research topics. Therefore, the research field covered by this thesis is constrained to a specific definition of SCD, which is stated in this chapter (Section 2.2). Before SCD is defined, Section 2.1 shows that SCD is consistent with other trends in SCM research. Furthermore, the general set-up and relevant decision areas within the SCD-decision are introduced.

2.1 Supply chain differentiation beyond the background of current trends in supply chain management research

In this section current challenges and trends in SCM integration are discussed and compared to what SCD offers. It is started by briefly stating the roots of SCD. Thereafter, the coherence of present challenges in SCM integration and SCD is presented. Multiple memberships in SCs, end-to-end SCs and the missing willingness of companies for integration in SCs will be discussed. A possible solution to these challenges in SCM integration is the so called decoupling of SCs, which will be introduced briefly.

SCM is concerned with two main performance goals, effectiveness and efficiency. While effectiveness means “doing the right things”, i.e. satisfying customers through suitable service levels, efficiency implies “doing things right”, i.e. having cost optimal operations (cf. Mentzer *et al.,* 2001). SCD stems from an increasing effectiveness focus in SCM. Research in SCM was traditionally rather efficiency focused than effectiveness oriented (cf. Ketchen *et al.,* 2008; Zokaei and Hines, 2007). Furthermore, the design of SCs was manufacturing centered and conducted downstream in the SC, from manufacturer to customer, instead of customer-oriented upstream SC design (cf. Aitken *et al.,* 2005). Lee (2004) postulates that a pure efficiency focus in SCM does not allow for building up long term competitive advantages. Yet, customer responsive SCM and thereby an effectiveness driven SCM approach deliver a sustainable source for competitive advantage (cf. Reichhart and Holweg, 2007). If a company serves different groups of customers with varying needs, a viable option to satisfy these customer groups effectively, is a differentiated SC strategy (cf. Godsell *et al.,* 2011).

In most cases, companies are rather member of several SCs than only one. Such a constellation is called multiple memberships in SCs (Bretzke, 2010; Stölzle and Bachmann, 2006). Christopher *et al.* (2009) state:

> *"In the twenty-first century business scenario, most organizations supply a range of products to multiple markets, so participate in several often quite different supply chains. Just as the linear chain is a simplification of a supply network, the single channel is a simplification of the true complexity many organizations face. When all products are pushed down a single channel, they are paced by the slowest and customers are charged an average price resulting in many being underserved. Manifestly, for most businesses "one size fits all" is not a viable option in delivery pipeline design and operation."*

Multiple memberships may lead to the challenge that companies have to satisfy varying customer needs and have to produce differing product variants. SCD may help in such cases, since it equips companies with an approach for managing several SCs concurrently and therefore with an opportunity to deal with varying customer needs and a large range of different products.

A controversial subject that drew a lot of attention in academia is end-to-end SCs. In this paradigm the whole SC (the whole network) is coordinated and planned as a quasi-company and therefore as one closed system. Such an approach requires a strong integration of all actors in the SC and a central unit for the steering of the SC, e.g. the focal firm. In recent years the perception of academics has grown that the end-to-end paradigm is unrealistic, since it is too complex and technically not implementable regarding the needed IT environment for a central coordination and planning of the whole SC (cf. Bretzke, 2002). Therefore, SC planning in a comprehensive process structure that considers the whole network is not regarded as a promising approach anymore (cf. Bretzke, 2010).

An issue closely related to the problem of end-to-end SCs is the missing willingness of companies for integration in SCs. A number of studies have investigated this barrier to a successful SCM implementation and identified that in most cases a lack of trust between the SC members lead to the unwillingness of the SC actors to share information (cf. Fawcett *et al.,* 2008).

A possible solution to the challenges of end-to-end SCs and the missing willingness of companies to integrate themselves in SCs is the decoupling of SCs (cf. Bretzke, 2010). In this approach all SC actors are regarded as autarchical independent systems, which are linked to each other and exchange information for the sake of coordination as well as planning. However, the integration of all SC partners for the composition of a quasi-company is omitted. Therefore, end-to-end SCs are not the final goal in decoupled SCs. The problem of missing willingness of companies for integration arises only for a few strategic partners, which should be integrated due to their importance to the network. The distinguished integration of SC partners is a constituting element of SCD, given that a basic assumption of SCD is that not all customers can be served efficiently and effectively by means of one SC (cf. Christopher and Towill, 2002). Based on this assumption Barratt (2004) proposes a segmentation of customers as well as suppliers and a distinction in the collaboration between the customer as well as supplier segments with respect to the importance of the customer and supplier segments to the corporate success. However, the end-to-end integration of all SC partners, indifferent to their importance, is not the goal of SCD.

SCD is therefore compatible with current challenges in SCM implementation, since it does not require and not propose the end-to-end integration of all SC partners. Furthermore, SCD incorporates the basic principle of decoupled SCs. Therefore, a conceptual relevance with respect to current challenges in SCM implementation is assumed.

2.2 Understanding of supply chain differentiation and distinction from other differentiation approaches

Before the conception of SCD of the thesis is defined, the understanding of SCM of this thesis is stated. Subsequently, decisions on SCD are characterized.

2.2.1 Understanding of supply chain management

There was a long dispute of academics in SCM with respect to a SCM definition. The first broadly accepted SCM definition originates from Mentzer *et al.* (2001). Shortly after this definition Gibson *et al.* (2005) introduced a similar SCM definition. Recently Stock and Boyer (2009) conducted a comprehensive literature review of former SCM definitions and defined SCM as:

> *“The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction.”*

The SCM understanding of this thesis adopts parts of the above stated SCM definition. SCM is comprehended as an inter-organizational approach by integrating customer requirements in the own SC design process and operational alignment of the companies value adding process as well as the operational alignment of suppliers. However, companies face SCD decision first on their own. It would be unrewarding to integrate customers and suppliers in this decision process. The integration of customers and supplier in the decision process would increase the complexity of SCD-decisions significantly, especially beyond the background of multiple memberships of companies in several SCs and therefore a high number of customers and suppliers with different opinions and strategies. In a narrow sense, the SCM perception of this dissertation is a “within the company understanding” or intra-organization SCM that integrates several functions in the company, particularly distribution, manufacturing and sourcing. The general goals of SCM, enhance efficiency and effectiveness (“achieving customer satisfaction” as stated by Stock and Boyer, 2009), are also primary objectives of SCD. *Figure 4* depicts the SCM understanding of this thesis.

2.2.2 Definition of supply chain differentiation

The operation of several SCs besides each other is very common in business practice. Diversified companies, which deliver several fundamental diverse products besides each other to different markets, are forced to have different SCs. For example, Siemens offers products for energy generation, like gas turbines or whole power plants, as well as consumer products, like cordless phones or washing machines. Yet, Siemens delivers these products to different markets. Bosch Powertools is only a single business unit of the whole Bosch company. However, they operate 13 SCs for delivering their various products to their markets. Furthermore, industrial companies often operate separate service SCs besides their main SCs for manufacturing their core products, and therefore have also several SCs besides each other. Computer manufacturer Lenovo operates a quite different designed service SC alongside their ordinary SC for manufacturing their products. The SCs are distinguished with respect to distribution. The ordinary SC operates a centralized distribution system, while the service SC is decentralized, each service employee holds stock of a certain amount of important spare parts. Yet, in the understanding of this thesis the operation of multiple SCs besides each other is unequal to SCD. Further constituting elements must be given for fulfilling the understanding of SCD of this thesis. *Figure 5* gives an illustrative example of multiple SCs besides each other, which is unequal to SCD.

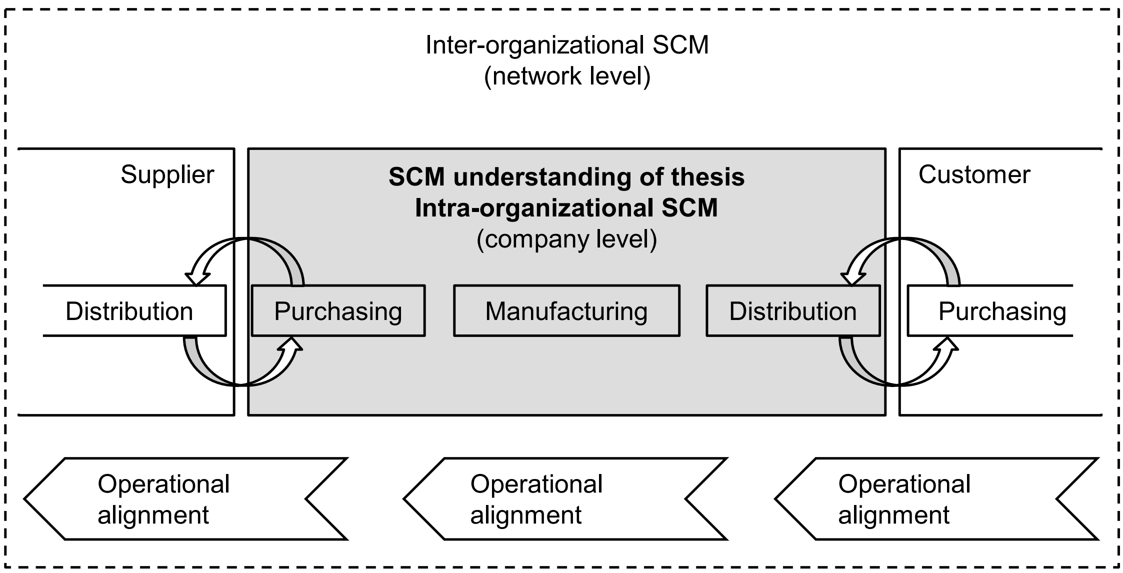

Figure 4: Supply chain management understanding of this thesis (Adapted from Beck *et al.*, 2012)

In what follows the SCD-definition, which is the basis for this thesis is stated and explained. A similar definition is found in Section B-4, including a brief integration of SCD in the strategic management context. Hilletofth (2009, p. 25) states a

> *"way to develop a differentiated SC strategy could be to combine different supply, manufacturing and distribution strategies into various SC solutions."*

The SCD-definition of this thesis includes Hilletofth's suggestion and expands it as follows (see also Appendix A):

> *Supply chain differentiation (i) is a strategic approach considering market structures and company resources and encompasses that (ii) one market is served with at least two supply chains, (iii) the supply chains are distinct with respect to the degree of customer interaction, (iv) the supply chains are standardized to a certain degree (a finite number of product variants is offered through the supply chains and pure engineer-to-order supply chains are excluded), (v) supply chain differentiation is cross-functional and – ideally – inter-organizational oriented while integrating at least functions in distribution and manufacturing, (vi) the objective of supply chain differentiation is to gain a competitive advantage through higher customer proximity and a diversified customer approach.*

SCD is a (i) strategic approach that considers market structures and company resources, since it is based on strategic management. Ever since Porter (1980) introduced the generic strategies cost leadership and differentiation, companies sought for opportunities to differentiate themselves from their competitors. First, products and services were possible subjects of differentiation. When products and services did no longer offer opportunities for differentiation, companies moved further and started to differentiate single functions, e.g. in logistics (especially in distribution) and in manufacturing.

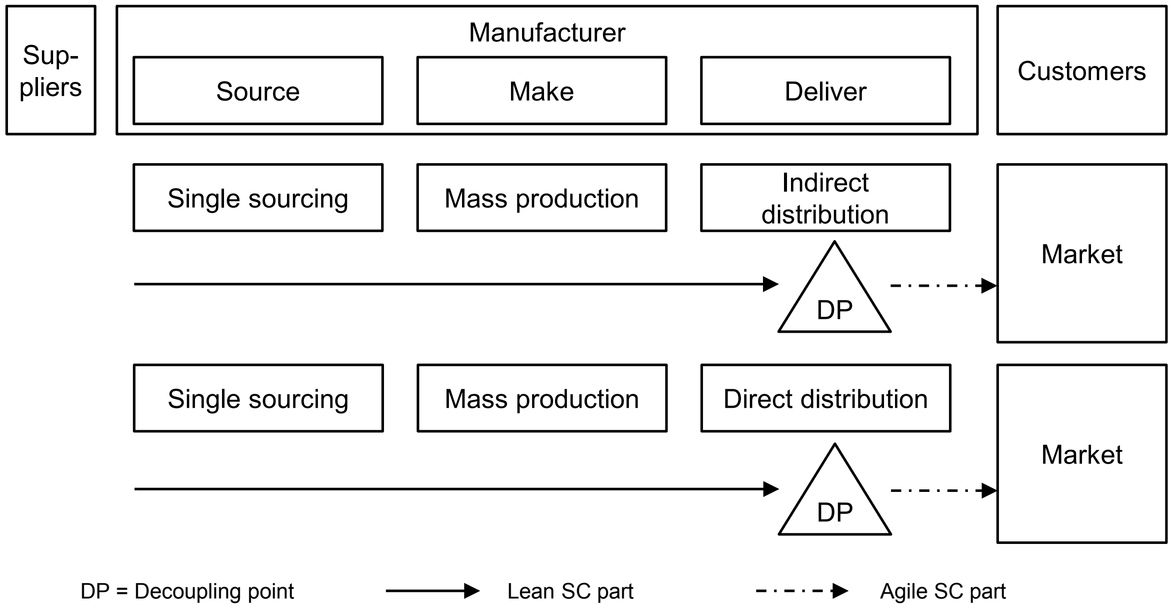

Figure 5: Illustrative example of multiple supply chains

The features that (ii) one market is served with at least two SCs and (iii) the supply chains are distinct with respect to the degree of customer interaction stem from the earlier introduced fact, that many companies operate several SCs without a differentiated approach to these SCs. Markets are definable with respect to different dimensions. Curran and Goodfellow (1990) state four dimensions for distinguishing makets: products (e.g. mobile phones market), needs (e.g. communication market), geographical (e.g. the European market), and demographic (e.g. customers within the age of 18 to 35). Wagner and Baldauf (2007) add a further dimension, the time distinction of markets, which refers to alterations of market definitions, e.g. boarders between countries that are removed lead to a new geographic market definition. For the purpose of this thesis especially the dimensions need and product are substantial for the definition of SCD. If the SCD-definition states one market is served by at least two SCs, it refers to the fact the SCs serve a similar basic need of the customers and the manufactured products do not deviate highly. E.g. Dell produces different kinds of notebooks within its several SCs, however these products are still notebooks and fulfill the need of mobile computing for customers. Hence, one market is served with several SCs. For a more detailed explanation of the issue varying degrees of customer interaction the terms push and pull SC are introduced. In push SC the manufacturing of products is based on forecasts and anticipates customer orders. In a pull SC the manufacturing of products is conducted after the customer orders these products (cf. Chopra and Meindl, 2007). If a company operates 13 push SCs, it manages all its SCs in the same way. All SCs are coordinated with respect to forecasts, the products are manufactured and stored until the customer orders these products. Hence, the company has a "one size fits all" approach for managing its 13 SCs. The company does need a certain set of capabilities for managing these 13 SC, but these capabilities are the same for all 13 SCs. Therefore, it does not differentiate its SCs from each other. Now, if the company handles some of its SCs as push and other SCs as pull SC, it operates varying kinds of SCs. The company therefore would differentiate its SCs in push and pull SCs. Furthermore, the company would need another skill set to manage its pull SCs besides its push SCs. Push and pull SCs require different degrees of customer interaction. While in a push SC the customer orders most likely a standard product which is delivered to him from stock, in a pull SC the customer has some influence on product characteristics, which the customer may modify prior to production. Hence, the SCs have varying degrees of customer interaction.

At this point the issue of serving one market with several SCs is reintroduced to complete the argument. If a company operates several push and several pull SCs but serves differing markets with this SC (like the above introduced example of Siemens) the company does not differentiate its SCs with respect to differing customer needs in one market. Therefore, in the understanding of this thesis, the company would not differentiate its SC. This constraint aims at focusing the phenomenon this thesis investigates.

Issue (iv) of the SCD-definition above states that SCD is cross-functional and – ideally – inter-organizational oriented while integrating at least functions in distribution and manufacturing. Since such differentiation approaches in single functions are well known and rather classical than modern differentiation approaches, SCD must be distinguished from these approaches. SCD is an integrated differentiation approach and incorporates single function approaches, at least in the area of distribution and manufacturing. Yet, a single function differentiation, like customer service level differentiation, is disparate from SCD. The distinction of single function differentiation approaches and SCD is stated in detail in Subsection 2.2.3. Furthermore, SCD is based on the assumption that there are different customer groups with distinct needs within one market, which would be served best by means of not one but several SCs. Various SCs may be combined with distinguished levels of customer integration in the different SCs. Additionally, a translation of the different requirements of the SCs with respect to the purchasing function is also possible. Thereby suppliers may be integrated variably in the different SCs. Hence, the approach may be inter-organizational.

Issue number (v) the supply chains are standardized to a certain degree refers to the exclusion of pure engineer-to-order SCs. Every craftsman and almost every industry company fulfills engineer-to-order assignments. In these cases, wholly new products are created that did not belong to the earlier product range of the company. In the mass customization literature this restriction is called a finite number of product variants is offered, which means there are a high number of different product variants. Yet, these product variants stem from a modular structure of these products and the products are not constantly new designed. Again, this constraint strengthens the focus of this thesis on a certain phenomenon.

The last issue in the SCD-definition, (vi) the objective of supply chain differentiation is to gain a competitive advantage through higher customer proximity and a diversified customer approach, completes the SCD definition. Like earlier differentiation approaches in business research, the goal of SCD is to offer a competitive advantage for companies. This competitive advantage is gained through a differentiated customer approach that considers varying customer needs and requirements within one market. *Figure 6* gives a declaring example of a differentiated SC according to the SCD-definition in this subsection.

2.2.3 Distinction of supply chain differentiation from other differentiation approaches

In the following several single function differentiation approaches are discussed and distinguished from SCD. Furthermore, it is briefly presented how these single function approaches may be integrated in SCD. Customer service level differentiation, multi-channel distribution, postponement, mass customization and purchasing portfolios are single function differentiation approaches considered in this subsection. Each of these single function differentiation approaches will be explained briefly. After that the single function differentiation approach is distinguished from SCD and a possible integration in SCD is shortly discussed. Note, the distinction of the

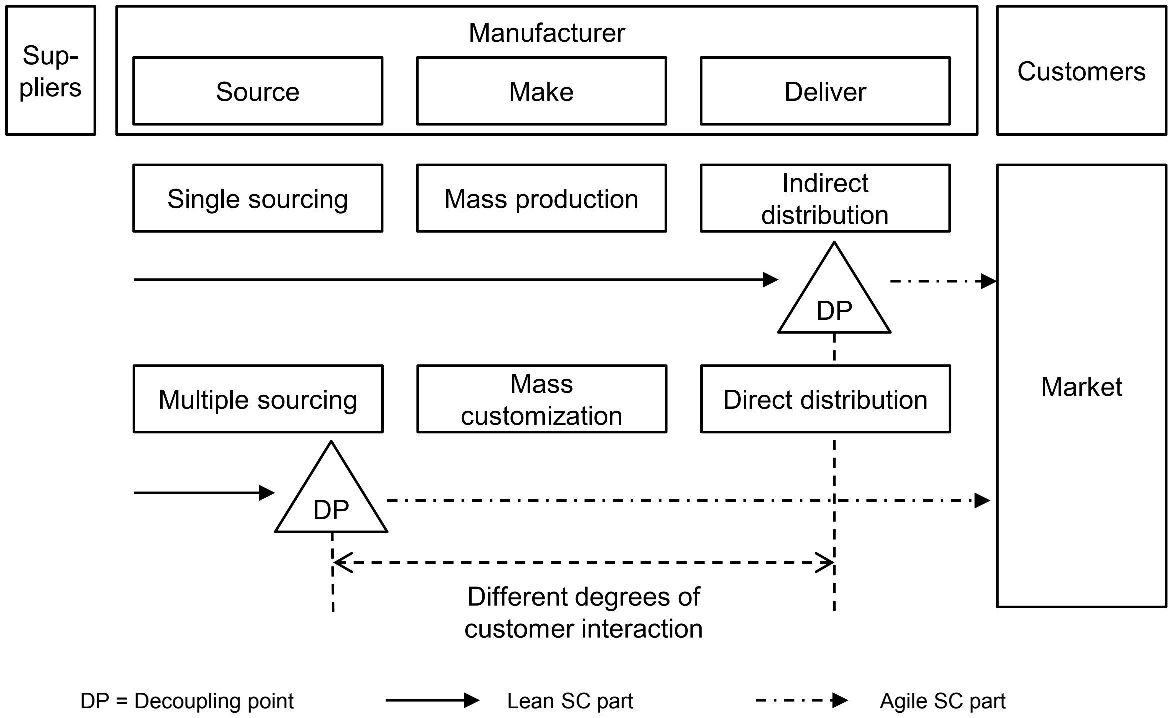

Figure 6: Illustrative example of differentiated supply chains

single function differentiation approaches from SCD is conducted by discussing the main violation of the SCD-definition stated in Subsection 2.2.2. The end of this subsection presents an overview regarding the fulfilled and the violated properties of the SCD-definition of each single function differentiation approach.

Customer service level differentiation

A concept in logistics is the differentiation of customer service levels. This concept differentiates customer service level according to the profitability of the customer segments (cf. Grant *et al.,* 2006). The concept is based on the decreasing marginal utility of logistics service levels, which means that the costs of raising the customer service level increases overproportional (cf. Pfohl, 2004). Customer service level differentiation in logistics is a classical approach and dates back to the 1970s (Grant *et al.,* 2006). Yet, it is still a very widely implemented approach in business practice. Actually, the contribution Fuller *et al.* (1993) on tailored logistics and customer service level differentiation was a basis for early contributions on SCD (cf. Childerhouse *et al.,* 2002). However, customer service level differentiation in logistics is a single function approach, which is restricted to operations in distribution. It does not mandatorily influence further functions like manufacturing, i.e. in case of a push SC (e.g. consumer goods) the goods are manufactured and stored until a customer order arrives. If there are competing customer orders, the orders are prioritized with respect to the importance of the customer. The higher prioritized customer's order is processed first. The manufacturing function stays untouched by customer service level differentiation. Therefore, it is unequal to SCD, but it may be part of SCD. When Adidas differentiated its SC, they introduced a pull SC besides their push SC for their standard products. While Adidas has a high service level for their standard products, which are delivered to their channel partners (like Intersport or Sportscheck), their customized products that are manufactured in a pull SC are only offered with the promise of delivery within 21 days after order placement (cf. Berger and Piller, 2003). In this manner a service level differentiation may be integrated in SCD.

Multi-channel distribution

A further differentiation approach within distribution is multi-channel distribution. While single channel distribution systems were predominant in business practice, multi-channel distribution systems have been growing in importance in recent years (cf. Kabadayi, 2011). Especially the emerge and broad usage of the internet has led a high number of firms to apply a multi-channel distribution systems (cf. Sharma and Mehrotra, 2007). Multi-channel distribution systems aim at delivering basically the same product line to the same market by means of different channels (cf. Wallace *et al.,* 2009). Generally, indirect and direct channels are distinguished. While indirect channels deliver the products through third parties to the consumer or user, like wholesalers and retailers, direct channels deliver the product to the consumer or user without any other participating partners (except for logistics service providers). Therefore, manufacturer of the good and the consumer or user of the good have to get in direct contact for the transaction. Yet, multi-channel distribution systems are a differentiated approach for a single function, the distribution function. For example, a retailer like Tchibo uses different distribution channels, like their two direct channels, their own stores and their online shop, besides their indirect distribution through other retail stores (e.g. Real or Kaufland). Naturally, these three channels have different requirements regarding distribution logistics, i.e. delivery, storage, service level or logistics service provider. However, the differing requirements are restricted to outbound logistics (distribution area) from the perspective of Tchibo.

The manufacturing and sourcing area are hardly influenced by the varying requirements of the three different distribution channels. On the other side there are examples for SCD in which the companies introduced a multi-channel distribution system as integral part of a differentiated SC design. In the already mentioned instance of Adidas, the company introduced a direct channel for their customer specific manufactured products besides their indirect channel for their standard products. The same is true for Nike and Oakley, who also implemented a direct channel for mass customized products alongside an indirect channel for standard products. Hence, multi-channel distribution may be a part of SCD, yet a company that uses multi-channel distribution does not imperatively have a differentiated SC.

Postponement

The concept of postponement is a differentiation approach that may influence manufacturing as well as distribution of a company. Hence, this differentiation approach can influence two functions within a company. Bucklin (1965) is one of the first authors contributing to this research area. Two main types of postponement are distinguishable, manufacturing and logistics postponement (also referred to as geographic postponement). With reference to other authors, Pagh and Cooper (1998) define these types of postponement as follows:

> *"The notion of manufacturing postponement is to retain the product in a neutral and noncommitted status as long as possible in the manufacturing process. This means to postpone differentiation of form and identity to the latest possible point. The notion of logistics postponement is to maintain a full-line of anticipatory inventory at one or a few strategic locations. This means to postpone changes in inventory location downstream in the supply chain to the latest possible point."*

The opposite of postponement is speculation, in which products are differentiated and distributed according to forecasts. Speculation accepts the risk of wrong forecasts for the advantage of economies of scale. Zinn and Bowersox (1988) state four types of manufacturing postponement: labeling, packaging, assembly and manufacturing. If one of these manufacturing postponement strategies is combined with logistics postponement a fifth postponement type emerges according to their remarks. Pagh and Cooper (1998) combine manufacturing and logistics postponement in a so called postponement/speculation matrix that yields four strategies: the full speculation strategy, the logistics postponement strategy, the manufacturing postponement strategy, and the full postponement strategy. The delimitation of postponement and SCD is not trivial. One criterion of SCD, at least manufacturing and distribution must be integrated, is fulfilled with a full postponement strategy. Yet, Postponement does not claim that a market must be served with at least two SCs and the basic concept of postponement provides that the approach is implemented for all products in the same way. An example of postponement was Hewlett Packard and its printer unit in earlier days. They utilized a full postponement strategy and manufactured their base units in Asia. They delivered their printers to Europe. The printers were not differentiated for the markets in different countries with respect to labeling and power adapter. When Hewlett Packard had enough information about the realization of demand, they differentiated their printers for the country markets. However, this was their standard proceeding for all products. Therefore, the criterion “serve one market with at least two SCs” is not given. Furthermore, different degrees of customer interaction are not considered in a standard postponement approach. Admittedly, postponement is very close to SCD. I.e. if a full postponement strategy would be operated besides a full speculation strategy and these two SCs would be used for the same market that would be most certainly a differentiated SC approach according to the definition stated in Subsection 2.2.2.

Mass customization

Mass customization is a single function differentiation approach that affects the manufacturing area. The fundamental idea of the concept is to build customer specific products in large quantities using almost the same efficiency as a mass production approach. A pioneer in the area of mass customization is Pine (e.g. Pine, 1992) in the Anglo-American countries. In German speaking countries especially Piller (e.g. Piller and Kumar, 2006) is a well-known author with respect to mass customization. Piller (2006) distinguishes two types of customization: soft and hard customization. Soft customization or open individualization does not provide an individual product. The manufacturer fabricates a low number of overall product variants. However, the products have an implemented opportunity for customization, which the customer himself or a retailer may use to customize the product. Hard customization or closed individualization provides customized products through positioning the point of individualization directly in the manufacturing process. Hence, the producing company offers a large number of differing product variants and the customer receives a fully customized product or service. In recent years mass customization approaches are increasingly investigated as integral part of SCs (cf. Liu and Deitz, 2011). Mass customization approaches often occur jointly with SCD. However, mass customization is unequal to SCD. The basic concept of mass customization does not require to serve a market with at least two SCs incorporating different degrees of customer interaction. Furthermore, the area of distribution is not mandatorily integral part of a mass customization approach. An example is the former business model of Dell. Before 2006 Dell operated only a mass customization and a direct distribution business model. Yet, Dell only operated one SC. In the years 2007 and 2008 Dell implemented a differentiated SC that incorporates mass customization of some of their products, while other standard products are manufactured according to forecasts and are stored until a customer order arrives. Hence, mass customization is a single function differentiation approach that occurs in “one size fits all” SCs as well as in differentiated SCs.

Purchasing portfolios

A prominent single function differentiation approach in the area of sourcing are purchasing portfolios. Like customer service level differentiation categorizes customer groups according to their importance to the company and sets a suitable service level for each customer group, purchasing portfolios follow the basic principle to classify suppliers or the items they deliver. Kraljic (1983) is one of the first contributions on purchasing portfolios. He proposes to distinguish purchased items in four groups, non-critical items, leverage items, bottleneck items and strategic items. The categorization of the items is conducted according to importance of the item to the end-product of a manufacturer and the supply risk incurred by the item. Additionally, he suggests generic sourcing strategies for each item group. The concept of purchasing portfolios was investigated and further developed by a number of authors (e.g. Gelderman and van Weele, 2005; Lee and Drake, 2010). Purchasing portfolios are the basis for the so called approach of category management different category purchasing strategies. While purchasing portfolios represent a convenient method to handle supply risks and the different nature of purchased items, these portfolios are strictly limited to the area of sourcing. The models result in implementing different sourcing strategies for various item categories, like global vs. local sourcing or single vs. dual- and multi-sourcing. Normally, companies implement these different sourcing strategies for gaining more efficiency in other functions, like manufacturing or inbound logistics. Yet, the fundamental idea of purchasing portfolios does not include incorporating another function. Purchasing portfolios do not integrate the basic idea of SCD to serve a market with several SCs, which are differentiated in their degree of customer interaction. Hence, purchasing portfolios are a single function differentiation approach that is unequal to SCD. Due to the separation of purchasing portfolios from other functions, this approach is easily implementable in SCD.

Table 1 represents a summary of the distinction between SCD and single function differentiation approaches considered in this subsection.

Table 1: Distinction of single function differentiation approaches from supply chain differentiation

Properties of SCD	Distribution area		Manufacturing area		Sourcing area
	Customer service level	Multi-channel distribution	Postponement	Mass customization	Purchasing portfolios
(i) strategic approach	X	X	X	X	X
(ii) one market served by two SCs	(X)	(X)	(X)	(X)	
(iii) SCs are distinct with respect to customer interaction	(X)	(X)	(X)	(X)	
(iv) the supply chains are standardized to a certain degree	(X)	(X)	(X)	X	
(v) cross-functional approach			(X)		
(vi) competitive advantage through higher customer proximity and a diversified customer approach	X	X	(X)	X	

X = Fulfilled; (X) = Conditionally fulfilled

2.3 Understanding of decisions on supply chain differentiation and related decision areas

This section presents a distinction of decisions on SCD from other decisions within SCM. Firstly, SCD-decisions are classified with respect to hierarchy of decisions in SCM. Secondly, SCD-decision areas and related decision areas are distinguished.

The hierarchical structure of decisions in SCM focuses on the timeframe for decisions. Chopra and Meindl (2007) classify decisions in SC strategy or design, SC planning and SC operation. While SC strategy and design decisions have a long-term timeframe, e.g. several years, SC planning and operation decisions are medium to short termed. Decisions on SCD largely influence the structure and configuration of a SC and belong therefore within the area of SC strategy and design decisions, as presented in *Figure 7*. The remainder of this section further distinguishes strategic decisions in SCM.

In the early stage of the development of this thesis a long-term research project was conducted. Four companies from the machinery and plant building industry as well as a manufacturer of dairy products in Switzerland participated in this research project. The goal of the research project was to investigate SCD in an explorative and descriptive manner as well as to understand SCD in its entirety. Therefore, the project analyzed by means of five case studies, which decision areas within SCM are affected by SCD. The core results and empirical findings of this research project are presented in the article Beck *et al.* (2012). The following statements are based on this article. Hence, the hereafter expounded remarks of decisions on SCD and related decision areas are grounded on empirical research.

Figure 8 illustrates the SCD-decision and related decision areas. Like SCM, SCD may be distinguished in intra-organizational and inter-organizational SCD. Intra-organizational SCD encompasses the research topic of this thesis, SCD-decisions. Decisions on SCD start with an analysis of customer requirements as well as product and demand characteristics. Then the company has to assess whether its “one size fits all” SC design effectively covers the needs arising from customer requirements or product and demand characteristics. The first component of such an assessment is the required SC strategy. The question arises, whether a lean, a leagile or an agile SC strategy is suited to satisfy customers (cf. Mason-Jones *et al.,* 2000b). If the answer to this question is that at least two different SC strategies are

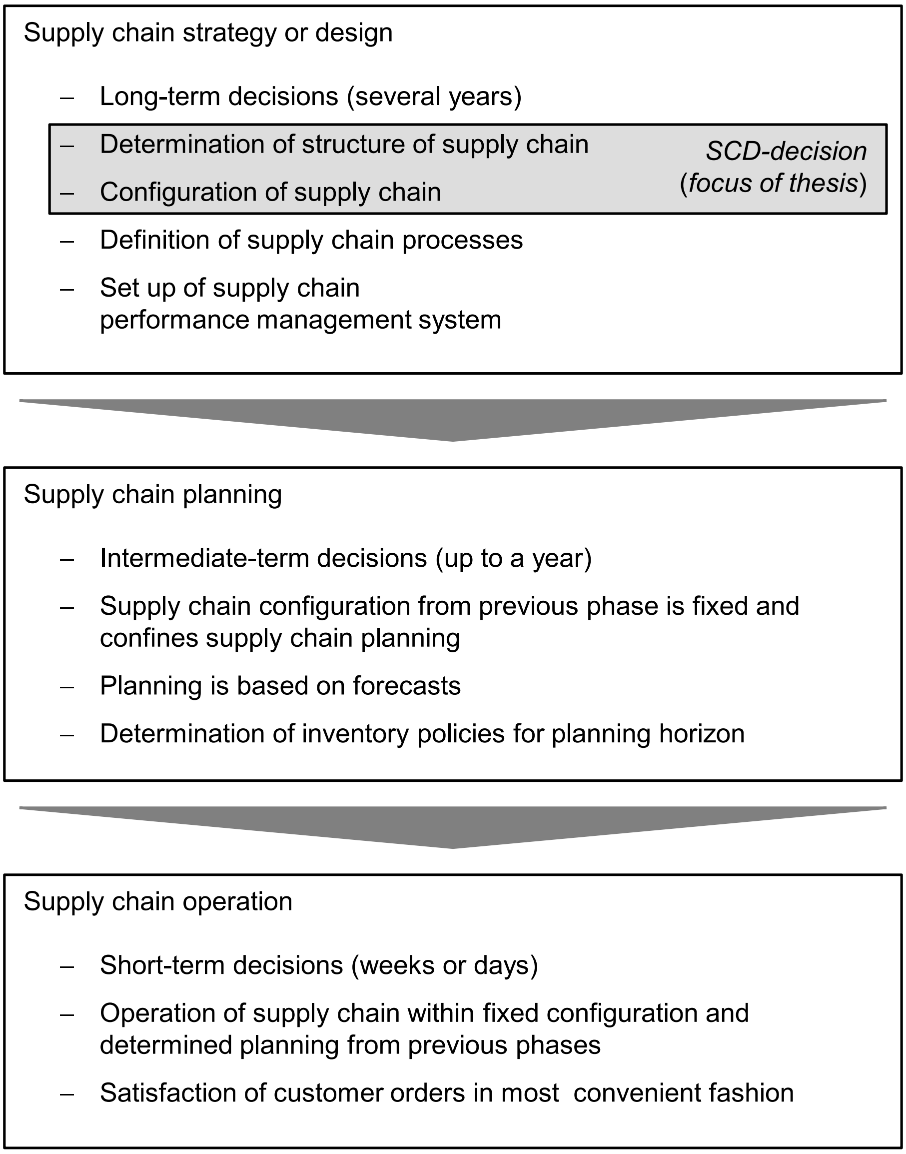

Figure 7: Hierarchical structure of decisions in supply chain management (based on Chopra and Meindl, 2007)

needed to satisfy customers, a differentiated SC design is a suitable option. Thereby the issue of how many SCs a company needs is addressed. The illustrative example in *Figure 8* shows two differentiated SCs. While on the first level appropriate SC strategies have to be selected, the second level incorporates the choice of aligned strategies for the functions distribution, manufacturing and sourcing. The decision area distribution encompasses, for example, the selection of suitable distribution channels. A lean SC strategy rather suggests indirect distribution for the realization of economies of scales (cf. Chopra, 2003). An agile SC strategy indicates that a direct distribution is the favorable choice for ensuring the needed flexibility (cf. Chopra, 2003). In the decision area manufacturing strategy, it is selected whether a push or a pull production approach should be adopted. This issue is sometimes also referred to as SC type. Examples for viable options in this area are make-to-stock (push SC) in case of a lean SC strategy, assemble-to-order (hybrid or push/pull SC) for leagile SC strategies or make-to-order (pull SC) for agile SC strategies (cf. Olhager, 2010). A sub-decision directly connected with the chosen manufacturing strategy or SC type, is the position of decoupling points (cf. Olhager, 2003). As emerged from the SCD-definition in Subsection 2.2.2, the purchasing function is no mandatory element of a differentiated SC design. However, differentiated purchasing strategies are easy implementable in SCD. For example, for lean SC strategies, approaches like global sourcing, especially in Asia, are appropriate options to realize cost efficient purchasing. In agile SCs local sourcing is more convenient for a higher flexibility.

Besides the SCD-decision, further decision areas affected by SCD are relevant. For instance, differentiated SC processes and a differentiated SC performance management are part of intra-organizational SCD. The SC processes have to be aligned with the SC strategy. A lean SC strategy demands other process structures than an agile SC strategy (cf. Stavrulaki and Davis, 2010). Hence, a differentiated SC design, incorporating several SC strategies calls for differentiated SC processes. Like the SC processes, the SC performance management must be matched to the SC strategy (cf. Agarwal *et al.,* 2006). Therefore, it is most probable that in case of a differentiated SC design, a differentiated SC performance management has to be implemented.

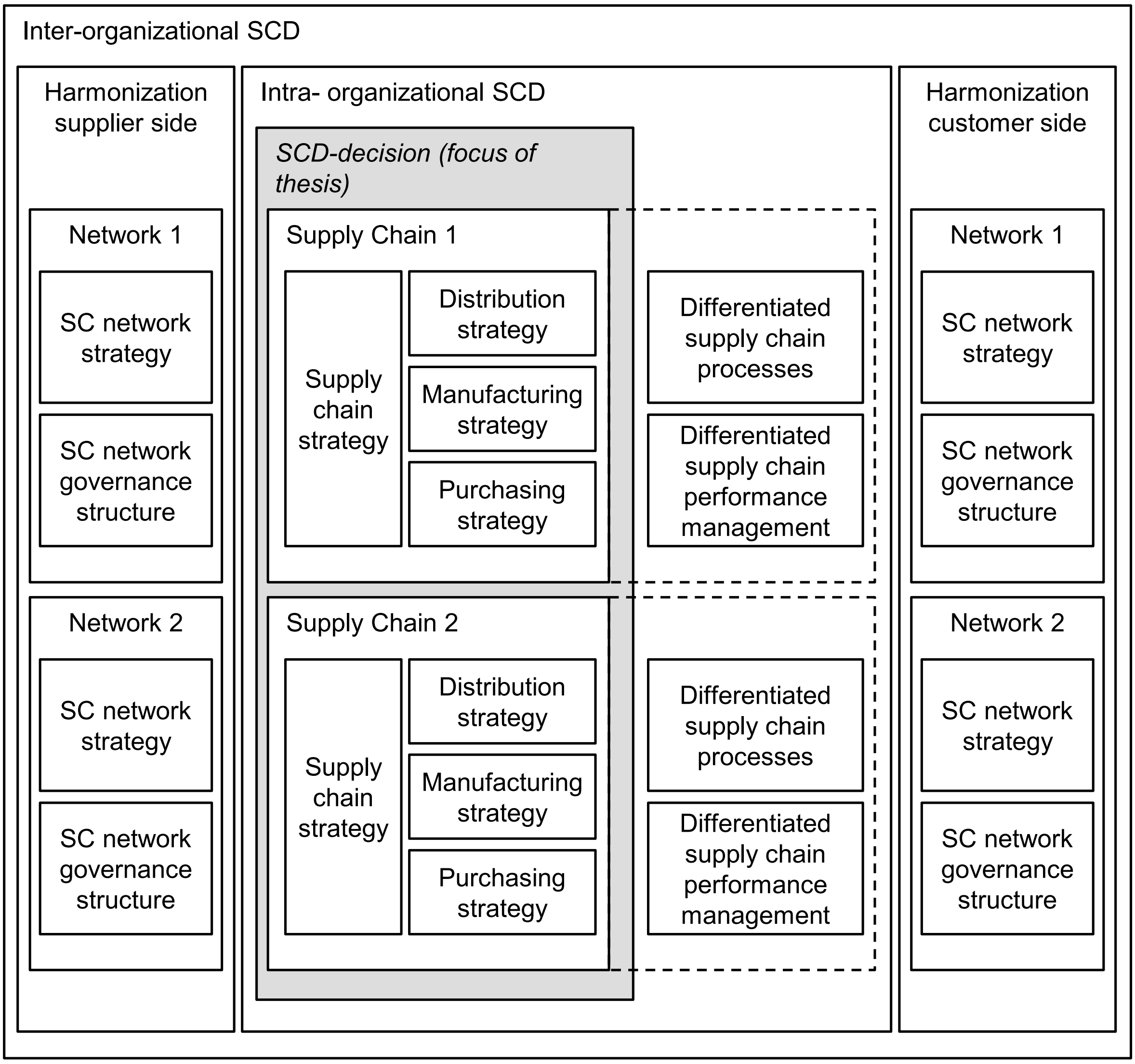

Figure 8: Supply chain differentiation decision and related decision areas

As stated in Subsection 2.2.1, companies should consider SCD-decisions from an intra-organizational perspective. Naturally, the objective of SCD is the increase SCM effectiveness, therefore, customer needs and requirements are crucial for SCD-decisions and should be analyzed for example through customer surveys. Yet, an integration of customers in the actual decision process would lead to an enormous increase in complexity of the decision. The same is true for suppliers. However, after a decision has been taken by a company, an alignment of the differentiated SC strategy and design with customers and suppliers should be conducted in an inter-organizational context. Inter-organizational SCD is concerned with the harmonization of the SC network strategy and the SC network governance structure. As stated in Section 2.1, companies are normally members in multiple SCs. *Figure 8*, for instance, shows two networks. The harmonization of SC network strategy is not a simple task, since each company within the network has its own perception of an appropriate SC strategy. While the focal firm of a network in most cases determines the SC network strategy through its intra-company SC strategy, non-focal firms have to consider their position and strategic orientation in several networks (cf. Hofmann, 2010). The SC network governance structure describes how the network is coordinated, i.e. by which mechanisms, like price, trust, or instruction (cf. Gereffi *et al.,* 2005). The governance structure encompasses the relationships as well as degree of information sharing with customers and suppliers. Strong relationships should only be implemented to customers and suppliers that are crucial to the success of a company and a network (cf. Barratt, 2004). The degree of information sharing as well as investments in information and communication technology between different SC partners should be aligned with the relationship between the partners.

Table 2 summarizes the SCD and related decision areas and gives some examples for decisions within these areas.

Table 2: Description of relevant decision areas for SCD-decision and related decision areas (Adapted from Beck *et al.*, 2012)

		Decision Area	Selected issues	Selected action alternatives
Intra-organiza-tional SCD	SCD-decision	Selection of a differ-entiated supply chain strategy on company level	- Which SC strategies have to be adopted to satisfy cus-tomers? - Which competitive priorities are the market winners, which are the market qualifiers?	- Generic supply chain strategies like lean, agile and leagile strategies may be adopted for each customer segment - A ranking of the competitive priorities (lead time, quali-ty, price, flexibility) expresses which focus is set by the company for satisfying customers
		Selection of distribution strategy	- Which distribution strategies should be adopted per customer segment? - How many and which distribution channels should be integrated? - Which delivery services should be offered to customers? - Which logistics concepts should offered to customers (Kanban, Just-in-time, Just-in-sequence)?	- The distribution may differ with respect to the incorpo-rated logistics service providers - For some companies an own delivery fleet may be an option - If a higher integration in the manufacturing process of a customer is demanded, concepts like Just-in-time and Just-in-sequence may be adopted
		Selection of manufacturing strategy	- Which manufacturing strategies should be adopted? - Which SC types are most favourable? - Where should the decoupling point be located?	- The upstream or downstream location of the decoupling point offer higher flexibility or leanness in the value adding process - According to the supply chain strategy, lean or agile strategies may be adopted in the manufacturing area
		Selection of sourcing strategy	- Where should be sourced? - Is single or multiple sourcing more appropriate? - Which inbound logistics concepts might be adopted (Kanban, Just-in-time, Just-in-sequence)?	- Global or regional sourcing are possible options regard-ing regional aspects of sourcing - With respect to the number of suppliers single, dual or multiple sourcing may be adopted - High level of supplier integration is possible through concepts like Just-in-time and Just-in-sequence or other concepts

Table 2 continued

	Decision Area	Selected issues	Selected action alternatives
Intra-organiza-tional SCD	Selection of appropriate differentiated supply chain processes	- Which process architecture is necessary to implement the differentiated supply chain strategy? - Which process types (in terms of the SCOR-Model) have to be implemented in the deliver, make and source area?	- Setup of an adequate process structure that suits the differentiated supply chain - Selection of different process types in the areas deliver (deliver stocked product, deliver make-to-order product etc.), make and source
	Selection of appropriate differentiated supply chain performance management	- How might a supply chain performance management system be configured that is suitable for controlling the differentiated supply chain? - Which KPIs are appropriate for managing the performance of the differentiated supply chains?	- Different key performance indicators are selected. which are aligned to the strategy in the possibly various supply chains - According to the competitive priorities in each supply chain, the performance management system is designed
Inter-organiza-tional SCD	Supply chain strategy on network level (harmonization)	- Which supply chain strategy is appropriate for which group of supply chain partners on the network level? - How might the supply chain strategy on network level be harmonized?	- For each supply chain an adequate supply chain strategy on network level (lean, agile, leagile) is selected in consensus with supply chain partners - For harmonizing the supply chain strategy on network level and for guaranteeing long term relationships, supply chain steering boards may be introduced
	Supply chain governance customer and supplier side	- Which supply chain governance structures are adequate between the different supply chain partners or groups of supply chain partners? - Which steering mechanisms (price, trust, instruction) are necessary and adequate for the network?	- Governance and steering mechanism (price, trust, instruction) is selected per supply chain and per customer or supplier group - Based on governance structure relationship management between supply chain partners is designed

3 Research framework and methodological principals

3.1 General research approach

As stated in section 1.4, this thesis adopts the design science research process and contributes to normative decision theory, which is a subdomain of operations research. In this subsection the general research approach for the development of a decision model for SCD is presented. The research approach in operations research is quite similar to the research approach in design science research. In what follows, the research approach in operations research is briefly introduced. Afterwards it is explained why the design science research process is more convenient for the purpose of this thesis and the application of the design science research approach is illustrated.

The operations research approach according to Hillier and Lieberman (2008), which is very similar to the approach described by other authors in this research area (see for example Eisenführ *et al.,* 2010; Winston, 2003), integrates six steps for the development of a decision model. (i) *Define the problem and gather data*: Most decision problems that require a decision support methodology for gaining a suitable solution are rather complex in nature. Therefore, the underlying problem has to be studied. Relevant information on the problem must be gathered and objectives, constraints and influencing factors must be defined and investigated. (ii) *Formulate a mathematical model*: A suitable approach to the problem must be formulated. Since there are various kinds of different decision problems, an appropriate method for the studied problem must be identified and adjusted to the considered decision problem. (iii) *Deriving solutions from the model*: In this step, the formulated mathematical model is implemented in a procedure for solving the problem. Normally, these procedures are computer based. By means of the computer based procedure, first solutions to the problem are generated. (iv) *Testing the model*: As common in large IT projects, the first version of the designed program contains often a number of errors. This is the same in constructing large mathematical models. Hence, the model must be tested and refined for functioning properly. (v) *Prepare to apply the model*: The content of this step depends on, whether the decision support methodology is used frequently or only irregular. In the case of a frequent use, the model and all needed databases and IT infrastructure must be prepared for an implementation in the IT system of the company that wants to apply the model. If the model is only used irregularly it must be only well documented, how the application works. (vi) *Implement*: This step only applies for frequently used decision support methodologies, since these models are implemented in the IT infrastructure of the company.

The general research approach in design science research is much more suited for the purposes of this thesis, since it is stronger related to applied science in the field of operations management. Naturally, operations research is also concerned with decision problems in operations management and SCM. However, the general research approach of operations research is strongly geared towards mathematical models. It would be also applicable to the objective of this thesis. Yet, the decision support methodology this thesis tries to develop is rather qualitative in nature than hard mathematical. Therefore, the general research approach in design science research is selected for this thesis. In the following, the general research approach of this thesis is stated, according to the design science research process.

(1) *Problem identification and motivation*: Within the in Section 2.3 already mentioned long-term research project, the need for decision support for decisions on SCD was identified. While the case companies within the research project mostly applied SCD, none systematic approach for deciding to do so was identified. Together with the statements in Section 1.1, this represents the managerial relevance for support of decisions on SCD. The demonstration of theoretical relevance of decision support for SCD is stated in Section 1.2. Additionally, Section 4.2 (survey of MCDM applications in SCM) will further support the relevance for decision support with respect to SCD.

(2) *Objectives of a solution*: This step states the general purpose of the artifact created by design science research. The research objective and the objective of decision support methodology for SCD are stated in Section 1.3.

(3) *Design and development*: The design phase incorporates the main research activities of this thesis. First, decisions on SCD are empirically investigated, and relevant criteria and variables for taking these decisions as well as design implications arising from these criteria and variables are investigated (Section 3.3, Section 4.1 and Appendix A). One main result of this research phase is that decisions on SCD are of multiple criteria nature. Additionally, already

existing decision support for multiple criteria decision problems in SCM are surveyed (Section 3.4, Section 4.2 and Appendix B). The actual design of a decision support methodology takes place in Section 3.5 (Section 4.2 and Appendix C).

(4) *Demonstration*: The suitability of the designed SCD-decision support methodology is demonstrated by means of an application of the methodology to an illustrative example (Appendix C).

(5) *Evaluation*: The illustrative example in the phase demonstration is also used to evaluate the solution by means of a scenario analysis (Appendix C).

(6) *Communication*: The communication of the research findings takes place by publishing results in academic journals and by means of this thesis.

Note, even if the general research approach of design science research is more suited for the purposes of this thesis, the thesis still contributes and is related to operations research. Therefore, similarities to as well as terminology in operations research are still relevant and will be stated in the course of this thesis.

3.2 Research framework

Research frameworks support academics in structuring, organizing and understanding complex research problems as well as cause- and effect-relationships in these problems (cf. Wolf, 2011). Yet, research frameworks also aim at clearly communicating research activities and results (cf. Wolf, 2011). Kubicek (1977) distinguishes four kinds of research frameworks: conceptual schemes, conceptual frameworks, frames of reference and heuristic frameworks. Conceptual frameworks are also used in operations research for describing the underlying decision model (cf. Shields and Tajalli, 2006). Therefore, a conceptual research framework is best suited for the purposes of this thesis.

According to Wolf (2011) a conceptual research framework consists of three types of variables, context variables, design variables, and success variables. Context variables are factors that influence the surveyed phenomenon or that are considered by a person, which has to make decisions with respect to the design variables. Design variables describe the investigated phenomenon as such. The success variables are factors, which are most certainly influenced by the design variables or the interaction between design variables and context variables.

In the context of this thesis the context variables are relevant criteria and variables for decisions on SCD, which ensure effectiveness. These relevant criteria and variables for decisions on SCD stem from the categories customer interaction as well as product and demand characteristics. The design variables are standardized SC design components, which are supposed to characterize a differentiated SC design. In operations research these design variables are also called decision variables. The SC design should be determined by means of the context variables customer interaction as well as product and demand characteristics. The success variables are the expected outcome of the selected SC design, which are positive effects as well as costs of the selected SC design. These criteria and variables constitute an efficiency constraint. Yet, since these success variables may also be estimated as possible outcome of various SC designs, these variables are also considered as relevant criteria for selecting a SC design. *Figure 9* graphically summarizes the statements above and the interdependencies of the different kinds of variables, shown by the direction of the arrows. The figure only represents the categories of criteria and how they influence each other. In Chapter 4 the criteria and variables within these categories are added and explained.

3.3 Empirical investigation of decisions on supply chain differentiation

In this phase of the research, the regarded decision problem is investigated in detail as common in the design and development phase in design science research. Therefore, this step is crucial for the overall outcome of the research, since the later designed decision support methodology is based on the findings in this phase.

The research questions (*RQ1a* to *RQ1c*) for the empirical investigation of decision on SCD aims at three subordinate issues. The questions of (1) how companies can decide whether to differentiate their SC, (2) which circumstances indicate that SCD is meaningful to a company, and (3) which variables are relevant for SCD-decisions. Hence, the characteristics and basic conditions of decisions on SCD are analysed. All three questions are openly formulated (how and which questions) and aim at investigating cause effect relationships in depth. This suggests that a case study approach is appropriate to tackle these research questions and the phenomenon under investigation (cf. Eisenhardt, 1989; Yin, 2007). Furthermore, if the con-

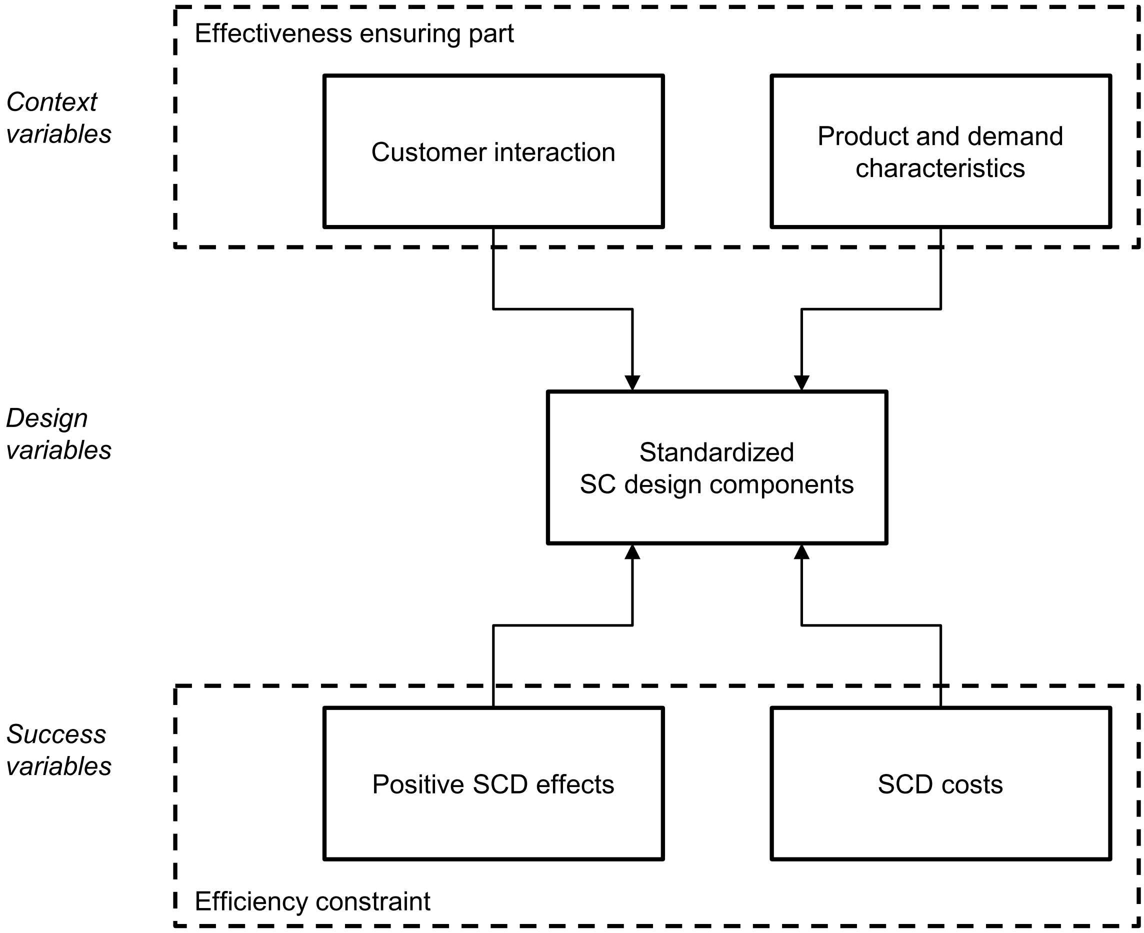

Figure 9: Research framework of the thesis

text and the process of decision making are essential for studied the phenomenon, case studies are well suited to investigate this phenomenon (cf. Pettigrew, 1997). Thus, the core of this research phase is a case study approach.

Overall, three research steps are conducted for the purposeful execution of the case study approach:

i.) Literature review: For increasing the focus of the case studies and building first hypotheses with respect to decisions on SCD, the relevant literature is surveyed.

ii.) Conceptual framework: The first hypotheses generated by means of the literature review are integrated in the conceptual framework, which builds the basis for the questionnaire used for the case studies.

iii.) Explanatory case studies: Investigates whether the conceptual framework and the integrated hypotheses are valid.

In the following, these three components of this research phase are briefly discussed.

Academics differ widely in their opinion on whether a literature review should be conducted prior to case studies. Eisenhardt (1989, p. 536) states that the “ideal of no theory under consideration and no hypotheses to test“ is a favourable starting point for the realisation of case study research. As opposed to this “theory development prior to the collection of any case study data is an essential step in doing case studies” (Yin, 2007, p. 29). Furthermore, Pye and Pettigrew (2005) suggest that hypotheses enhance the effect of case study research and provide a stronger focus of the investigation (see also Hancock and Algozzine, 2006; Stake, 1995). Hence, for the purpose of this thesis, it seems more appropriate to start with a literature review for building hypotheses for decisions on SCD and increase thereby the focus of the investigation.

The hypotheses from the literature review are integrated in a conceptual framework. The conceptual framework in this section tries to explain, which variables and criteria are relevant to decisions on SCD and which implications they do have on SC design decisions. Therefore, it is the first step in further developing the research framework presented in the previous section. More specifically, the aim of this step is to derive an explanatory conceptual framework by means of conceptual deduction. Meredith (1993, p. 9) states “with conceptual deduction, a framework is postulated and its ramifications (or predictions) are detailed for comparison with reality, as well as to provide guidelines for managers.” The result is a first draft of a SCD-decision framework.

The SCD-decision framework is verified and tested by means of case studies. Hancock and Algozzine (2006) categorizes three different types of case studies: explorative, descriptive and explanatory case studies. Explorative case studies are conducted if a phenomenon is entirely unexplored, descriptive case studies are used for the comprehensive specification of a phenomenon and explanatory case studies try to build cause- and effect-relationships. Since the final goal of the SCD-decision framework is to present the cause- and effect-relationships in decision on SCD, explanatory case studies are a suitable approach to verify hypotheses within the SCD-decision framework. For the selection of the case studies, theoretical sampling was used (cf. Eisenhardt, 1989). A careful selection of the case studies is most crucial for ensuring external validity of the conducted research (cf. Yin, 2007). Instead of analyzing the whole organization, the explanatory case studies focuse on decisions on SCD or SC design. Therefore, an embedded unit of analysis is selected (cf. Yin, 2007). Date collection is performed by means of semi structured interviews. Semi structured interviews admit not planned follow-up questions, which increase the flexibility in an interview and are supposed to enhance accuracy and honesty of the interviewee (cf. Rubin and Rubin, 2011). Data analysis is performed through the measures data reduction, data display, and conclusion drawing as well as verification (cf. Miles and Huberman, 1994). To improve and validate the results of the case studies, the results are discussed with the interviewees for guaranteeing internal validity (cf. Yin, 2007). Furthermore, the case study results are compared to contradicting and supporting literature (cf. Eisenhardt, 1989).

A detailed representation of the research approach for the empirical research phase is found in Chapter A-2.

3.4 Survey of available multiple criteria decision support in supply chain management

The research questions (*RQ2a* and *RQ2b*) of this research phase aim at illuminating, which decision areas in SCM are already well covered by methods in MCDM and which future trends may arise in MCDM for SCM. For answering these questions it must be analyzed, which research already exists in MCDM for SCM. A literature survey is suitable for this purpose (cf. Hancock and Algozzine, 2006; Webster and Watson, 2002). Besides investigating the area delimited by the research questions, a further objective is to back the relevance of decision support for SCD.

This section represents a brief introduction to the methodological proceeding for the literature survey, a detailed representation is found in Subsection B-3.3.

The literature is reviewed for the period from 2000 to 2011. The considered databases are EBSCO Host (Business Source Premier, EconLit, Computer Source) and ABI/INFORM Complete (ProQuest). The contributions are searched in titles and abstract for method unspecific and method specific MCDM search terms as well as SCM search terms. The literature survey focuses on contributions that allow for the consideration of intangible, qualitative information. This is due to the fact that SCD-decisions are strategic in nature. Strategic decisions normally include qualitative and conflicting criteria and therefore require approaches that are suited to incorporate qualitative criteria. Pure mathematical approaches do not allow for the consideration of qualitative criteria. Furthermore, literature surveys for pure mathematical approaches are already available (e.g. Meixell and Gargeya, 2005; Melo *et al.,* 2009; Mula *et al.,* 2010). Therefore, pure mathematical optimization approaches were excluded from the literature survey. Yet, hybrid approaches that combine mathematical procedures with an opportunity to include qualitative information are also considered in the literature survey. Altogether, 334 academic contributions match the search terms and 124 contributions are relevant to the literature survey. The relevant contributions fulfilled the following three constraints:

(i) the contribution integrated a multiple criteria approach,

(ii) the applied multiple criteria approach is geared for the consideration of qualitative information, and

(iii) the contribution shows a clear relation to SCM and does not only mention the term “supply chain” or “supply chain management” by coincidence.

For matters of classification, the attributes regarded are publication year, journal of publication and whether a group decision approach or empirical results are included.

Methods in MCDM are distinguishable in four different categories (cf. Figueira *et al.*, 2005). (1) Multi objective programming is mainly concerned with optimization problems under the consideration of several objectives. (2) Multi attribute utility theory (MAUT) quantifies and objectifies preferences of decision makers, for example by means of an AHP. (3) Non-classical approaches incorporate modern methods like fuzzy logic, which are mainly used in situations with high uncertainties with respect to the quality of the input information. (4) Outranking approaches are the “European school” of MAUT and are also used for the quantification of decision makers qualitative preferences. Exactly this MCDM method category is the first surveyed property of the relevant contributions. Additionally, the specific MCDM method (e.g. AHP or fuzzy logic) is analyzed. Furthermore, the application area within SCM (e.g. manufacturing or purchasing) and the specific application area (e.g. supplier selection in purchasing) are investigated.

3.5 Multiple criteria decision support for supply chain differentiation

The last step in the design and development phase of the design science process is to transfer an appropriate MCDM method to the problem and thereby to present a SCD-decision model. The research question (*RQ3*) for this step is concerned with how a MCDM methodology may support decisions on SCD. Therefore, a suitable MCDM methodology must be identified and applied to a SCD-decision. The following subsection gives first and overview of available MCDM methodologies and subsequently discusses which method is most qualified to support decisions on SCD. Subsection 3.5.2 introduces the methodological principals of the selected MCDM methodology.

3.5.1 Selection of a suitable multiple criteria methodology for supporting decisions on supply chain differentiation

As presented in Subsection 3.4, there are several different categories of methodologies in MCDM. These MCDM methodology categories are applicable to different kinds of multiple criteria problems. According to Wallenius *et al.* (2008) two main classes of problems are distinguishable multiple criteria discrete alternative problems and multiple criteria optimization problems (see also Dyer *et al.,* 1992; Figueira *et al.,* 2005).

Multiple criteria discrete alternative problems are concerned with decisions, which have a limited and normally small number of solutions. The value function in these instances is implicit, which means the value function follows the preferences of a decision maker. Additionally, for such decisions uncertainty is much more likely. This uncertainty stems not only from an unpredictable outcome of the decision or from future environment developments, but from a low quality and imprecise input information for the decision. For multiple criteria discrete alternative problems approaches from the MCDM methodology categories multi attribute utility theory and outranking are best suited, since these approaches capture the preferences of a decision maker and transfer them into a value function for the decision problem (cf. Wallenius *et al.,* 2008). In cases of very high uncertainty with respect to the quality and precision of input information multi attribute utility theory and outranking are combined with non-classical approaches, especially fuzzy logic (cf. Figueira *et al,*. 2005).

In contrast to multiple criteria discrete alternative problems, multiple criteria optimization problems address decisions that may be expressed precisely through mathematical formulae. These problems have a large, often infinite, number of solutions and an explicit value function. Uncertainty of low quality or imprecise input information is less probable in these decisions. Approaches for such decision problems are multi objective programming (cf. Figueira *et al.,* 2005). *Figure 10* illustrates the attributes of multiple criteria discrete alternative problems and multiple criteria optimization problems.

As stated in Section 3.4, SCD-decisions are strategic decisions and are often subject to imprecise input information and have a low number of possible solutions. SCD-decisions are therefore multiple criteria discrete alternative problems and MCDM methodologies in multi attribute utility theory and outranking are the appropriate MCDM methodology categories for such decisions.

The most popular methodologies in multi attribute utility theory are the "simple multi attribute rating technique" (SMART) that is more commonly known as scoring, the AHP and its further development the analytical network process (ANP) as well as the "measuring attractiveness by a categorical based evaluation technique" (MACBETH). Additionally multi attribute utility theory is often characterized as a concrete methodology itself, in which a decision maker states value functions for all relevant criteria and selects the alternative with the highest value. Well known outranking methodologies are "elimination and choice expressing reality" (ELECTRE) and "preference ranking organization method for enrichment evaluation" (PROMETHEE). Basically, all methodologies in multi attribute utility theory and outranking have the properties to deal with SCD-decisions, since all methods are able to incorporate qualitative information. Most of these methods are based on pairwise comparisons of solution alternatives with respect to relevant criteria. Yet, the AHP methodology is best suited for the purposes of this thesis.

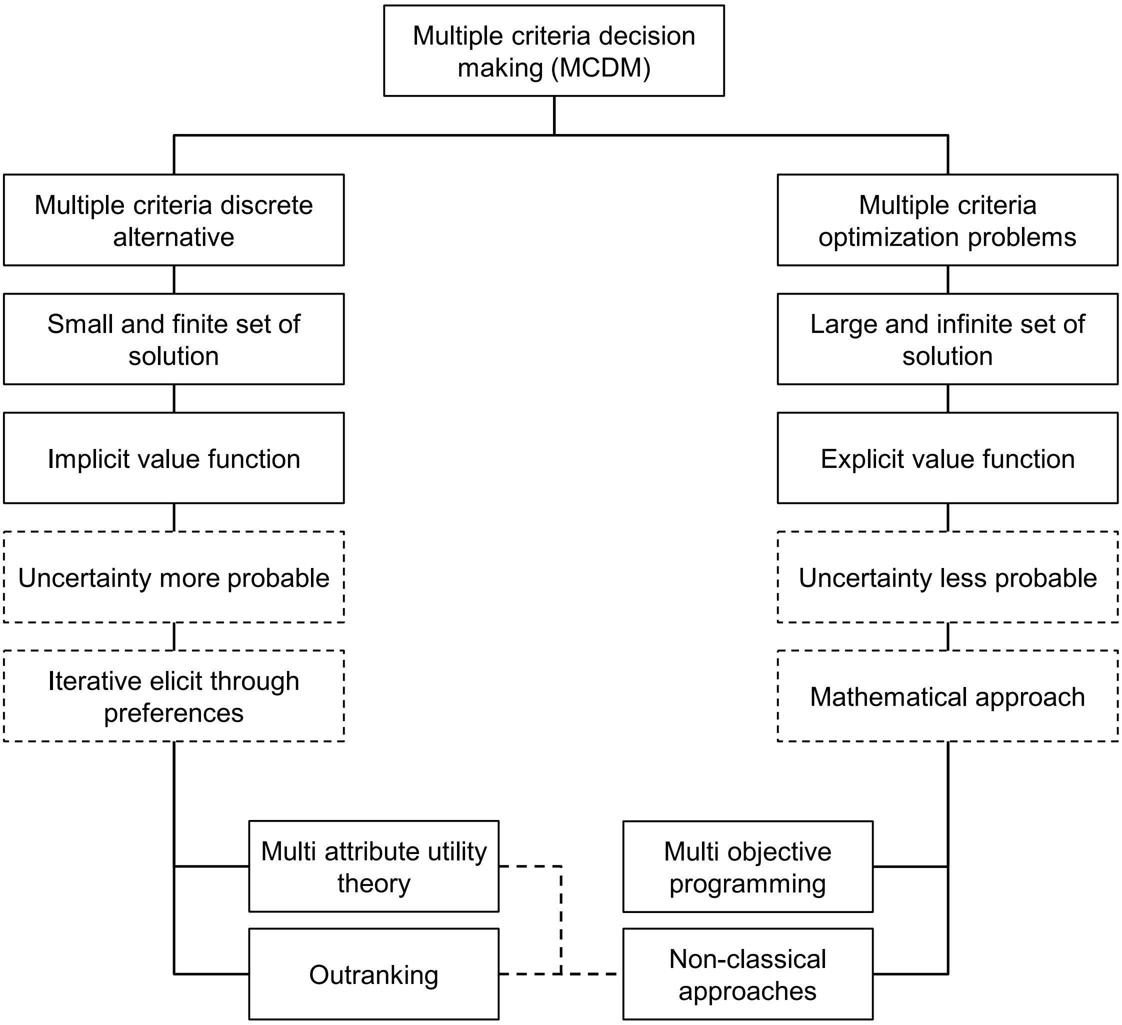

Figure 10: Distinct sorts of multiple criteria decision problems and linked methodologies (based on Wallenius et al., 2008)

Since the AHP is easy to use and very flexibly applicable to several types of decision problems, the AHP is one of the most utilized decision making tools in several research fields (cf. Sipahi and Timor, 2010), one of them operations management. An important advantage of the AHP is that quantitative and qualitative input information may be considered besides each other (cf. Vargas, 1990). Subramanian and Ramanathan (2012) review 291 AHP applications to operations management and find that the AHP is mostly applied if qualitative and quantitative information have to be integrated in the decision making process. Especially the property to incorporate quantitative as well as qualitative criteria in a decision problem is vital for SCD-decisions. As Section 4.1 shows, decisions on SCD have to consider both types of criteria. Furthermore, the AHP is well known by managers, which normally implies a higher acceptance through manager since they often reject solutions of methods they do not understand. Finally, an AHP deals especially well with complex decision problems, as it structures the decision problem hierarchically. Thereby, the AHP supports managers in better understanding the overall decision problem (cf. Bhagwat and Sharma, 2009).

3.5.2 Methodological principles of the analytical hierarchy process

The AHP was first proposed by Saaty (1980). In the following the methodology is briefly explained. Hereafter, the application of an AHP is described in five steps.

(1) The problem needs to be defined. Therefore, a specific question has to be formulated, which should be solved by an AHP. Also, all relevant data is collected that is needed for successful decision making. In particular, the relevant criteria and variables are determined as well as the possible solution alternatives are defined between which the decision maker is able to choose to achieve his goal.

(2) The decision has to be structured hierarchically. The objective of this step is to include the relevant criteria in a hierarchical order. For a better understanding, this step is described by means of the decision problem and the criteria for decisions on SCD. The detailed determination of the relevant criteria for decisions on SCD is found in Appendix A. On the first level of this structure, the decision problem is stated. In the case of this thesis the decision problem is formulated as "which is the most suitable SC design for the regarded market" from the perspective of a certain company. On criteria level one the main criteria for the decision problem are given, here effectiveness ensuring and efficiency constraint. Criteria level two presents the criteria categories encompassed in the effectiveness ensuring part, i.e. customer interaction as well as product and demand analysis, and the criteria within the efficiency constraint, i.e. positive effects and costs of the SC design. The third criteria level states all detail criteria. The last level of the structure represents the solution alternatives to the decision problem, here different SC designs, which may be differentiated SC designs. *Figure 11* shows the hierarchical structure of SCD-decisions and relevant criteria.

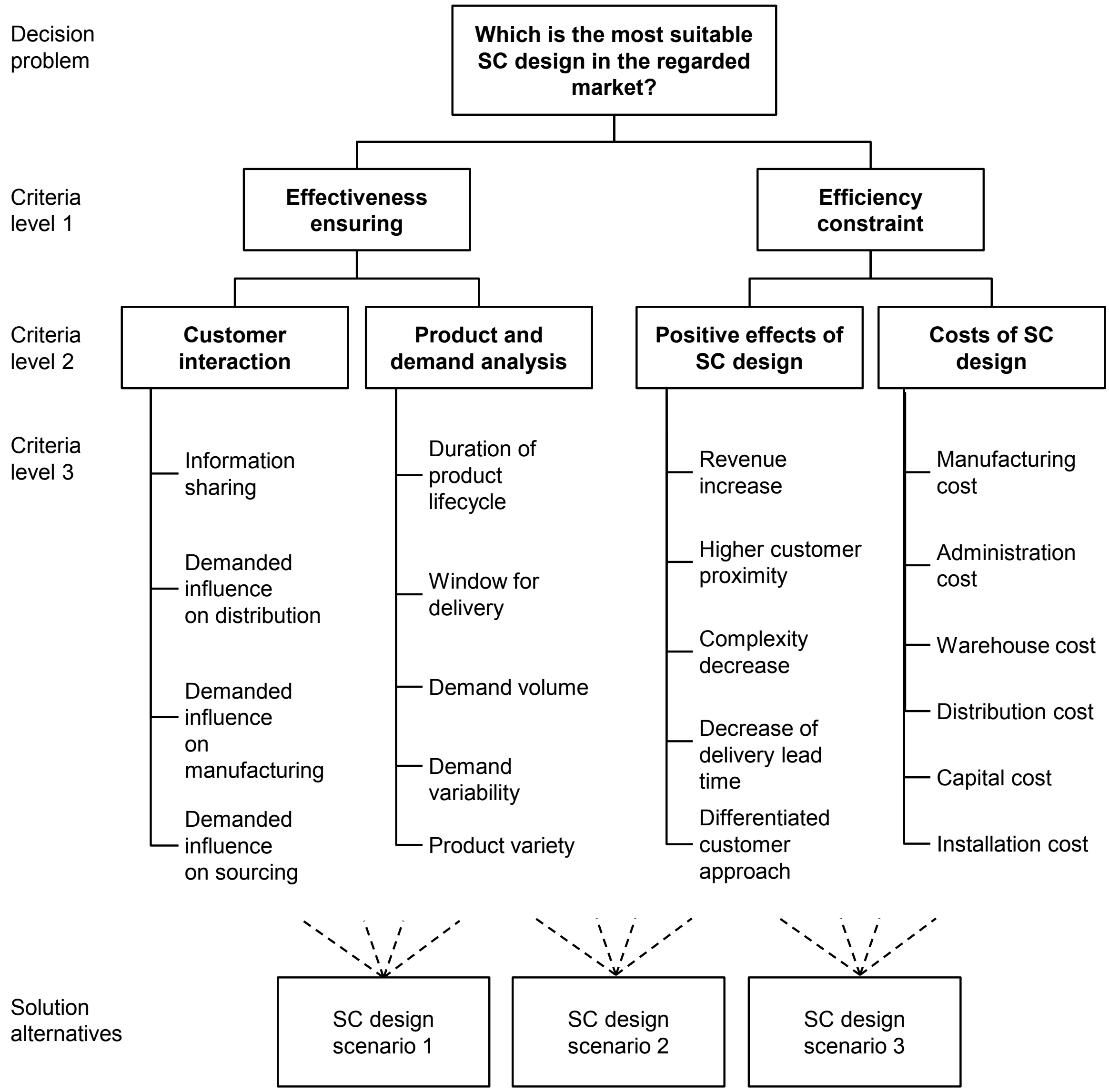

Figure 11: Hierarchical structure of criteria and variables for decisions on supply chain differentiation

Normally, it is claimed that criteria on one level should be independent from each other, i.e. demand volume and demand variability, in the criteria category product and demand analysis, should not influence each other. Apparently, demand volume and variability are dependent. Yet, Saaty (1994) states that the AHP is also usable in decision problems with dependencies of criteria on one level.

(3) The next step includes the pairwise comparisons of each criterion with the other criteria on the same level with respect to the higher level criteria. The pairwise comparison is conducted by the decision maker and aims at objectifying the preferences of the decision maker. The level one criteria is compared to each other with respect to the decision problem. The level two criteria, customer interaction and

product and demand analysis is compared to each other with respect to the higher importance for ensuring effectiveness. These comparisons are conducted down the solution alternatives. On the level of the solution alternatives, these are compared to each other with respect to each level three criteria, e.g. which SC design is better suited to satisfy the information sharing needs of the customers (in the criteria category customer interaction). The values for conducting these pairwise comparisons are given in *Table 3*.

As example, *Table 4* contains the pairwise comparisons of the SC design scenarios (corresponding to activity in *Table 3*) with respect to the criterion demand volume. In the example with three SC designs and all criteria considered like illustrated in *Figure 11*, 27 of these tables would have to be filled in to solve the decision problem. The columns three, four and five contain the pairwise comparisons. On the principal diagonal the values are always 1, since these values symbolize the importance of each SC design scenario compared to itself. The value 0.5 in the table means that SC design scenario 1 is slightly less suited to fulfill the requirements of product demand than SC design scenario 2. Mirrored on the principal diagonal, the reciprocal value 2 is filled in. The weights are calculated using the arithmetic mean method, proposed by Saaty (1980).

Table 3: Scales for pairwise comparisons in the AHP

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Ratios	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Source: Adapted from Saaty (1994)

Table 4: Pairwise comparison of SC design scenarios with respect to criterion demand volume

	1	2	3	Weights
1 SC design scenario 1	1	0.5	0.3333	0.1698
2 SC design scenario 2	2	1	1	0.3873
3 SC design scenario 3	3	1	1	0.4429

(4) After the pairwise comparisons have been conducted, which represent the preferences of a decision maker, it must be checked whether the preferences of the decision maker in each matrix are consistent. For example, if a decision maker finds option A is more important as B, and B more important as C, then A should also be more important as C. In economics this rule is called transitivity of preferences. The AHP does not claim that the preference must be strictly transitive; yet, a certain degree of consistency of the preferences within a matrix must be given. Saaty (1980) has developed a method which checks whether the preferences are consistent enough. The consistency index (*CI*) and the consistency ratio (*CR*) are used for this purpose.

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad CR = \frac{CI}{RI}$$

λ_{max} denotes the maximum eigenvalue of the matrix. The term *n* stands for the rank of the matrix. *RI* describes the random index, which was defined by Saaty (1980) and is given in the following as an example.

n	2	3	4	5	6
RI	0	0.52	0.89	1.11	1.25

In case of perfect consistency of the pairwise comparisons within a matrix $\lambda_{max} = n$. If the pairwise comparisons are not perfectly consistent $\lambda_{max} > n$. Saaty (1980) states that if $CR \leq 0.1$ the pairwise comparisons are sufficiently consistent for guaranteeing a correct solution of the AHP. If $CR > 0.1$ the pairwise comparisons in a matrix have to be reviewed and checked for inconsistencies. In the example matrix represented in *Table* 4, the values assume $\lambda_{max} = 3.0183$, $CI = 0.0092$ and $CR = 0.0172$. Hence, the pairwise comparisons in *Table 4* are sufficiently consistent.

(5) If all matrices are sufficiently consistent, the priorities (given by the weights in *Table 4*) of all solution alternatives (SCD-design scenarios) have to be summarized by multiplying the weights on the different criteria levels with each other. This calculation results in the final weights of the solution alternatives and yields a ranking of the solution alternatives. The solution alternative with the highest weight represents the best solution to the considered problem, on basis of the preferences of the decision maker.

4 Key research findings of the thesis

4.1 Relevant variables and decision framework for decisions on supply chain differentiation

In this section the main findings of the empirical research phase are summarized. A detailed description of these research findings as well as a comparison to conflicting and confirming literature is presented in Appendix A-5 and A-6.

The objective for this research phase is to present a SCD-decision framework that integrates relevant criteria and variables as well as their influence on a SC design. As stated in the research framework in Subsection 3.2, there are an *effectiveness ensuring* part and an *efficiency constraint* within the SCD-decision framework. The *effectiveness ensuring* part of the framework is especially important, since SCD is a customer-oriented SCM approach that aims at delivering products and services to customers in way the customers appreciate it. The thesis extended earlier contributions by the integration of customer interaction. Customer interaction broadens the information basis for decisions on SCD and proves as a worthwhile extension. Customer interaction is operationalized by means of the criteria and variables information sharing as well as the demanded influence of customers on distribution, manufacturing and sourcing. The relevance of these factors is confirmed by the empirical investigation. While a higher customer interaction leads to a more agile SC design, different groups of customers that demand different levels of customer interaction are an indicator for a meaningful application of SCD. The variables in the product and demand analysis area are based on the so called DWV^3 model (Childerhouse *et al.,* 2002). This model consists of the five variables “duration of product life cycle”, “time window for delivery”, “demand volume”, “product variety” and “demand variability”. The case studies confirmed earlier findings of other authors with respect to the DWV^3 model criteria and variables. A long duration of product life cycle favors a lean SC design and short duration of product life cycle speaks for an agile SC design. A short time window for delivery points at a meaningful implementation of a lean SC design or strategy, a long time window for delivery allows for an agile SC design. A high demand volume indicates that a lean SC design may be most appropriate for realizing economies of scale, while a low demand volume normally requires an agile SC strategy. A high demand variability calls for an agile SC design and a low demand variability admits a lean SC design. Finally, a high product variety is an indicator for the need of an agile SC and a low product variety permits a lean SC design. If there are different product clusters, which assume varying characteristics with respect to the five explained criteria and variables, the implementation of SCD may be meaningful.

The *efficiency constraint* claims that positive effects of SCD are not overcompensated by its costs. Such an economical plausibility check was conducted by all case companies, before implementing SCD. With respect to the positive effects of SCD, higher revenues were considered. The possible costs of SCD were estimated by means of increasing manufacturing and distribution costs.

Besides the findings related to the SCD-decision framework, further findings are generated in the empirical research phase. The case companies are of differing sizes. Therefore, it is assumed that SCD is not only subject to large corporations but also a suitable approach for medium sized businesses. Additionally, SCD is in most cases part of corporate growth strategy. From this it follows that SCD-decisions are top-down, since they follow corporate growth strategies, which lie within the highest level of corporate strategy, while the SC strategy corresponds to a functional strategy.

The criteria and variables in the effectiveness ensuring part and in the efficiency constraint must be considered in decisions on the *standardized SC design components*. The decision on a SC design includes also the setup of several differentiated SCs besides each other, hence, a differentiated SC design.

Figure 12 presents the research framework including relevant criteria and variables for decisions on SCD.

4.2 Multiple criteria decision making approaches in supply chain management

In course of this thesis a detailed analysis by means of a literature survey of MCDM methods in SCM took place, which is presented in Appendix B. In the period from 2000 to 2011, 124 academic articles are analyzed. Like this literature survey shows, MCDM applications to SCM grow exponentially. This fact is due to the appropriateness of such approaches for decision problems in SCM. In cases of multiple objectives or relevant criteria, a decision maker requires suitable support if he or she

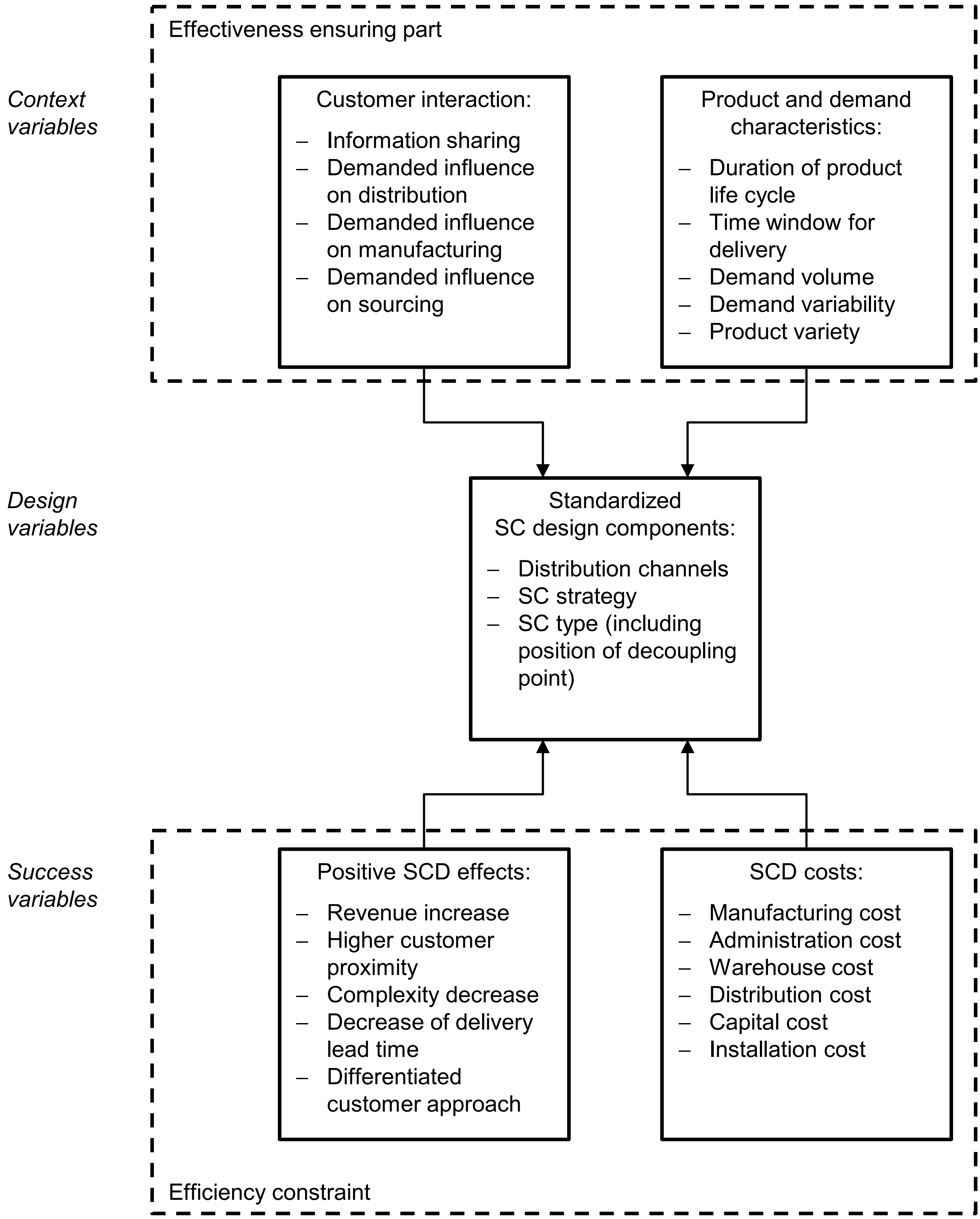

Figure 12: Research framework of the thesis including relevant criteria and variables for decisions on supply chain differentiation

wants to consider trade-offs between the different objectives or criteria. MCDM problems in SCM are especially located in the SCM application areas design, distribution, manufacturing, purchasing and logistics. The specific application areas supplier selection and supplier evaluation in the area purchasing, as well as general performance management have drawn the most academic attention. Furthermore, the literature survey was conducted regarding SCM in general and not only SCD. However, a survey of the literature with respect to MCDM in SCM also allows for conclusions regarding MCDM in SCD. Regarding MCDM methods for the SCD-decision it can be stated that there currently are no methods, which support these decisions. More precisely, at the moment no MCDM applications to decision problems in SCM are available, which would even be remotely related to the decision problem considered in this thesis. In fact, the MCDM approaches in the SCM application area of SC design are concerned with network design and are therefore hardly related to the SCD-decision as considered in this thesis. The mostly applied methods are the AHP, followed by fuzzy set theory and the ANP.

Overall four research gaps and two possible future trends for MCDM in SCM have been identified. The research gaps point at SCM application areas, which have not been sufficiently provided with MCDM approaches. These SCM application areas are:

1) Distribution in a supply chain context, including distribution network design as well as (collaborative) distribution planning,
2) Supply chain risk management, including a pure focus on the supply side,
3) Supply chain strategy, including supply chain differentiation, competitive positioning and alignment of supply chain strategy, and
4) Supply chain performance management, especially for the performance management of several parallel supply chains.

Possible future trends in MCDM show new methodologies, which have not been applied to SCM but draw much attention in the operations research community. Two methodologies, which have to potential for a meaningful application to SCM are:

1) Mental models and
2) Revisiting targets.

4.3 A multiple criteria decision making approach for decision on supply chain differentiation

The objective of this research phase is to create a SCD-decision model based on the SCD-decision framework that resulted from the empirical research phase. The complete model as well as a full statement of the findings of this research phase is found in Appendix C.

The SCD-decision model is based on an AHP and includes all relevant criteria and variables in the effectiveness ensuring part of the framework and the efficiency constraint from the empirical research phase and is structured according to the hierarchy presented in *Figure 11*. The standardized SC design components represent the decision areas presented in Section 2.2.3. The distribution strategy is incorporated by means of the used distribution channels. The SC type represents the manufacturing strategy, which also encompasses the position of the decoupling point (e.g. a MtS SC implies a downstream positioning of the decoupling point.). Finally, the SC strategy is integrated within the standardized SC design components. The purchasing strategy is omitted within the standardized SC design components, since a differentiated purchasing is not necessarily a component of SCD according to the SCD-definition of this thesis. Furthermore, the purchasing area is only subject to SCD in rare occasions, as apparent from the case study results.

The application process of the SCD-decision model includes three steps:

(1) Analyze customer interaction as well as product and demand characteristics within the effectiveness ensuring part of the SDC-decision framework and build suitable customer groups and product clusters.

(2) Derive appropriate SC design scenarios based on the analyses of the effectiveness ensuring part of the SCD-decision framework.

(3) Apply the AHP based SCD-decision model, integrating the effectiveness ensuring as well as the efficiency constraint and conduct sensitivity analyses for testing the robustness of the solution.

The model is tested by means of an illustrative example, based on one of the case studies from the empirical research phase. The above stated application process combined with an AHP for selecting the most suitable (differentiated) SC design given the preferences of a decision maker, seems easy to understand and quite user friendly. The derivation of suitable SC design through the SCD-decision framework fosters the understanding of the dependencies between the relevant criteria and variables and their influence on the standardized SC design components by decision makers. When it comes to the actual assessment of the various SC design scenario by means of the AHP model, the decision maker has a good comprehension of how which SC design scenario fulfills the requirements of the relevant criteria and variables. Additionally, the sensitivity analysis shows that the results of the AHP are quite robust against variations in the weightings of the criteria.

From a theoretical point of view, the designed SCD-decision model yields adequate results and seems to incorporate all important aspects of decisions on SCD.

5 Conclusion

5.1 Contribution of this thesis

The contribution of this thesis is presented in terms of managerial as well as theoretical contribution and is structured according to the three main research phases of this thesis, the *empirical research phase*, the *literature survey* and the design of a *SCD-decision model*.

5.1.1 Managerial contribution

Through the results of the *empirical research phase* a SCD-decision framework is now available for managers or decision makers. The SCD-decision framework contains a summary of relevant criteria and variables for decisions on SCD and a description of how these criteria and variables interact with standardized SC design components. The SCD-decision framework can guide managers and decision makers confronted with decisions on SCD.

By means of the *literature survey* of MCDM applications to SCM, managers and decision makers are provided with a comprehensive overview with respect to available MCDM methodologies for decision problems in SCM. The categorization of the MCDM applications considering SCM application areas (e.g. purchasing, manufacturing, logistics) and specific SCM application areas (e.g. supplier selection, production planning, information sharing) equips managers and decision makers in SCM with a means to identify an appropriate MCDM methodology for their decision problems.

Furthermore, managers and decision makers can now revert to a *SCD-decision model*. The scope of application of the SCD-decision model is very flexible. It is usable for problems with pure qualitative information (preferences of decision makers and expert judgments). However, the scope of application may be extended through the integration of quantitative information. The quantitative information must be gathered or generated through educated estimations, which strongly increases the effort necessary to apply the model. Nevertheless, the integration of quantitative inputs objectifies the results, since the SCD-decision is in such cases not based on pure subjective preferences of decision makers and expert judgments. Additionally, as the presented SCD-decision model is based on an AHP, it is relatively simple converted to a group decision methodology for SCD-decisions. Finally, since the core of the SCD-decision model is an AHP application, it is expected that the decision model finds a high acceptance under decision makers. This is due to the fact that the AHP is a widely applied and known methodology as well as relatively simple to conduct in contrast to other MCDM methodologies.

5.1.2 Theoretical contribution

The *empirical research phase* offers for academia further empirical findings on SCD in general as well as on SCD-decisions and thereby broadens the theoretical background on SCD in operations management. For example, the results indicate that SCD represents a possibility to deal with varying customer requirements as well as volatile product and demand characteristics, especially, if the manufactured products differ in demand volume and variability. Moreover, customer interaction has been integrated besides the purely product and demand focused set of criteria and variables for decision on SCD. Additionally, a SCD-decision framework integrating the relevant criteria and variables as well as cause-effect relationships between the relevant criteria as well as variables and the standardized SC design components are introduced. Finally, the finding that SCD is part of corporate growth strategies was not mentioned so far in the corresponding literature.

Through the *literature survey* research gaps and possibilities for future research of MCDM applications to SCM are presented, which may guide academics interested in this research field. Based on a discussion of future trends in MCDM, MCDM methodologies that are currently not applied to SCM are identified and their potential for an application to SCM is explained.

The introduced *SCD-decision model* represents the first MCDM decision methodology for decisions on SCD. The model contributes to the research area of operations research through presenting an approach for a problem that was not considered so far. Additionally, the model contributes also to SCM research, since it integrates a comprehensive spectrum of criteria and variables relevant to decisions on SCD.

5.2 Limitations of this thesis and future research

5.2.1 Limitations of this thesis

In the *empirical research phase* only three case studies are investigated. Therefore, the generalizability of the results is limited. Furthermore, the considered case companies belong to manufacturing of machinery, wiring devices and equipment industries. These companies are all located downstream their SC. Hence, it is possible that companies, which are located upstream in their SC like producers of chemicals, have to consider other or further criteria and variables for decisions on SCD. Additionally, in general it is not certain that all relevant criteria and variables for decisions on SCD have been identified by means of the case studies. The employed case studies in the empirical research phase are a qualitative research approach. Such qualitative research approaches come with certain sources for biased results, e.g. an interpretation bias of the interview results or a selection bias with respect to the case studies. The empirical research was conducted according to scientific standards to prevent these biases, yet, it is not excludable that the results are biased.

The *literature survey* only reviewed contributions in academic journals. No text books, no master and doctoral theses have been considered for the survey. However, MCDM in SCM is a very young research field. Therefore, it is questionable whether such approaches are already considered in textbooks. Furthermore, only publications in English were analyzed. It is assumed that there is also a body of literature on MCDM in the Russian language, yet it is not certain whether these applications consider SCM. Additionally, only publications with clear relation to SCM have been surveyed. MCDM contributions that purely focused on manufacturing or purchasing are not considered. Finally, the literature survey is based on a keyword search in the databases EBSCO Host (Business Source Premier, EconLit, Computer Source) and ABI/INFORM Complete (ProQuest). It is possible that some relevant literature did not match the search terms.

Regarding the designed *SCD-decision model*, the model was only tested with respect to an illustrative example which is based on one of the case studies from the empirical research phase. Therefore, the actual applicability to a real world problem is not tested so far. Yet, less than 50% of scientific articles that develop a multiple decision support methodology for SCM integrate a real life application (see Appendix B.3.2). Moreover, since an AHP is applied, there are no sources for methodological mistakes in terms of wrong formulation. This due to the fact, that the approach simply objectifies the preferences of managers and decision makers and does not specify certain relations between a solution and the relevant criteria of the problem. Additionally, in general an AHP application requires independence of criteria on one level. The SCD-decision model includes dependencies of criteria on the same level, e.g. the demanded influence of customers on manufacturing (criteria category customer interaction) is linked to the criteria product variety as well as demand volume and variability (criteria category product and demand characteristics). These interdependencies are not considered by the AHP. Yet, Saaty (1994) states that an AHP is also applicable to cases in which dependencies and feedbacks between criteria are existing. This disadvantage of the AHP is compensated by other advantages, like clear hierarchical structure of the problem, easy to understand and apply by managers and decision makers and therefore more accepted under users. An ANP would be an alternative for the problem of interdependencies between the considered criteria. But the ANP comes with other disadvantages, less easily applicable, less simple to understand, less accepted by managers and decision makers. Hence, an AHP is therefore the more user friendly alternative, which is more focused on applicability in business practice than on strict theoretical accuracy.

Generally, the developed SCD-decision model answers the question “how many SCs does a company need” only by objectifying the preferences of a single or a group of decision makers. The main objective of this thesis, to develop decision support for a transparent and structured approach to complex SCD-decisions, was achieved. However, the provided SCD-decision model does not “calculate” the optimal number of SCs on the basis of input information.

5.2.2 Possibilities for future research

The possibilities for future research are distinguished in the three areas general research on SCD, research with respect to the SCD-decision framework and research regarding the SCD-decision model.

General research on SCD offers several possibilities for future research, since SCD is an emerging research field. To date the research on SCD was only concerned with the design of differentiated SCs and covers just the strategic level of this research field. Future research must identify, which capabilities are necessary to successfully operate a differentiated SC. Additionally, it must be investigated which processes and performance management systems are adequate for differentiated SCs and how SCD is implemented properly in a company. Also, the general profitability of SCD has not been investigated yet. Finally, inter-organizational aspects of SCD, like cross-company implementation of SCD as well as influence on SC governance and relationship structures may offer potential for future research.

Regarding the SCD-decision framework and relevant criteria and variables for decisions on SCD, it should be further investigated whether the criteria and variables are complete. Additionally, the relation between relevant criteria as well as variables and the design of differentiated SCs may be continued in analyzing. This may be done by means of further case study research. Yet, there is already a body of theory regarding cause-effect relationships between criteria and variables relevant for SCD decisions and differentiated SC designs. Therefore, if realizable, quantitative research methods like structural equation modeling should be applied to test the theory on SCD-decisions.

Future research on the SCD-decision model should test the model in a real life problem. Thereby the presented SCD-decision model would be developed further through the adaption to the needs of decision makers. Moreover, alternative MCDM methodologies could be applied to SCD-decisions. A visionary decision support methodology for decisions on SCD would be a multiple criteria optimization approach, which really deals with the tradeoffs regarding effectiveness (higher customer satisfaction) and efficiency of SCD (incurred costs of differentiated SC). A multiple criteria optimization approach would have the capability to compute the optimal number of SCs for a company. Such an approach would be extremely helpful for managers and decision makers in SCM. However, a multiple criteria optimization approach for decisions on SCD would be very complex. Furthermore, it is questionable whether the uncertainties implied for example by the estimation of future revenues generated by SCD are easy to handle by means of a multiple criteria optimization approach. Moreover, the SCD-decision as presented in this paper is a hierarchical decision, which is also hard to implement in an optimization approach.

Acknowledgement: Parts of chapters 1 to 5 of this thesis are based on the paper Beck *et al*. (2012).

Appendix

Appendix A: Beck, P. and Hofmann, E., 2012. Decisions on supply chain differentiation – How to ensure effectiveness in inter-organizational operations?

Published earlier version of the paper: Beck, P. and Hofmann, E., 2012. Supply chain differentiation: An empirical investigation of relevant decision criteria. Proceedings of the 4th Productions and Operations Management World Conference, Amsterdam.

Appendix B: Beck, P., and Hofmann, E., 2012. Multiple criteria decision making in supply chain management – Currently available methods and possibilities for future research. *Die Unternehmung* 66 (2), 181–214.

Appendix C: Beck, P., 2012. Designing differentiated supply chain strategies – A multiple criteria decision making approach. in Review.

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A Decisions on supply chain differentiation – How to ensure effectiveness in inter-organizational operations?

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Abstract

Supply chain management (SCM) has evolved from a cost optimization topic to a customer-oriented and increasingly strategic issue. Companies have discovered an opportunity to sustain competiveness by means of SCM. Supply chain differentiation (SCD), the concurrent operation of several supply chains (SC), is an integrated SC segmentation approach. This paper investigates how decisions about SCD are made. We derive a SCD-framework including relevant decision variables and standardized SC design components. We use three explanatory case studies with an embedded unit of analysis for the verification of our framework. Our findings indicate that the integration of customer interaction analyses in addition to classical analyses of product and demand characteristics enrich the information basis for decisions on the design of differentiated SC strategies. This paper contributes to academia by providing further empirical evidence on relevant criteria for decisions on SCD in manufacturing industries and offers managers support in making these decisions.

Keywords: *Supply chain management, supply chain differentiation, supply chain segmentation, customer orientation, decision support, case study*

A.1 Introduction

Since Porter introduced differentiation as a competitive strategy, various types of differentiation have been presented in business research. Most kinds of differentiation are directly attached to products, i.e. they focus on the consistency, reliability, quality or innovation of a company's offerings (cf. Porter, 1998). However, strategic differentiation approaches are not restricted to product attributes or characteristics. Skinner (1969) states that processes and functions – especially operations management – always possess a strategic component. Therefore, differentiation approaches are often applied to single functions of business tasks. In logistics, customer service level differentiation by distinct market segments and their requirements was introduced (cf. Gilmour *et al.*, 1977). Providing products and value-adding services according to customer needs – utilizing tailored logistics – represents an additional opportunity for differentiation (cf. Fuller *et al.*, 1993). Moreover, a number of manufacturing-centered differentiation approaches have been presented, e.g. postponement (Zinn and Bowersox, 1988) along with mass customization concepts (Pine, 1992). Finally, several differentiation approaches in the information and communication area are available that can integrate varying customer integration, bearing in mind the importance of customers and suppliers (cf. Fawcett *et al.*, 2007).

Currently, companies realize that product or service differentiation or differentiated approaches focusing on single functions, like logistics, manufacturing or information and communication are not sufficient for maintaining competitiveness. Modern differentiation approaches need to integrate these concepts in a more holistic manner.

To deal with varying customer needs, many companies today introduce differentiated SCM approaches, so that they use several SC strategies and therefore multiple SCs for serving a market. Mayer *et al.* (2009) surveyed 150 European companies' SC strategies and found that companies with a differentiated SC strategy were, on average, more successful than their competitors. Malik *et al.* (2011) report that SCD represents an opportunity for dealing with increasing complexity of customer needs and variability of demand. Davis (2010) presents the computer manufacturer Dell's SCD efforts. Dell has departed from its "one size fits all" pull (make-to-order) SC and currently operates up to six different SCs; Adidas, Nike and Oakley also introduced differentiated SCs. All three consumer goods manufacturers operate a push (make-to-stock) and a pull SC in parallel to each other. However, prior to the implementation of SCD, a differentiated SC must be designed and a decision must be made on how many supply chains the company should operate. In many cases the operation of several SCs at the same time seems to be an emerging, if less systematic, occurrence. Over time further SCs are added due to new product introductions and acquisitions of new customer groups without eliminating an existing SC by adjusting the range of offered products and services. Market driven effectiveness considerations, as well as resource and capacity oriented deliberations, demand a systematic approach of SCD-decisions.

Fitting SC strategies to different market or product characteristics has been the subject of various academic publications (e.g. Fisher, 1997; Lee, 2002; Mason-Jones *et al.*, 2000b). However, until now academia has hardly addressed how differing customer requirements could be served by applying various SC strategies and configurations simultaneously (cf. Hilletofth, 2009). Decision support for the design of differentiated SC strategies particularly deserves more academic attention (cf. Christopher *et al.*, 2009; Godsell *et al.*, 2011).

The paper at hand addresses this research gap in operations management and attempts to answer the following research questions (RQ):

RQ a: *How can companies decide whether to differentiate their supply chain?*

RQ b: *Which circumstances indicate that supply chain differentiation is meaningful for a company?*

RQ c: *Which variables are relevant for SCD-decisions?*

We tackle this research questions by means of explanatory case studies (Eisenhardt, 1989; Yin, 2007). Based on a literature review, we built a set of relevant criteria, which is integrated in semi-structured questionnaires. Through the case studies we evaluate the set of relevant criteria. Thereby, we follow the postulation of Craighead *et al.* (2007) to conduct more interpretative research on direct observation of a phenomenon, in our case decisions on SCD.

The theoretical contribution of our paper is to present further empirical insights regarding SCD. In particular, we offer findings for a better understanding of a company's decision to differentiate its SC (SCD-decision). The managerial contribution is a set of criteria that must be considered in SCD-decisions. We base our analysis on the early work of Childerhouse *et al.* (2002) in the *Journal of Operations Management*. Their article was one of the first contributions to SC segmentation and differentiation. Our aim is to integrate these considerations and develop them further.

This paper is organized as follows. In the next section, our research design is outlined. In Section 3 we briefly review the relevant literature and demonstrate the theoretical relevance of our paper. In Section 4, we discuss conceptual considerations related to SCD-decisions. Section 5 presents the empirical results from our case studies. We discuss our findings and propose areas for further research in Section 6. Section 7 consists of a conclusion.

A.2 Research design

A.2.1 Research methodology

Our general research approach encompasses three steps as follows. (i) As suggested by Yin (2007), we begin our research with a literature review for developing theory before we collect data and increase thereby the concentration of our research on important aspects of the surveyed phenomenon (Section A-3). (ii) According to Meredith (1993) we then built a conceptual framework, a SCD-decision framework (Section A-4). (iii) Thereafter, we verify our SCD-decision framework by means of an explanatory case study approach (Section A-5). As Meredith (1993) points out, this step improves a conceptual framework by means of conceptual deduction (in that a postulated framework is compared in detail to reality). The third step in our research is most crucial to the general research, since the results allow for statements about the functionality and practicability of our framework. In the remainder of this section we discuss our explanatory case study approach.

A consideration of the context in which SCD-decisions take place in and the decision process involved, are essential to our research. According to Pettigrew (1997) a case study approach is convenient to investigate the context and process of strategy making, i.e. in our instance decisions on SCD. A quantitative research proceeding would be another way of conduct context and process related research. However, the number of companies that have implemented a differentiated SC is not large enough to allow for sound statistical analyses, which is a further argument for conducting case study research.

A.2.2 Case selection and unit of analysis

According to Eisenhardt and Graebner (2007) single case studies allow for the thorough investigation of a rare phenomenon. However, multiple case studies are useful with respect to the basis for theory building. Since we were able to identify several companies that apply SCD, we can exploit that opportunity and utilize a multiple case study approach. External validity is ensured through the repeatability of the case study research conducted (Yin, 2007). A careful case selection is essential for external validity of the case study results. We utilize theoretical sampling for case selection for ensuring that our cases are suitable for investigating the phenomenon (Eisenhardt, 1989). Our criteria for selecting the cases are as follows. We build stronger evidence regarding circumstances in which a differentiated SC design is favourable over a “one size fits all” approach by including two case companies that have implemented SCD. We are also interested in the negative hypothesis, whereby circumstances would exist in which it would not be meaningful to apply SCD. In our study, we include one case of a company that did not implement SCD. Furthermore, we make sure that our case companies are of different sizes and slightly different geographical scope, two being large global enterprises and a medium sized international company.

We use an embedded unit of analysis by focusing on decisions about SCD or SC design (Yin, 2007). One of our case companies (case A) actually decided two times on SCD over the last 15 years, and both units were pro SCD. Case B offers one unit of analysis in which the decision was pro SCD. Case C differs slightly in terms of the unit of analysis, since the company never actually decided whether to implement SCD. However, they made considerations with respect to a possible implementation of a geographical postponement combined with a hybrid manufacturing strategy, which is strongly related to SCD, and rejected this approach. Hence, overall we can analyse four units.

A.2.3 Data collection and analysis

Interviews are a prominent method for data collection in case studies. An interview is a goal-oriented approach, since the interviewer has the opportunity to focus on topics of interest. The results may provide considerable insights, since the interviewee may provide information on cause-effect relationships from his point of view (cf. Yin, 2007). We can identify key interviewees within each firm (decision makers in the area of SCM) and interview them individually, since individual interviews yield significant amounts of information (cf. Hancock and Algozzine, 2006). An appropriate method for data collection by means of interviews is the application of semi structured interviews. Semi structured interviews allow for unplanned follow-up questions that can enhance the flexibility of an interview (cf. Rubin and Rubin, 2011). Furthermore, follow-up questions are supposed to increase accuracy and honesty of the interviewee. For the preparation of the semi structured questionnaire, we use the insights (hypotheses) that resulted from our literature review and our conceptual considerations (SCD-decision framework). However, we did not provide the interviewees with the theory driven hypotheses. Instead, we asked for their conception in open questions and confronted them with theory in closed follow up questions. In the semi structured interviews, we collected data on the customers, their requirements, distribution channels used and the resulting SC design. *Appendix A-A* provides an excerpt of our semi structured questionnaire.

Data analysis is conducted according to Miles and Huberman (1994), who distinguish between three interdependent data analysis processes (data reduction, data display, and conclusion drawing and verification). As a first step we transcribed the interviews, to get an overview of the statements of the interviewees. Secondly, we reduced the full transcripts to statements that backed or contradicted our hypotheses. Thereafter, we drew our conclusions and discussed them internally. In the verification phase we focused on the internal validity of our case studies. To enhance the internal validity we further discussed our case study findings with the interviewees, ensuring that the results were also valid from the practitioners' points of view (cf. Yin, 2007). Finally, we compared our findings with conflicting and similar literature for crosschecking them with existing theory (cf. Eisenhardt, 1989).

A.3 Literature review

The following literature review discusses research streams supplying criteria for designing differentiated SC strategies and defines the research gap this paper addresses.

The idea of SCD, or SC segmentation, can be traced back to earlier considerations of logistics service level differentiation with respect to the varying logistical requirements of different customer segments (e.g. Gilmour *et al.*, 1977). Fuller *et al.* (1993) argue that logistics must be tailored to the requirements of every distribution channel and to the needs of customers served by these channels. From their point of view, such a logistics differentiation can be a main strategic component because it represents a way to add value for customers. Fuller *et al.* introduce a set of variables for segmenting products and assigning them to different "logistics pipelines". In their opinion, understanding and analyzing customer needs is crucial for meaningful product segmentation.

The criteria for SCD-decisions are also strongly based on SC strategy considerations. Therefore, we can briefly review essential publications related to SC strategy. In defining SC strategies, lean, agile and hybrid strategies may be distinguished. Lean strategies are initially introduced in the manufacturing sector (cf. Krafcik, 1988; Womack *et al.*, 1990). Basically, the concept is focused on cost minimization by eliminating all non-value-adding processes (waste) and is transferred to SCM shortly after its introduction to manufacturing (cf. Hines and Rich, 1997; Hines *et al.*, 1998; Lamming, 1996; Levy, 1997). The discussion of lean (efficient) vs. agile (market responsive) SC strategies was initiated by Shapiro (1984) and Fisher (1997). This dialogue yielded the first criteria for deciding whether a lean or an agile SC strategy is more suitable, given product or market and demand characteristics (cf. Lee, 2002; Li and O'Brien, 2001; Mason-Jones *et al.*, 2000b). Hybrid SC strategies (Naylor *et al.*, 1999) are based on decoupling points in logistics literature (cf. Bucklin, 1965; Hoekstra *et al.*, 1992) and combine lean and agile SC strategies for creating "leagile" approaches that increase the number of SC solutions. In addition to the lean (make-to-stock) and agile (engineer-to-order, source-to-order) strategies, hybrid approaches (make-to-order, assemble-to-order) are available. The criteria for determining which hybrid approach and which position of the customer order decoupling point fit – according to product or demand characteristics – are discussed in literature (cf. Bruce and Daly, 2004; Christopher and Towill, 2001; Christopher, 2000; Christopher and Towill, 2002; Mason-Jones *et al.*, 2000a; Mason-Jones and Towill, 1999; Olhager, 2003; Olhager, 2010; Sun *et al.*, 2008). Furthermore, the discussion of positioning a customer order decoupling point is very similar to the discussion of the optimal degree of custom-made production in mass customization approaches. The strong relationship between mass customization capabilities and relationships in SCM has been explored in recent years (cf. Liu and Deitz, 2011).

The criteria used to decide whether a lean, agile or leagile SC strategy is suitable in a specific situation are also introduced in the discussion on differentiated SC strategies. Christopher and Towill (2000) present the so called DWV^3 model, later published by Childerhouse *et al.* (2002). The model incorporates five product- and demand-focused variables (duration of product life cycle, time window for delivery, demand volume, product variety and demand variability) and is used to analyze the product portfolio of a company. Several product clusters are formed; for each product cluster, a suitable generic delivery-focused SC strategy is chosen, e.g. make-to-order or make-to-stock. Some publications test and validate the DWV^3 model (Aitken *et al.*, 2003; Aitken *et al.*, 2005). Additionally, Christopher *et al.* (2009) and Godsell *et al.* (2011) present evidence that the regarded case determines which variables of DWV^3 must be considered. A further segmentation approach, similar to the DWV^3 model, is presented by Lovell *et al.* (2005).

Other publications on SCD do not focus on the criteria and variables for the derivation of differentiated SCs. Hilletofth (2009) stresses the importance of employing varying sourcing, manufacturing and distribution strategies in order to differentiate a SC and presents empirical results from two Swedish companies. Barratt (2004) states that a segmented approach should be introduced to SC relationship management and strong collaboration should be limited to a small number of customers and suppliers crucial to the company's business.

These contributions represent the state of the art in the core research area targeted by this article. The authors combine ideas from SC strategy research and the trend toward effectiveness (market) driven SCM. Some initial approaches to the design of differentiated SC strategies are available, but experts agree that further empirical research in the form of case studies is necessary (cf. Christopher *et al.*, 2009; Godsell *et al.*, 2011). However, the question arises of whether the introduced variables and criteria are complete and how they may be integrated in a framework for SCD-decisions. We address this research gap and survey further relevant decision criteria.

A.4 Conceptual derivation of a SCD-decision framework

Basically there are two main performance goals in SCM, effectiveness and efficiency. Effectiveness in SCM aims at satisfying a customer by means of a higher customer orientation or the achievement of customer service levels, i.e. "doing the right things" (cf. Mentzer *et al.*, 2001). Efficiency is equated with cost reduction through optimal processes or stock keeping levels, i.e. "doing things right" (cf. Mentzer *et al.*, 2001; Zokaei and Hines, 2007). According to Zokaei and Hines (2007), today's rapidly changing customer requirements demand a higher SCM effectiveness orientation. Furthermore, focusing purely on efficiency in SCM does not provide a competitive advantage in the current business environment (cf. Lee, 2004). In the following we briefly introduce our perception of SCD based on the effectiveness and efficiency concepts in SCM, embed SCD in the strategic management context and state our definition for SCD.

SCD is a customer responsive SCM approach. Based on the conditions within a market and customer requirements it seeks to improve the overall effectiveness of SCM, i.e. by providing the product in a way the customer values (in coherence with the market based view based on Porter, 1979; Porter, 1981). SCD draws further on the development of the capability to manage several SCs simultaneously and thereby create an improved utilization of the company's resources (in coherence with the resource based view based on Barney, 1991; Teece *et al.*, 1997; Wernerfelt, 1984). The market structure and the resources of a company directly affect the company's strategy, which is the foundation for SCD. Finally, SCD is inter-organizational since it integrates and is based on differing customer requirements and encompasses differing approaches to supplier management (in coherence with the relational based view of Dyer and Hatch, 2006; Dyer and Nobeoka, 2000; Dyer and Singh, 1998). Hilletofth (2009, p. 25) states a "way to develop a differentiated SC strategy could be to combine different supply, manufacturing and distribution strategies into various SC solutions." The definition of SCD that we use as a basis for this paper includes these suggestions and expands it as follows:

> *Supply chain differentiation (i) is a strategic approach considering market structures and company resources and encompasses the fact that (ii) one market is served with at least two supply chains, (iii) the supply chains are distinct with respect to the degree of customer interaction,*

(iv) the supply chains are standardized to a certain degree (a finite number of product variants is offered through the supply chains and pure engineer-to-order supply chains are excluded), (v) supply chain differentiation is cross-functional and – ideally – inter-organizationally oriented while integrating at least functions in distribution and manufacturing, (vi) the objective of supply chain differentiation is to gain a competitive advantage through higher customer proximity and a diversified customer approach.

The above stated SCD-definition is illustrated in *Figure A-1*.

In the following, we briefly explain our SCD-decision framework. First we will elaborate on the influence of the initial situation of a company's supply chain on the basis of available information and additionally required analyses. Then we will discuss our framework of differentiation variables. Our framework consists of two parts, one ensuring effectiveness and the other acting as an efficiency constraint. The effectiveness ensuring part includes two decision variable categories: (a) customer interaction, and (b) product and demand characteristics. These variables give insights into possible SC design features. Finally we will discuss the efficiency constraints.

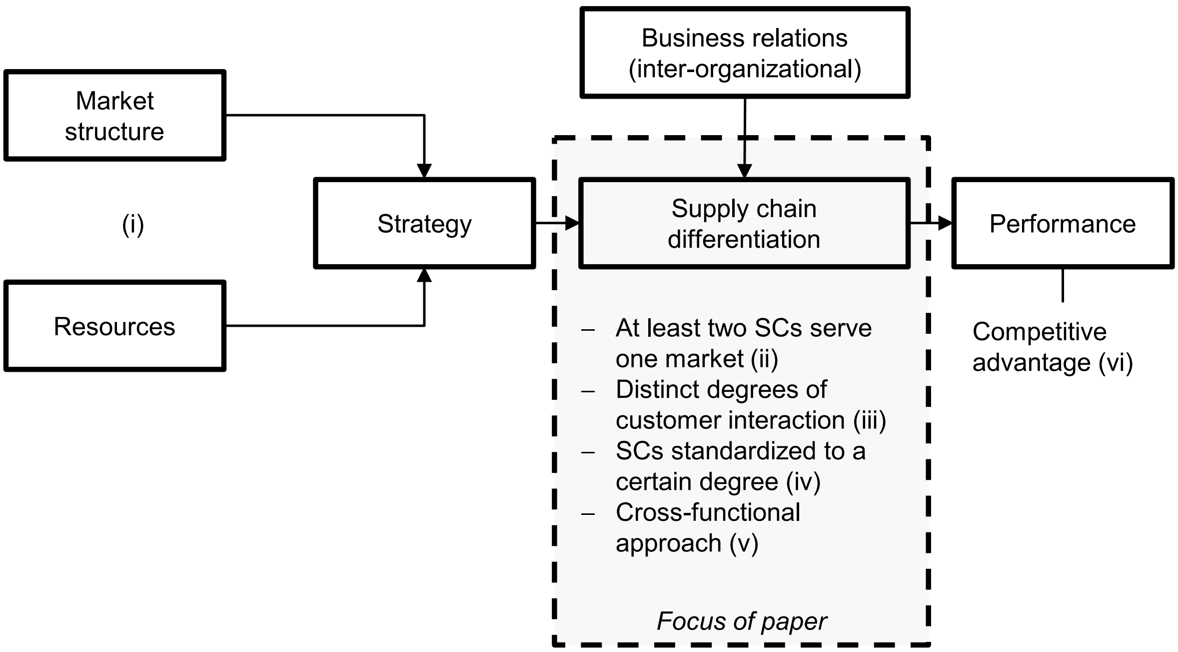

Figure A-1: Embeddedness of SCD in strategic management context

The *initial situation* defines which information is available for the SCD-decision. For example, if a company considers differentiating a push or MtS SC, the information on demanded product variants is restricted to the product variants the company currently offers. Knowledge regarding the demanded customer interaction is also limited. However, if a company differentiates a pull or make-to-order (MtO) SC, more information will be available. E.g., for the past few years, Dell has been differentiating its SC (cf. Davis, 2010). Since Dell operated a MtO SC and offered a broad spectrum of product variants, information regarding their product variants and a suitable degree of customer interaction was available and was used for demand profiling. However, when Adidas Salomon introduced a MtO SC in addition to their MtS SC for regular products (cf. Berger and Piller, 2003), they had only limited knowledge of the demand for product variants and customer interaction. In such cases, additional investigations into customer requirements in the following areas of analysis in the effectiveness ensuring part of the framework may be proposed. For example, Griffin and Hauser (1993) suggest the application of quality function deployment for the integration of customer requirements in the design of new products and services. Naylor *et al.* (1999) recommend the translation of customer requirements directly into order winner or order qualifier criteria, which may be utilized for the formulation of SC strategies. In a recent publication, Aguwa *et al.* (2012) provide a procedure for integrating customer requirements in the determination of critical targets for design process of products or services. They introduce a new method for the estimation of a customer satisfaction ratio, which is meant to increase, for example, quality perception of the goods or services. *Figure A-2* presents the required analyzes depending on the initial situation.

A.4.1 Effectiveness ensuring part

The basic rationale of SCD is that “one size fits all” SCM approaches are not up to date, since different customer groups’ requirements cannot be satisfied through one SC. Therefore, the main goal of SCD is to ensure effectiveness by using several SCs. We will now explain differentiation variables, which are important to the effectiveness ensuring part of our framework.

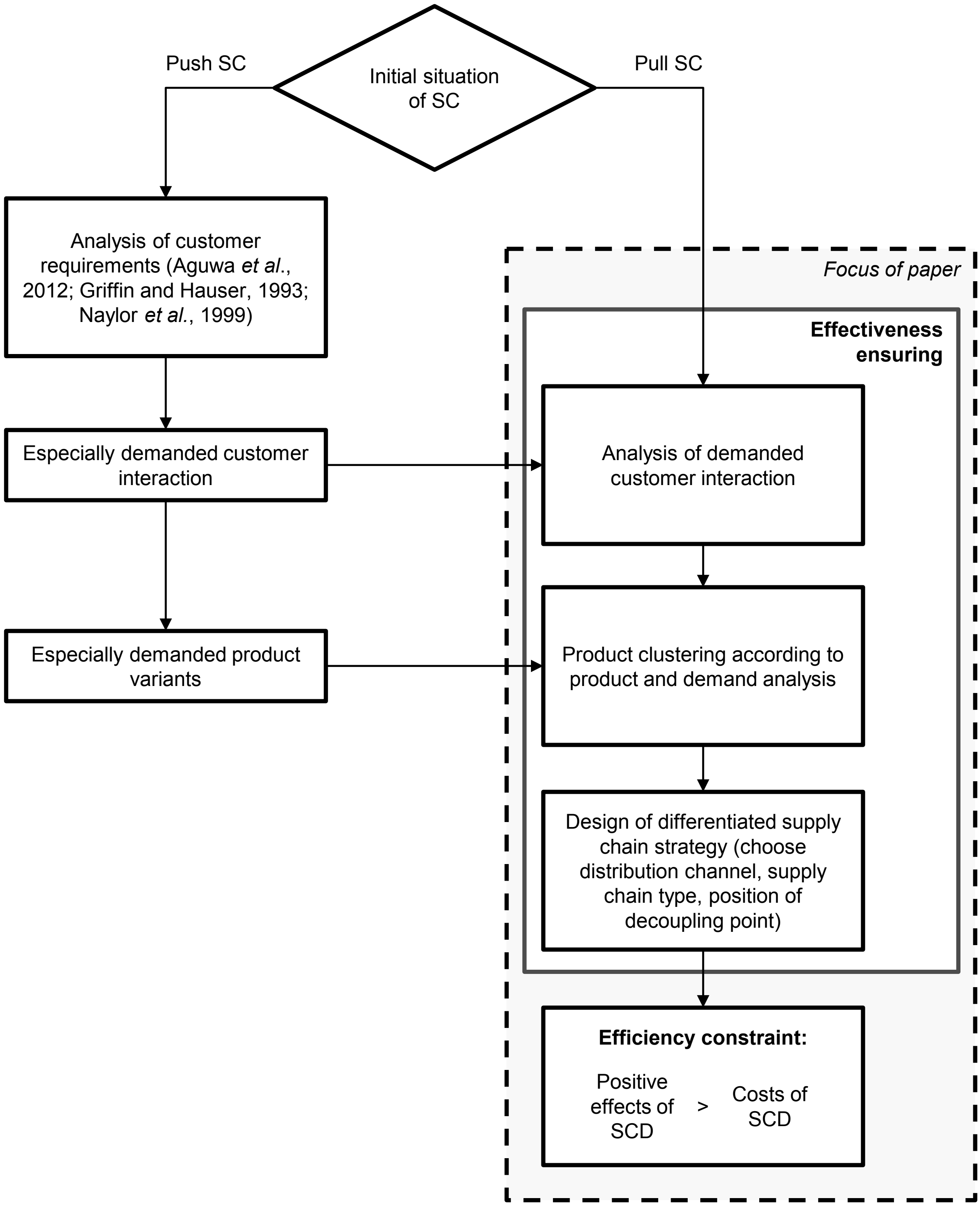

Figure A-2: Initial situation of the regarded SC and its influence on required analyses

Customer interaction

An exclusive concentration on product and demand characteristics for SC differentiation is questionable; customers and their requirements must also be integrated in a SC differentiation approach. A promising opportunity to address these requirements is to consider customer interaction. Stemming from service-dominant logic (cf. Vargo and Lusch, 2004) and one of its basic premises, “the customer is always co-creator of value" (Vargo and Lusch, 2008, p. 7), academics increasingly utilize a co-creation perspective to integrate customer requirements in SCM. Jüttner *et al.* (2010) integrate the "customer participation intensity" into a segmentation approach by differentiating between "co-production" and "co-design". We support these arguments and propose the inclusion of a co-creation-based customer interaction analysis in decisions on SCD. However, the operationalization of customer interaction is not a trivial task. The differentiation between co-production and co-design in the value adding process seems insufficient. Co-design indicates that the customer is integrated in the design process before the manufacturing process even starts. Co-production covers the whole manufacturing process and is therefore not sophisticated enough. Therefore, we suggest the integration of the following indicators for demanded customer interaction: information sharing, demanded influence on distribution, demanded influence on manufacturing, and demanded influence on sourcing.

Information sharing has the potential to reduce risk and decrease inventory costs in SCM, since the demand variability is decreased (cf. Li and Gao, 2008). Therefore, information sharing is perceived as a main contributor to coordinated SCM. However, a high level of information sharing also indicates a stronger partnership and cooperation between SC partners. In demanded customer interaction, information sharing is the first indicator for an influence of the customer on any process of the supplier of these goods or services.

An integration of demanded influence of customers on distribution seems natural. A differentiation between distribution processes, especially logistics of distribution, is probably one of the earliest discussed kinds of differentiation (see for example Gilmour *et al.*, 1977). Furthermore, the customized delivery of goods often occurs in business practice. For example, the delivery of intermediate products in automotive production via just-in-sequence is an essential part of supplier and automotive manufacturer value co-creation.

The core of customer interaction and the co-creation of value, however, lie within the demanded influence of customers on the manufacturing process. In this phase, the customer is actually able to intervene in the configuration of a product or a service and tailor it to his needs. Therefore, the value in use of the product or the service is fundamentally altered through customer interaction on this phase of the value adding process. Furthermore, the analysis of customer interaction regarding their intrusion in the manufacturing process is coherent with the previously proposed analysis of demanded product variants (when differentiating a make-to-stock SC).

In rare instances, customers also demand to influence the sourcing process in a manufacturing company, e.g. through demanding the use of specific raw materials or even specific sub-supplier ("intel inside"). Due to the principle of completeness, we suggest the integration of this variable too.

Product and demand characteristics

We have broadly discussed publications regarding variables for the analysis of product and demand characteristics in our literature review. Fuller *et al.* (1993) present a set of 21 variables in five different categories focused on demand and product characteristics as well as value adding services of distribution logistics. Childerhouse *et al.* (2002) provide an overview of variables for the analysis of products, as well as demand analysis and propose using the DWV^3 model, as introduced in the literature review. Until now, this is the most discussed and applied model for demand profiling in academia. The considered variables are "duration of (product) life cycle", demand "volume" and "variability", and "product variety". Since the DWV^3 model has been tested several times and seems to yield adequate results, we can incorporate the model in our framework.

We will now briefly point out the importance of the variables to our framework. The most significant variables within the DWV^3 model are demand volume and variability. These variables give important clues to whether the demand pattern of a product is suited for a certain kind of SC. For example, a high volume, low variability product may be provided to markets by means of a MtS SC, whereas low volume, high variability products are more suited for a MtO SC. Classifications of products or SKUs using demand volume and variability are often found in literature (e.g. Vitasek *et al.*, 2003). The variable variety is defined by number of different product variants. A high number of product variants is often an indicator of a meaningful SCD, since the product variants differ with respect to demand volume and variability. However, the variable becomes obsolete if the demand analysis is conducted on SKU-level (cf. Godsell *et al.*, 2011). The variable duration of life cycle refers to the product life cycle. Products with a longer life cycle, like kitchen appliances, can be held longer in stock, while highly technical products, e.g. personal computers, require shorter stock keeping times because their decrease in value is economically unacceptable. The time window for delivery relates to possible lead time of a product. Certain customers demand lead times impossible when using a MtO approach. In these circumstances, the company must keep the product in stock in a MtS SC.

Table A-1 summarizes the statements above and presents further reasons for the integration of the variables discussed. Which variables are relevant to a specific decision on SCD depends on the company and case (cf. Christopher *et al.*, 2009; Godsell *et al.*, 2011). Often, a focus on demand volume and variability is sufficient to decide which products should be manufactured lean and which products should be manufactured in an agile SC. However, if the customer expects a short lead time

Table A-1: DWV^3 variables and explanation (Source: Childerhouse et al., 2002)

Classification variables	Key reasons for use within value stream classification system
Duration of life cycle	− Short life cycles require rapid time to market and short end-to-end replenishment pipelines − The value stream is required to “fast track” product development, manufacturing and logistics − Replenishment lead times vary according to stage within the product’s life cycle
Time window for delivery	− Rapid response is required to replenish fashion goods that are selling well at a particular point in time − Competitive pressures are continually reducing acceptable response times − Many value streams compete on the basis of very short windows for delivery of customized products
Volume	− High-volume mass markets allow for lean-type production and make-to-forecast strategies − Lower volume markets benefit from flexibility throughout the entire demand chain
Variety	− Greater variety results in a larger number of SKUs − Continuous appraisal of the split between variants required during the product’s life cycle − Variants popular at the introductory stage may be less popular in the decline stage
Variability	− Variability relates to both demand and supply predictability − Spikes drastically affect capacity utilization and resultant production techniques − Unpredictability increases the risk of obsolescence and lost sales

for the products in question, the results of a demand volume and variability analysis may be irrelevant, since increased lead times will not allow the company to sell a single unit using an agile SC.

Finally, we must stress the interdependence of variables in customer interaction analysis and in product and demand analysis. Certainly, a high demanded customer influence on manufacturing and customization indicates low volume and high variability of the single SKU, as well as a high number of product variants. However, from our point of view, analysis of demand volume and variability is not obsolete, since this is an analysis of realized demand for a given product (quantitative), while demanded customer interaction is future oriented qualitative analysis. The combined analysis of both areas will enrich the information provided for a decision maker.

Standardized SC design components

After the analysis of customer interaction and as well as product and demand characteristics, an appropriate SC design must be set up. We can restrict the discussion to substantial SC design components that are highly generalizable, i.e. distribution channels, SC strategy, SC type and position of the decoupling point.

In examining distribution channels, the question can be raised as to which customers receive their products through which channels. The combination of customers and assigned distribution channels may lead to different requirements for SCM. Use of different distribution channels, especially if direct and indirect channels are combined, fosters the implementation of SCD. While direct distribution channels often have lower volumes and higher degree of customer interaction, indirect distribution channels are primarily concerned with high volume and customer unspecific orders.

We integrate SC strategy by means of the manifestations lean, leagile and agile. While low demanded customer interaction and high demand volume, combined with low demand variability, suggest a lean SC strategy, and high demanded customer interaction coupled with low demand volume and high demand variability requires an agile SC strategy. Competitive priorities – an alternative to the previous description of a SC strategy (order winner & order qualifier) – would be another appropriate expression of SC strategy. According to Ketchen and Hult (2007), these competitive priorities are lead time (or speed), flexibility, quality and costs. Lean

SCs are rather cost oriented and agile SCs are focused on flexibility (cf. Agarwal *et al.*, 2006).

The SC strategy is strongly related to the SC type (or manufacturing strategy) chosen. Lean SC strategies often result in MtS or deliver-to-order (DtO) SCs. Leagile SC strategies most often lead to an assemble-to-order (AtO) SC and the SC types MtO and source-to-order (StO) are categorized as agile approaches. The consideration of a suitable SC type includes the positioning of the decoupling point (cf. Olhager, 2003).

Our SCD-decision framework that integrates relations between the standardized SC design components and variables in the customer interaction as well as product and demand analysis areas is summarized in *Figure A-3*.

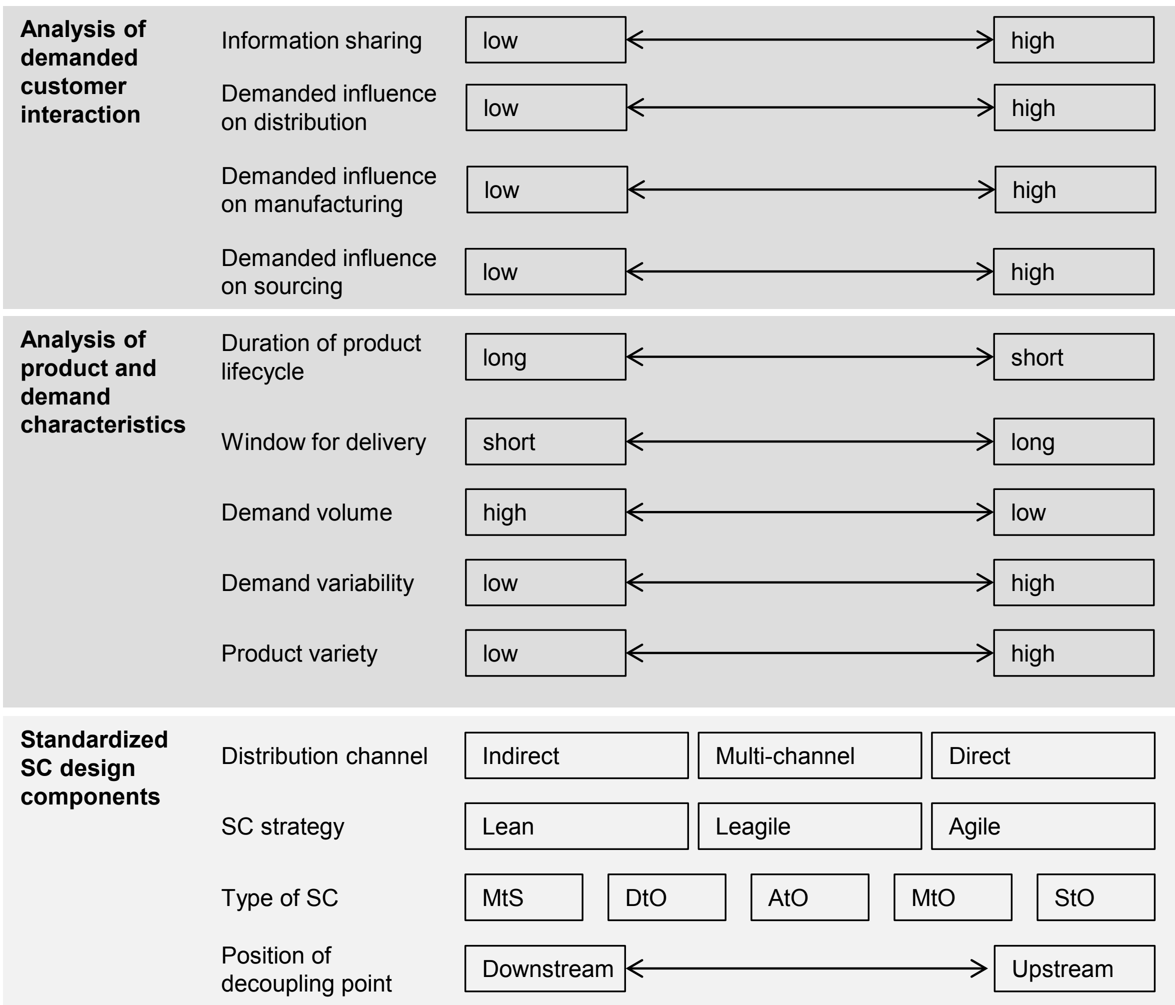

Figure A-3: Integrated SCD-decision framework including criteria categories, variables and standardized SC design components

A.4.2 Efficiency constraint

Even if our proposed SCD framework is focused on customer orientation and on effectiveness, efficiency must be considered. To facilitate this, we integrate a plausibility check, which ensures that the positive effects generated by differentiated SC design are not overcompensated through costs incurred by SCD. The goal of the proposed framework is to find the number of concurrently operated SCs that also yields the best financial performance. This goal is endangered if an extensive number of SCs is used to satisfy customer needs, since this may lead to poor operational performance and substantial cost increases (cf. Christopher *et al.*, 2009).

In the following, we summarize positive effects of SCD mentioned in literature. Childerhouse *et al.* (2002) present a case study of an UK lighting manufacturer that implemented a differentiated SC. They report a “reduction in product development time of 75%; manufacturing costs reduction of up to 27%; and up to 95% reduction in delivery lead times” through SCD. Davis (2010) presents the SCD efforts of Dell in recent years. The Dell managers state increased customer proximity by providing the customers with exactly what they want and a complexity reduction through decreasing the number of provided product variants on the basis of customer requirements. Furthermore, internal cross functional cooperation was increased and a cost reduction realized due to complexity reduction as well as simplified design. Finally, forecast accuracy is improved as a further result of the complexity reduction.

An additional possible positive effect of SCD is a revenue increase from entrance in new markets or the penetration of existing markets. If a company switches from a “one size fits all” MtS approach to a differentiated supply chain and offers customized products, these customized products sell normally at higher prices, e.g. customized shoes of Adidas sell on average on a 30% higher price (Berger and Piller, 2003). Moreover, Mayer *et al.* (2009) conducted a survey of 150 European manufacturers and their SCM approaches. They state that companies that utilize a differentiated SC approach on average have lower days of inventory carrying, higher percentage of orders on time and significantly lower logistics costs.

As presented above, several academics state cost reductions as positive outcomes of SCD. Yet, one has to bear in mind that these reported results are due to thorough analyses with respect to an optimal SCD design. Possible costs incurred by SCD are, for example, coordination costs, higher costs for employing different logistics service providers or opportunity costs for unutilized production capacities. Therefore, we propose to estimate the incurred cost of SCD and track whether a cost reduction will be outcome in a specific SCD decision. If no cost reduction will be achieved by means of the differentiated SC design, other positive effects must outweigh the SCD costs. This is a crucial point of our SCD framework. A possible structure for these cost estimations is presented by Pettersson and Segerstedt (2012), who introduce a model for the measurement of SC cost. They divide SC costs in six categories: manufacturing cost, administration cost, warehouse cost, distribution cost, capital cost, and installation cost.

A.5 Empirical results

A.5.1 Description of case companies

Case A analyzes the SCD-decisions (two units of analysis) of an international printer manufacturer. For the case study, we examined the company's SCs for their European businesses. Case company A manufactures a broad product line, from low-end consumer printers to industrial printing machines. Case company B is a multinational producer of communication equipment. They produce cable solutions based on fiber and copper technology. Due to the complexity of such solutions, they offer a wide range of different solution variants. Case company C is a globally acting manufacturer for machinery and equipment for the building industry as well as for consumers use. A summary of the company characteristics is given in *Table A-2*.

Table A-2: Case company characteristics

Case	# of employees 2011	Revenue 2011	Geographical scope	Industry (NACE description)
Case A	70,000	24 bn. US $	Global	Manufacture of consumer electronics Manufacture of office machinery and equipment
Case B	600	210 m. US $	Multi-national	Manufacture of wiring and wiring devices
Case C	20,000	5 bn. US $	Global	Manufacture of machinery and equipment n.e.c.

Note: rounded figures

A.5.2 Case A

Over the last 15 years, case company A actually decided twice to differentiate their SC. Therefore, we can consider two embedded units of analysis in case A.

Unit of analysis 1

The first differentiation occurred approximately 15 years ago. In the *initial situation* before the decision the company already operated two different push SCs; the volume low-end and the volume mid-range SC. The volume low-end SC delivered products mainly to consumers via an indirect distribution channel, using a MtS SC with a lean strategy and a focus on costs. The volume mid-range SC delivered products to consumers, small and medium sized businesses as well as large enterprises, mainly via an indirect distribution channel, incorporating a combined MtS/AtO SC with a lean strategy and a focus on costs, meaning that the company already operated multiple SCs. Yet the SCs were only differentiated in the manufacturing area. The sourcing, distribution and the customer interaction were the same.

The trigger for the differentiation of their SCM was a growth decision. The board decided to acquire a firm that provided larger scale products mainly for print service providers. The acquired value-standard SC provided its products to small and medium sized businesses, to enterprises and to print service providers. Besides the indirect distribution, the value-standard SC also used a direct distribution channel. The strategy of this SC was rather leagile with a focus on lead time and flexibility. The interviewee explained that, in their company, not all SCD-decisions are made according to customer requirements. Often, internal considerations regarding costs and synergies between different SCs have a high priority in such decisions; i.e. the newly acquired firm and thereby the value-standard SC were examined for an integration in one of the other SCs. However, their analyses revealed that no synergies and cost advantages would result from merging this SC with another SC. Therefore, e*ffectiveness ensuring* considerations have not been the focus of this differentiation. As the case company constantly analyzes whether to change their SC design, it investigated whether a change to an AtO or MtO SC would make sense for the value-standard SC after the acquisition. Yet, the customers demanded short lead times, which are only realizable by means of a MtS SC. The *efficiency constraint* for this specific SCD-decision was clearly more highly prioritized than considerations of effectiveness. Due to the estimation that synergies of merging the new

SC with the already existing SCs would be low, the company concluded that the operation of three SCs would be less cost intensive than merging these SCs.

Unit of analysis 2

Approximately three years ago, case company A took a second SCD-decision. Again, the trigger for this differentiation was a growth decision. In this case they developed a new product and designed the value high-end SC upstream from the customers. In the *initial situation* case company A operated the three SCs described above, which were mostly push SCs. Hence, case company A had to analyze customer requirements with respect to the value high-end SC. For this specific SCD-decision, *effectiveness ensuring* reflections had a high priority. Since the customers desired a high customer interaction, the value high-end SC had to be designed completely different compared to already existent SCs. Customers demanded a high influence on distribution and manufacturing, which also implied a high information exchange with customers. Regarding variables for product and demand analysis, "time window for delivery" (lead time) has historically been the most important factor influencing the design of their SC. Yet, these customers were prepared to accept longer lead times for the products provided by the value high-end SC. Therefore, case company A was not forced to introduce a MtS SC. Furthermore, the customers demanded a high number of product variants. Hence, it was expected that for the single SKU, provided by the value high-end SC, demand volume would be low and demand variability would be high. Due to these customer requirements and expectations, case company A implemented a SC design, which integrated only direct distribution and utilized an agile SC strategy. The competitive priorities chosen for this SC were quality and flexibility. The implemented SC type was MtO and the decoupling point was positioned upstream. Regarding the *efficiency constraint*, the company expected high revenues from the products provided. On the other side the company also assumed that manufacturing and distribution costs would strongly increase in this new SC. Yet, the revenues were estimated to significantly overcompensate for the incurred cost of the SC differentiation.

Case company A dynamically adapts its SC design to developments in markets, resource prices, technologies etc. Besides the above described differentiation within unit 1 and 2, they introduced a services SC. Since this SC is only an add-on process to SC2 (volume mid-range SC), we will describe it briefly. In this SC, they do not sell their products, but sell the service to manage their customers' complete printer fleet. The most extreme manifestation of this business model is a so called "pay-per-page" model, which follows increasingly implemented performance based contracting. A summary of the differentiated SCs of case company A and the variables relevant to their SCD-decision is presented in *Figure A-4*.

A.5.3 Case B

Case company B serves two main customer segments. The private segment incorporates solutions for companies from different industries, as well as consumer solutions. The public segment consists of telecommunication companies, which build information and communication infrastructure.

An increasing demand for non-standard solutions triggered the implementation

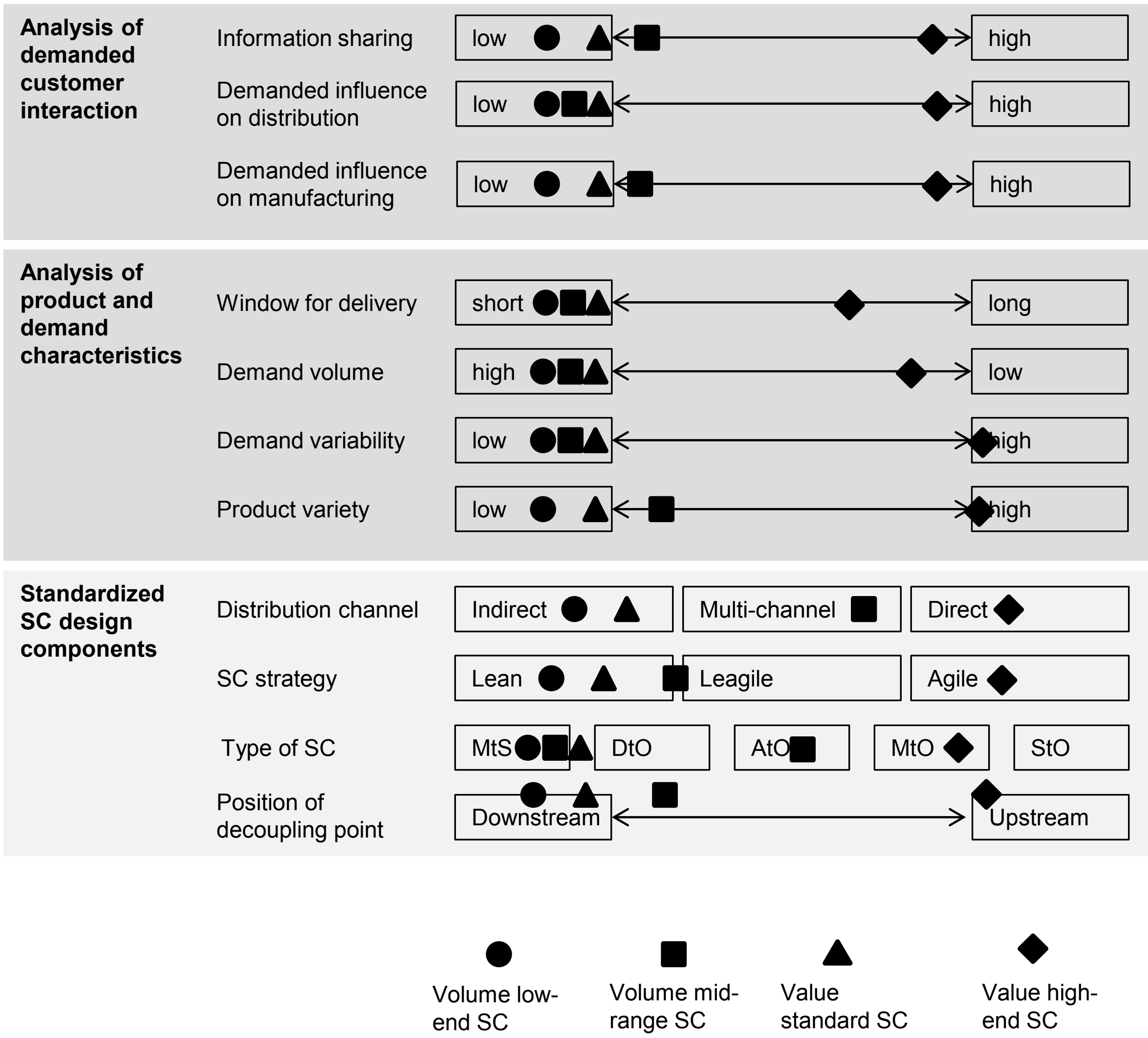

Figure A-4: Relevant SCD-decision criteria and SC design of case company A of a differentiated SC in case B. The company realized that they could not satisfy this demand using a pure MtS configuration in their SC, since the stock keeping of these variants would be impossible. They therefore introduced a new business model and designed two differentiated SCs. Since the *initial situation* in case B was a push SC, they had to analyze the customer requirements relevant for their SCD-design decision. Due to their high customer proximity in distribution, they had a very good knowledge of demanded solution (product) variants. Besides their standard SC they introduced a high-end SC. Since the high-end SC was introduced to cover the growing demand of non-standardized solutions, this SCD-decision was mainly due to a corporate growth strategy and to stay competitive. *Ensuring effectiveness* in form of providing customers with solutions tailored to their needs was the main concern of the differentiation of case company B's SC. A high degree of information sharing with customers was crucial to the successful operation of the high-end SC. The distribution of the high-end SC differed from project to project and customers had a strong influence on distribution logistics. Furthermore, the customers of the high-end SC demanded a high influence on manufacturing. While the private segment (mainly served by the standard SC) required little to no customization, the public segment (mainly served by the high-end SC) demanded a high customization of its solutions. In some instances public customers even demanded an influence on the sourced material. Regarding variables in the area of product and demand analysis, demand volume and variability are especially relevant. Case company B evaluates on a regular basis, which SKUs are assigned to which type of SC. Lead time considerations ("time window for delivery") were also integrated in their SCD-decision. The lead time demanded by private customers is shorter than the lead time required by the public segment. Due to the high degree of customization, public customers are prepared to accept longer lead times. The new differentiated SC design of case company B integrated a multi-sales channel distribution for the private segment and direct distribution to the public segment. Both SCs, standard and high-end SC, integrate MtS, MtO and StO configurations. However, the standard SC mostly operates the MtS configuration (80% of produced SKUs) and the high-end SC primarily the StO and MtO configuration (80% of produced SKUs). They strongly increased the offered solution variants by introducing a StO and a MtO SC configuration in addition to their MtS configuration. Furthermore, they wanted to increase flexibility offered to customers, especially for the public segment. From their point of view, flexibility lies within the opportunity to switch between MtS, MtO and StO configurations within both their SCs. With respect to the *efficiency constraint,* the company had to decide between two scenarios in order to remain competitive. Offering the demanded broader range of solution variants by a "one size fits all" MtS SC and storing all SKUs, or switching to a differentiated SC design and manufacturing certain SKUs if needed. Their cost estimations were clearly in favor of the differentiated SC design. *Figure A-5* summarizes the differentiated SC design and the relevant decision variables in for case B.

A.5.4 Case C

Case company C delivers its products to two main customer segments, industrial users and consumers. As apparent from the SCD-definition stated in Section 4, it is possible to operate more than one SC for a market, but not to apply SCD. This is

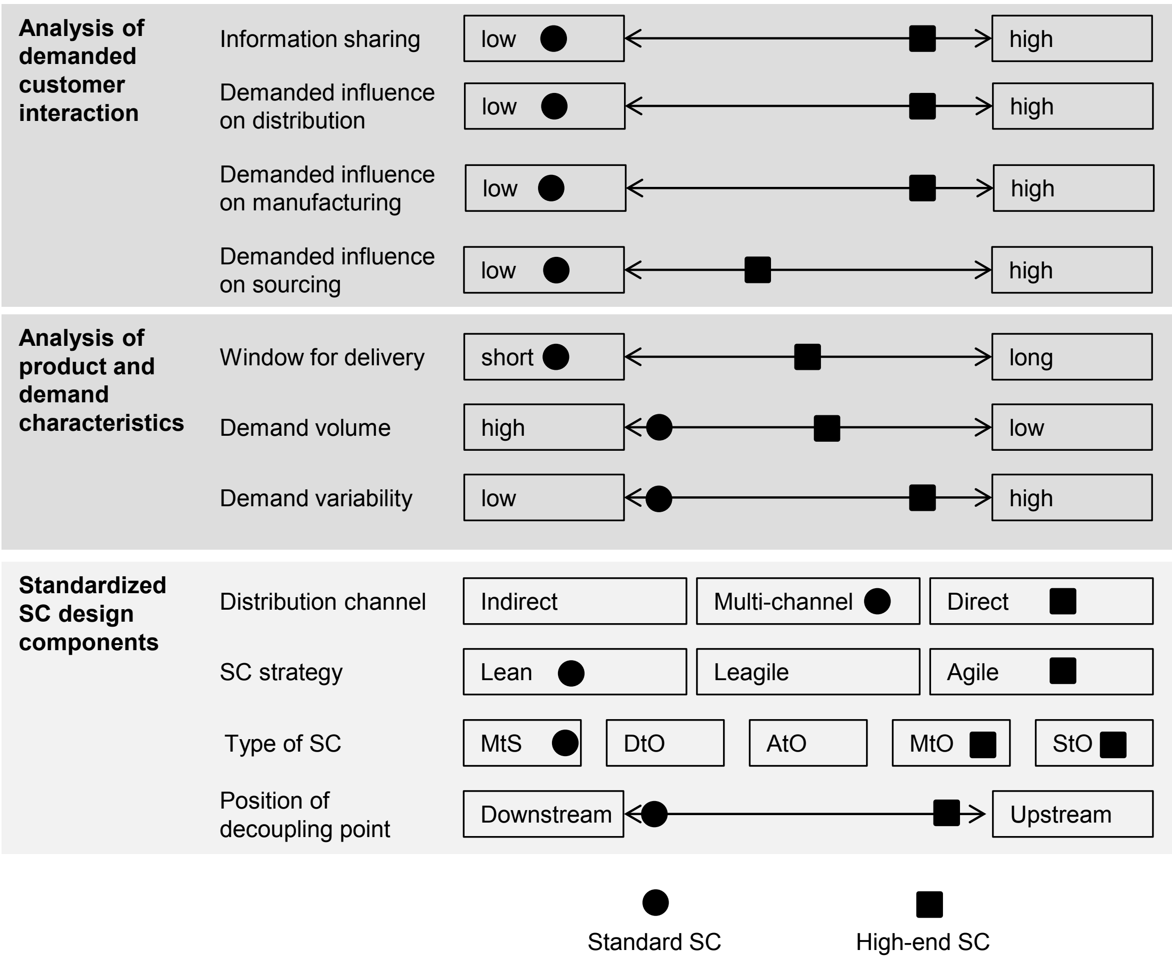

Figure A-5: Relevant SCD-decision criteria and SC design of case company B true for case company C. The company operates multiple push SCs, which are not distinct with respect to the degree of customer interaction. Moreover, the unit of analysis slightly differs for case company C, since the company did not consider differentiating their SCs. However, case company C decided on whether to implement geographical postponement by combining it with a hybrid manufacturing strategy, which is strongly related to SCD.

In its *initial situation* case company C already operated several push SCs. Since their sales force is in constant exchange with their customers, they had a very good knowledge of their customers' requirements. Regarding the *effectiveness ensuring* part of our framework, we briefly state the main reasons for the implemented "one size fits all" SC approach of case company C. The data analysis indicated that the relatively low number of product variants was the main cause for the current SC design of case company C. Furthermore, the demand volume for their products was high and demand variability was relatively low. The duration of product lifecycle for all their products was high, since technological change is slow in their market. Hence, their products are suited to be stored for longer time periods. Additionally, their customers do not seem to demand a higher level of customer interaction. Overall, these circumstances do not offer sufficient reason for an implementation of a differentiated SC. Therefore, case company C operated an indirect distribution channel for two customer segments, industrial and the private customers. The company rejected the implementation of a postponement concept for the production of their products and mainly operates according to a push concept. However, some products are produced using a pull organization. Yet, their SCs are not differentiated with respect to their distribution system and the levels of customer interaction in their SCs. Since the effectiveness ensuring part already suggests no meaningful implementation of SCD for case company C, an *efficiency constraint* was not necessary for conducting an economic plausibility check for SCD. The summary of the differentiation variables and the SC design of case company C is presented in *Figure A-6*.

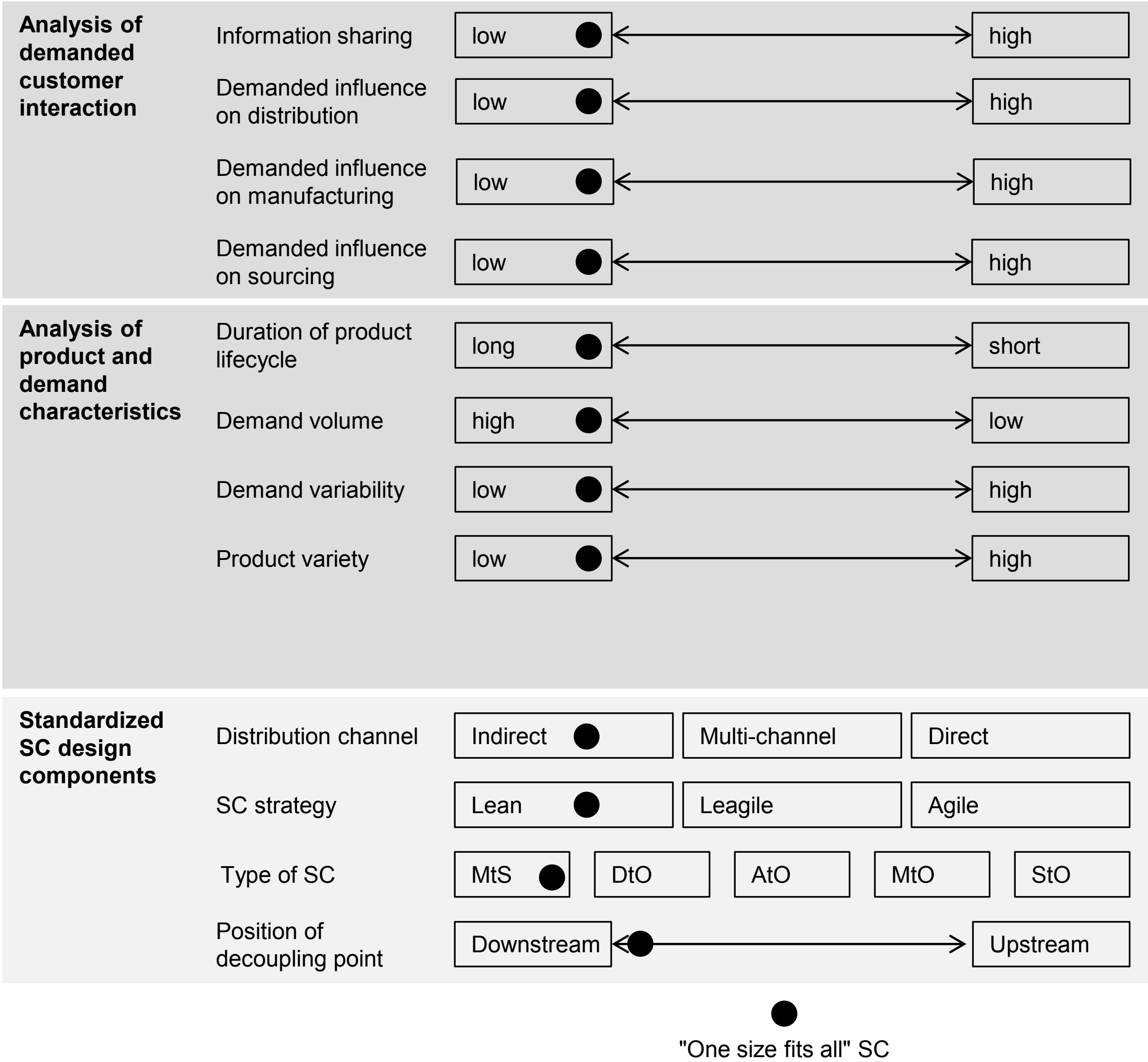

Figure A-6: Relevant SCD-decision criteria and SC design of case company C

A.6 Discussion and outlook

A.6.1 SCD-decision framework related findings

In this section, we discuss our findings and compare them to supporting or conflicting literature, to ensure the internal validity of our case studies (cf. Eisenhardt, 1989). We can begin by critically reflecting the findings which are directly linked to the SCD-decision framework. These findings are confirmations or falsifications of our conceptual considerations.

As previously stated, the *initial situation* of the SC design, push or pull SC configuration, has to be considered when setting up a differentiated SC design, since the information basis differs strongly in these situations. Depending on the initial SC configuration, a thorough analysis of demanded customer interaction, demanded requirements regarding distribution channels and demanded product variants should take place (in case of push configuration). Case A and B support this statement. The SCD-decision in case A unit two and the SCD-decision in case B both implemented a pull oriented SC besides the earlier push oriented SC. For both decisions, the customer requirements were analyzed to broaden the information basis of the decision.

The main objective of any SCD-decision is to increase competitiveness by means of improved customer proximity and a differentiated customer approach. Therefore, *effectiveness ensuring* considerations are of particular importance for this customer-oriented SCM approach. From our point of view, an analysis of customer interaction is a meaningful extension for designing differentiated SC strategies. This proposition is coherent with the postulation of a higher degree of integration between marketing and SCM (Jüttner *et al.*, 2010). Moreover, the proposition goes hand in hand with the foundational premise of service-dominant logic that "the customer is always a co-creator of value" (Vargo and Lusch, 2008, p. 7) and thereby contributes to the further development of the SCM discipline. All our cases indicate that differences in demanded customer interaction are a main reason for the implementation of a differentiated SC design. In case A and B, SCD was introduced due to differences in demanded customer interaction. For case company C, one reason that SCD is irrelevant is the homogeneity of demanded customer interaction. As our case study findings suggest, a high degree of customer interaction indicates that an agile SC (MtO) is appropriate (see *Figures A-4* and *A-5*). All the suggested variables in this area seem to be relevant. Information sharing is of crucial importance to collaborative SCM (cf. Fawcett *et al.*, 2007). In all cases with differentiated SC, there have been considerable variations in information sharing. Furthermore, the distinction between demanded customer influence on different value adding processes (distribution, manufacturing, sourcing) appears to be useful in terms of assessing the sophistication of customer interaction. While in case A, customers only demanded influence on distribution and manufacturing, in case B customers also demanded influence on sourcing.

There are certainly strong interdependencies between variables in customer interaction and variables in the area of product and demand analysis. For example, a high degree of customer interaction leads to an extensive number of product variants, due the customization of products. However, the incorporation of customer interaction in the design process of a differentiated SC strategy yields a more comprehensive view of cause and effects between customer requirements and a differentiated SC design. Furthermore, an analysis of demanded customer interaction gives clues about a suitable decoupling point position in the SC.

The areas of product and demand, as well as the DWV[3] variables have been broadly discussed in relevant literature (e.g. Childerhouse *et al.*, 2002). Our results confirm earlier findings. E.g., whether all or only selected variables are relevant to a SCD-decision is case-related (cf. Christopher *et al.*, 2009). The duration of product lifecycle was only in case C a primary variable. In case B the variable was considered. Due to the value stability of their products, case company B is able to store its products over a longer time horizon. If the products are on stock for half a year, the value decrease is negligible. Since this is true for all their products, the SCs were not differentiated with respect to this variable. Hence, a long product lifecycle allows for lean SC strategies (MtS), while short product lifecycles demand agile SC strategies (MtO) (cf. Aitken *et al.*, 2003). The window for delivery (lead time) was a relevant differentiation variable in all case studies, especially when the customers demanded a high degree of customization they were prepared to accept longer lead times. In our case studies, a long window for delivery indicated that an agile SC strategy (MtO) is appropriate; a short window for delivery favored a lean SC strategy (MtS). This finding is consistent with literature (cf. Christopher *et al.*, 2006). The variables demand volume and variability were proofed as being the most important for assigning SKUs to different types of SCs. High demand volume and low variability suggest the implementation of a lean SC strategy (MtS) and low demand volume and high variability imply that an agile SC strategy (MtO) may be more appropriate. Again, this finding coincides with literature (cf. Vitasek *et al.*, 2003). Finally, the variable product variety was relevant in case A, where differences in product variety were one reason for the differentiation of the SC. In case C, the low product variety of all product groups led to the perception that SCD was not a meaningful approach for the company. However, if the product and demand analysis is conducted on SKU level, the variable product variety will become obsolete (cf. Godsell *et al.*, 2011).

As our case studies prove, the *standardized SC design components* we integrated in the framework were affected by different characteristics in customer interaction and product and demand characteristics. The most important statements and related literature regarding the influence of the differentiation variables on the SC design are incorporated in the discussion above. The components we considered are suitable for describing a SC design on a low level of detail. However, in a real life application of the discussed framework, more SC design components should be considered in order to formulate a more detailed description of an appropriate SC design.

The *efficiency constraint* prevents the positive effects of SCD from being overcompensated by the costs incurred by SCD. Such an economic plausibility check must be integrated in the design of a differentiated SC strategy. The formation of different product clusters to specific SC configurations is insufficient if the required SC configurations are not implementable due to cost reasons. Thus, an estimation of the costs and benefits (e.g. higher revenues) arising from a differentiated SC should be conducted. In case A unit 1, costs have actually been a differentiation variable. However, that situation was special, since case company A acquired a firm and renounced to merge the SCs of the companies due to the lack of synergy.

A.6.2 Further findings

Beyond our findings directly related to the SCD-decision framework, we gained further general findings with respect to SCD.

As we considered companies of different sizes, different industrial foci and varying geographical scopes, SCD does not seem to be dependent on these circumstances. Even case company C would have implemented SCD if they faced differing demanded customer interactions and a higher product variety. Christopher *et al.* (2009) report case study findings for six different companies that differ in sizes and vary regarding to their industrial foci. Even in fast moving consumer goods industries, which are mostly commodities of low value, SCD is a relevant topic (cf. Godsell *et al.*, 2011). Hence, it may be assumed that SCD is not restricted to specific industries or certain minimum sizes of a company, as long as the company actually belongs to a manufacturing industry. We assume the same for the geographical scope of companies.

In all the cases that we observed, SCD was part of a growth strategy. In case A unit 1, the SCD-decision was part of an anorganic growth strategy. Company A acquired another manufacturer of printers and entered a new market segment. Case A unit 2 was an organic growth strategy, since the company entered a new market segment through the development of a new product line. Case company B did not enter a new market. However, with their decision to differentiate their SC and remain competitive in a fast growing market, they placed their focus on participating in the market growth. Other examples support this finding. Dell differentiated its SC and switched at the same time from a single distribution channel strategy (direct distribution) to a multi-channel distribution strategy (cf. Davis, 2010). Thereby Dell fostered a higher market penetration as they reached customers that prefer to buy their personal computers in retail stores. Adidas implemented a MtO SC for customized sport shoes besides their MtS SC for their standard sports shoes (cf. Berger and Piller, 2003). Whether they entered a new market segment (customized sports shoes) or focused on a higher market penetration through adding a direct distribution channel is perhaps irrelevant and hard to quantify, but the differentiation of their SC was certainly part of an organic growth strategy.

From this link between growth strategy and SCD, a further finding arises; SCD-decisions are mostly top-down decisions and follow, in the cases discussed above, the decisions of top management on the corporate strategy level. This result supports the arguments of academics, such as Fisher (1997) and Hofmann (2010), that the SC strategy has to be strongly aligned with the corporate strategy or that the corporate strategy dictates the SC strategy.

A.6.3 Limitations and future research

The framework we presented is a summary of relevant criteria and variables for SCD-decisions and their influence on a SC design. A possible direction for future research is to further develop the presented framework into a decision support methodology for SCD-decision. As presented, SCD-decisions are subject to multiple conflicting criteria. Hence, suitable decision support methodologies lie within the area of multiple criteria decision making. Future research into decision support for SCD should investigate which methods from multiple criteria decision making are suited for SCD-decisions and integrate the presented set of variables in an appropriate decision model.

With respect to the limitations of our research methodology, our findings are based on three case studies with an embedded unit of analysis. On the one hand, we cannot guarantee that the here presented variables and criteria for SCD-decisions are complete. On the other hand, our qualitative research comes with several sources for biased results. We have tried to avoid causes of possible biases by carrying out our case study research by the book. However, it is hardly possible to exclude all biases; e.g. a biased interpretation of interviewee statements could exist or the case selection could be biased. Furthermore, the generalization of findings from three case studies is only conditionally possible, even if we try to enhance generalizability through the incorporation of case companies from different industries, varying international scopes and sizes. The findings we have presented are mostly consistent with already existing research. Yet, it is still possible that by chance research until now was lucky enough to pick examples for supporting momently established theory regarding SCD. For the exclusion of biases and the generalization of theory on SCD, future research should further examine the findings presented in this and related papers. This could be conducted in form of further qualitative research, e.g. by case studies. Research into SCD has developed a body of new theory and hypotheses regarding operations management that should be tested by means of quantitative research methods. High potential for testing and further developing the theory on SCD and operations management have research methodologies like structural equation modeling (cf. Shah and Goldstein, 2006) and partial least squares, if sufficient numbers of companies that apply SCD are not available (cf. Peng and Lai, 2012).

Finally, research into SCD is still a young and developing field. Academia in operations management to date has only regarded the strategic level of SCD. Research with respect to SCD implementation on process level or resources and capabilities needed for SCD have not yet been investigated.

A.7 Conclusion

This paper presents an investigation of decisions on SCD for the derivation of an integrated SCD-decision framework. Based on conceptual considerations drawn from a literature review, we conducted three explanatory case studies with embedded units of analysis. Within the case studies we utilized semi-structured interviews and collected evidence regarding relevant variables for decisions on SCD. Since SCD is a customer-oriented SCM approach, our framework consists of an effectiveness ensuring part as well as an efficiency constraint, incorporates variables for demand profiling from earlier publications on the design of differentiated SCs (e.g. Childerhouse *et al.*, 2002; Godsell *et al.*, 2011) and integrates variables for the analysis of customer interaction. Our case studies support the relevance of demand profiling and present evidence that the integration of a customer interaction analyses broadens the information basis for decisions on SCD.

The theoretical contribution of our paper is represented by further developing the knowledge of relevant variables for designing differentiated SC strategies. Besides the set of relevant variables we also introduce what kind of effects the relevant variables have on specific SC design components. Academia in operations management may integrate the presented findings in the development of decision support methodologies for differentiated SC strategies. For managers, the framework provides an overview of variables they should consider when deciding on SCD and which results these variables may deliver, especially whether SCD offers a means of improving competiveness through increasing effectiveness.

Appendix A-A: Sample of the semi-structured questionnaire

Question categories	Sample content
(1) Description of the regarded market	– Market size and market growth – Profitability of the companies within the market – Industry structure and maturity – Distribution channels normally used within this market – Trends and success factors in the market
(2) Customers and distribution channels	– Customer segmentation and criteria used for customer segmentation – Special customer segmentation with respect to SCM – Distribution channels used by the case company and description of these channels – Influence of customer segments and distribution channels on SC strategy
(3) Description of (differentiated) SC design	– Number and characteristics of the operated SCs – Connection of SCs to customer segments and distribution channels – Competitive priorities of the SCs – Position of decoupling points within the SCs – Functional strategies (distribution, manufacturing and sourcing) within the SCs – Process structures and performance management systems within the SCs

(4) Decisions on SCD	– Year of the implementation of the differentiated SC design
	– Main reasons for the implementation of SCDs
	– Variables and criteria used for the SCD-decision
	– Influence of customer segments and distribution channels on SCD-decision
	– Effectiveness considerations for SCD-decisions
	    – Importance of customer interaction with respect to SCD-decisions
	    – Importance of product and demand characteristics for SCD-decisions
	– Efficiency considerations for SCD-decisions

B Multiple criteria decision making in supply chain management – Currently available methods and possibilities for future research

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Abstract

Decisions in supply chain management (SCM) are subject to various conflicting criteria and multiple objectives must be considered in the decision process. Furthermore, a group, rather than a single decision maker, is often involved in the process. For such decisions, methods in multiple criteria decision making (MCDM) are certainly appropriate. However, an overview concerning applications of MCDM methods in SCM is not yet available. This paper conducts a literature survey to fill this gap and give an overview of MCDM applications in SCM; a research map is developed to guide researchers interested in this field. We categorize 124 reviewed articles according to application areas in SCM, applied methods, journals, publication year and we ascertain whether the papers incorporate a group decision approach or use empirical support for the MCDM application. A central review finding is the strong growth of MCDM applications in SCM in the last six years, expected to continue in the future. In addition, the application area purchasing is already well covered, contrary to the application area distribution. This article's contribution to academia, as well as business practice, is represented in the MCDM methods overview, currently available for SCM decision problems. We also present potential areas for future research.

***Key words**: Literature review, Supply chain management, Multiple criteria decision making, Multi-attributive utility theory*

B.1 Introduction

A properly functioning supply chain management (SCM) is crucially important in dealing with dynamically changing customer requirements. In fact, in the current business environment, whole supply chains are competing with each other instead of single companies (cf. Li, 2002; Ha and Tong, 2008). While earlier research in SCM was mostly efficiency driven, the focus today moves to effectiveness issues and a stronger customer orientation (cf. Godsell *et al.*, 2011; Zokaei and Hines, 2007). SCM developed from a subject of operational and tactical consideration to a strategic topic within management research and business practice (cf. Hofmann, 2010; Melnyk *et al.*, 2009).

As the importance of certain management areas increases, the need for suitable decision support in these areas also rises. Decision problems in SCM range from single quantitative criterion analyzes to multiple criteria and/or multiple objectives problems, where quantitative as well as qualitative criteria must be incorporated. A very common decision problem in SCM is the single-criterion, purely quantitative consideration of inventory control. For such problems, classical methods only consider costs and minimize them under certain constraints, like customer service. However, even in such cases, authors tend to state that conflicting goals are balanced (cf. Axsäter, 2006). An extension of this problem would be the introduction of a second objective, e.g. simultaneous minimization of costs and maximization of customer service, a bi-objective problem. One SCM problem is supplier selection; its complexity and importance for manufacturers, requires consideration of several conflicting quantitative and qualitative criteria (cf. Wu *et al.*, 2010). Such problems often include objectives like maximizing quality and reliability of the supplier, while minimizing cost and risk linked to the sourced item. All of the decision problems above have a tremendous impact on the success of single companies and whole supply chains. Incorrect decisions may cause decreasing competitiveness or even the collapse of companies or whole supply chains. Due to the importance and impact of correct decisions within SCM, suitable decision support for different decision problems in SCM is relevant and should not be neglected by academia.

Regarding optimization problems, there are many academic contributions about applications of such methods in SCM or topics relevant to SCM. These papers include applications for operative and tactical problems like production and transportation planning, as well as utilization in strategic context, e.g. supply chain network design. These optimization approaches ensure optimal solutions for the considered objective functions and may save money for the company or ensure flexibility in customer service. Several literature reviews give a comprehensive overview of these applications (e.g. Meixell and Gargeya, 2005; Melo *et al.*, 2009; Mula *et al.*, 2010; Tamiz *et al.*, 1998).

However, many strategic decisions are not subject to optimization, as they involve multiple imprecise, uncertain and qualitative criteria. MCDM offers support for such strategic decisions (cf. Montibeller and Franco, 2011), allowing for the consideration of conflicting and qualitative objectives (cf. Ram *et al.*, 2011). Wallenius *et al. (*2008) state that the most crucial support delivered by MCDM approaches to decision makers is probably the structured examination of the decision problem as part of the process. While many applications of such methods to SCM already exist, a literature survey of MCDM methods, allowing the consideration of qualitative information in SCM, is not available yet.

This paper aims to close this gap through a structured literature survey. We answer two research questions (RQs):

RQ a: *Which supply chain management application areas are covered by suitable multiple criteria decision making approaches?*

RQ b: *What multiple criteria decision making trends may develop in supply chain management?*

To answer these questions, we analyze academic peer-reviewed articles, published from 2000 to 2011. We use the literature platforms EBSCO HOST (Business Source Premier) and ABI/INFORM Complete. 334 papers match our search terms and 124 are relevant to the considered topic. We analyze the identified papers within the SCM application areas design, purchasing, manufacturing, distribution, collaboration, logistics, and performance management, deriving research gaps in different SCM application areas. Future trends of MCDM in SCM are deduced through current trends in SCM and in MCDM research, yielding promising prospective research fields.

In the following section, we give a general overview of MCDM. Section three presents the findings of our literature study, first a general description of the development of MCDM in SCM in the considered time frame. The second part of section three categorizes the surveyed articles by their application area in SCM and analyzes selected approaches in detail. In section four, we discuss our findings critically and state current research gaps as well as possible future trends of MCDM in SCM. Section five summarizes our findings.

B.2 Multiple criteria decision making in general

B.2.1 Categorization of multiple criteria decision making methods

MCDM began in the 1960s. Many authors mention the contribution on goal programming by Charnes and Cooper (1961) as the origin of MCDM. Multi-attributive utility theory (MAUT) is sometimes referred to as another research stream of multiple criteria problems (cf. Dyer *et al.*, 1992). However, other authors classify it as a method category within MCDM methods. An early contribution on MAUT is Churchman and Ackoff (1954). In the 1970s and '80s the research streams in MCDM and MAUT evolved in close conjunction to each other (cf. Dyer *et al.*, 1992). The first conference on MCDM was organized in 1972 in South Carolina at Columbia University. A more detailed description concerning the origins of MCDM, especially historical influences, may be found in Figueira *et al.* (2005).

In categorizing different MCDM methods, there is no complete consensus between authors. However, categorizations of MCDM methods do not differ widely. Our categorization of MCDM methods follows Figueira *et al.* (2005), who distinguish multi-objective mathematical programming, multi-attributive utility theory, outranking and non-classical approaches. We chose this categorization, since it most suitably represents research streams within MCDM. An alternative to this categorization is Wallenius *et al.* (2008) who distinguish between discrete alternative problems (finite often small number of solutions) and multiple criteria optimization (high sometimes infinite number of solutions). This classification is related to the categorization we presented; since MAUT and outranking approaches may be summarized under discrete alternative problems, the mathematical programming may be referred to as multiple criteria optimization.

Multi-objective mathematical programming (MOMP) deals with optimization problems incorporating two or more conflicting goals and is mostly concerned with quantitative or simply quantifiable information. Well-known approaches in this area are goal programming and multi-objective linear programming. Goal programming approaches are normally structured in the form of one objective function, which includes the weighting of the different goals. The accurate specification of goal criterion functions are formulated within the constraints (cf. Steuer and Na, 2003). In multi-objective linear programming, the different objectives are each formulated as an objective function, which leads to several objective functions, each subject to optimization (cf. Ehrgott and Wiecek, 2005). Furthermore, data envelopment analysis (DEA) is often referred to as MOMP due to its close relation to such problems (cf. Wallenius *et al.*, 2008).

MAUT is a further class of MCDM methods. MAUT approaches use utility theory and apply it to problems with multiple conflicting criteria. The central idea is to create a sort of value function relating to the decision maker’s preferences. In most cases, the regarded criteria are intangible or hardly quantifiable and the MAUT methods offer a way to objectify the decision maker's implicit knowledge of the problem (cf. Dyer, 2005). The analytical hierarchy process (AHP) and the analytical network process (ANP) (Saaty and Vargas, 2006) are, in several cases, categorized as MAUT approaches (cf. Dyer *et al.*, 1992), since they basically use the preferences of the decision maker concerning solution alternatives with the background of multiple hierarchical or interdependent criteria. Further approaches often summarized under this topic are measuring attractiveness by a categorical based evaluation technique (MACBETH), simple multi attribute rating techniques (SMART), technique for order preference by similarity to ideal solution (TOPSIS) and aggregation – disaggregation methods also known as utilities additives (UTA).

Outranking is often described as the European counterpart to MAUT approaches in America (cf. Wallenius *et al.*, 2008). Based on information obtained from a decision maker, preferences regarding two or more solution alternatives are derived, which admit the derivation of a ranking of the solution alternatives. Like MAUT approaches outranking methods are mainly concerned with intangible, hardly quantifiable criteria. Well-known approaches in the outranking class are elimination and choice expressing reality (ELECTRE) (see Roy, 1991) and preference ranking organization method for enrichment evaluation (PROMETHEE) (see Brans and Vincke, 1985).

A class of more recent MCDM methods, therefore, referred to as non-classical approaches, incorporates fuzzy set theory, grey relational analysis and choquet integrals. These approaches emerged in the last ten to 15 years and are concerned with situations where information is imprecise and uncertain. *Figure B-1* summarizes the categorization with respect to MCDM approaches we utilize for this review.

B.2.2 Multiple criteria decision making in other research and management disciplines

MCDM approaches are widely applied to various research areas. On the following pages, selected reviews of MCDM applications are summarized. The reviews are classifiable as: (1) general reviews that do not focus on specific methods or research areas, (2) reviews with a focus on certain methods in various research areas and (3) reviews, which focus on MCDM applications to business administration.

An early and frequently cited general review is Dyer *et al.* (1992), who discuss the state of MCDM and analyze further developments. They identify seven different areas where they expect promising future developments for methods in MCDM. Zopounidis and Doumpos (2002) present a general overview with respect to classification and sorting methods and their application area (e.g. medicine, human resource management or financial management and economics). The review focuses

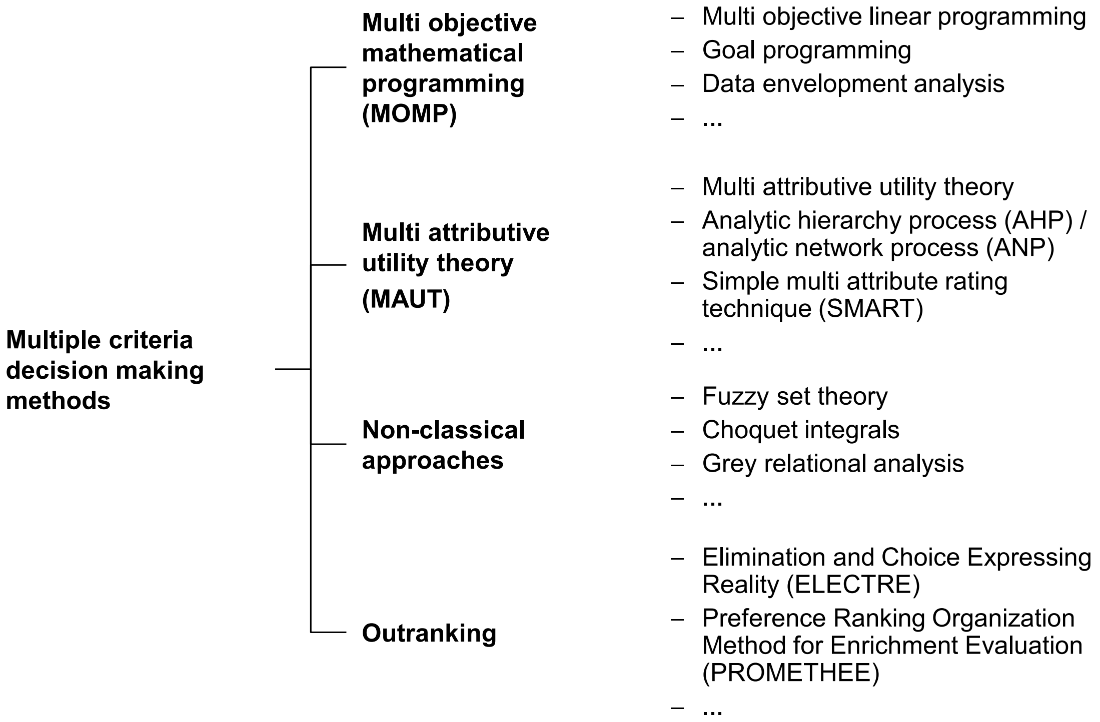

Figure B-1: Multiple criteria decision making methods categorization very strongly on methods and their development; the conclusions of the authors are rather technical. Wallenius *et al.* (2008) is an update of Dyer *et al.* (1992). The review contains a bibliometric analysis with respect to general applications of MCDM and shows fields for future research. They state that MCDM publications have grown by the factor 4.2 from 1992 to 2006, while the growth of science in general is estimated to have roughly increased by factor 2. In addition, they report that 34.9% of the articles included in their study are applied to operations research and management science, 23% are applied to management and business. Furthermore, they state an extraordinary increase of AHP applications in the last 20 years; in fact, AHP is the most widely applied MCDM method. Bragge *et al.* (2010) conduct a "research profiling study" and update as well as extent the bibliometric study of Wallenius *et al.* (2008). For the analysis of more than 15,000 articles, they utilize text mining software.

In reviews with focus on specific methods, Vargas (1990) survey the AHP methodology and its applications to several research areas, e.g. economic and management problems, social problems as well as political problems. They find that the majority of AHP applications occur in management and economics. A further review on AHP applications is presented by Vaidya and Kumar (2006), who consider 150 articles and analyze 27 in detail. They classify the application problem (i.e. selection, evaluation, allocations, planning and development, medicine and related fields etc.) and the application area (i.e. social, personal, education, manufacturing, engineering etc.). A central result of their study is that the AHP is heavily applied to selection and evaluation problems, in engineering and social application areas. Ho (2008) reviews 66 integrated AHP applications. The majority of the reviewed AHP applications relate to the logistics (21 / 66) and manufacturing (18 / 66) fields. The primary methods applied with AHP are goal programming and quality function deployment. Furthermore, Ho states that in the rate of publication in the first review period (1997-2001) to the second review period (2002-2007) is 25 to 41. He assumes a further increase in integrated AHP applications in the following years. Liberatore and Nydick (2008) review 50 AHP applications in medical and health care. They report a steady number of applications since 1997, predominantly on evaluation problems, e.g. treatment or even capital goods selection. Behzadian *et al.* (2010) review 217 articles on the outranking method PROMETHEE, used for preference modeling. They categorize the articles with respect to their application area (e.g. environmental management, business and financial management, logistics and transport etc.) and survey occurring methodological extensions, i.e. integrated PROMETHEE applications with other MCDM methods. Behzadian *et al.* (2010) report a steady increase of PROMETHEE applications and a low rate of integrated approaches (15 of 217 applications). A further method specific review is presented Sipahi and Timor (2010). They survey 232 AHP/ANP applications with respect to several research areas. Like earlier studies Sipahi and Timor (2010) state an exponential increase with respect to AHP/ANP applications and support the statement of Ho (2008) regarding a trend to integrated AHP approaches. The industries with the highest numbers of applications are the manufacturing industry (76 / 232) as well as environmental management and agriculture (26 / 232).

Besides the general and the methodological specific reviews, several surveys consider MCDM applications in other management disciplines. Steuer and Na (2003) examine 265 MCDM applications concerning finance and related problems. They classify the reviewed studies by the applied method (e.g. goal programming, multiple objective programming, AHP etc.) and the application area (e.g. capital budgeting, working capital management, portfolio analysis, general financial planning, etc.). The bulk of contributions reviewed by Steuer and Na (2003) apply goal programming (103 / 265) and multiple objective programming (83 / 265). Furthermore, the top two application areas consider portfolio analysis (77 / 265) and general financial planning (45 / 265). A broad review of supplier-related topics is provided by Jain *et al.,* 2009. They concentrate on areas like supplier selection, supplier-buyer relationships and supplier-buyer flexibility. Their review is not focused on MCDM applications, yet many MCDM methods are included in the articles they survey (e.g. fuzzy set theory, AHP, etc.). Ho *et al.* (2010) present a study on MCDM applications in supplier selection and evaluation. From 2000 to 2008 they find 78 articles that match their search criteria. *Ho et al.* report that the most applied single MCDM approach in supplier selection is data envelopment analysis (DEA), whereas the most frequently utilized integrated approach is the AHP. Furthermore, they state that all the approaches they review can consider qualitative as well as quantitative criteria.

The high number of reviews on MCDM applications general or method-specific or about a certain research areas, reflects the strong interest of academia in this topic, confirming the relevance of MCDM methods in several research areas. The interest of academia concerning MCDM methods is not surprising from the perspective of modern decision making and management practices. Pure cost minimization – as well as profit maximization – is, in many cases, a strong simplification of the underlying problem. The persistent rejection of shareholder value concepts and the continual increase of sustainability aspects will further influence decision making in the future and lead to an additional relevance increase of MCDM approaches in several management areas. Due to the high applicability of MCDM approaches to different kinds of problems, MCDM approaches are applicable to many decision problems. Generally, MOMP approaches are applied to optimization problems (with some exceptions), non-classical approaches are applied to problems that incorporate high uncertainty, especially uncertainty regarding information quality, and MAUT as well as outranking methods are applied for preference modeling. One of our goals in this paper is to give an overview of MCDM methods and the problems they are applied to in SCM.

B.3 Multiple criteria decision making in supply chain management

In this section we present the results of our literature review. We start with an introduction to our research approach, followed by a general overview on the development of MCDM applications to SCM. The last subsection reviews the MCDM applications in the various SCM application areas in more detail.

B.3.1 Methodological approach of the literature survey

Our literature review is restricted to peer reviewed publications. This includes academic journals and conference proceedings, but excludes books, master and doctoral theses. We reviewed articles published in the period from 2000 to 2011. The literature query took place on 30th April 2011. We used the databases EBSCO Host (Business Source Premier, EconLit, Computer Source) and ABI/INFORM Complete (ProQuest). We searched within titles and abstracts. *Table B-1* lists the search terms we considered. We used method unspecific as well as method specific MCDM search terms and SCM search terms. The search terms within the columns

Table B-1: Search terms for the literature survey

MCDM search terms		**MCDM search terms**		**SCM search terms**
method unspecific		method specific		
"multicriteria"		AHP		"supply chain"
"multi criteria"		"analytic hierarchy process"		SCM
"multi attribute"		"analytical hierarchy process"		
"multi attributive"		ANP		
"multiple criteria"		"analytic network process"		
"multiple attribute"	*OR*	"analytical network process"	*AND*	
"multiple attributive"		ELECTRE		
"multiattribute"		fuzzy		
		MACBETH		
		PROMETHEE		
		SMART		
		TOPSIS		
		UTA		

were linked with each other with the operator "OR", method specific and unspecific search terms (column one and two) were linked with the operator "OR", the SCM search terms (column three) were linked with the operator "AND". Therefore each hit at least included a method specific or unspecific search term and "supply chain" or "SCM". The methodological approach of our literature survey is similar to Glock and Hochrein (2011) as well as to Kudla and Stölzle (2011).

Since we are especially interested in approaches for the consideration of intangible, qualitative information in MCDM, search terms such as "goal programming" or "mathematical programming" were not included directly in the literature retrieval. However, they also were not excluded, since combinations with qualitative methods and, therefore, consideration of qualitative information are possible in mathematical programming approaches. Overall, 334 papers matched the search terms; 124 were relevant to the topic.

The following three conditions with respect to the retrieved articles were evaluated for the decision whether or not to include an article in the review:

(1) usage of a multiple criteria approach,

(2) consideration of qualitative or intangible information, and

(3) clear relation to SCM research.

As described in the introduction, since reviews on purely mathematical decision support are already sufficiently available, we will focus on approaches that allow for the incorporation of qualitative or intangible information. Therefore, mathematical programming approaches that do not consider qualitative or intangible information are excluded from the review. Furthermore, methods that handle pure quantitative problems, which include qualitative information about uncertainties (e.g. fuzzy demand), are not considered (e.g. Mahnam *et al.*, 2009). In addition, all non multiple criteria applications of fuzzy set theory are excluded (e.g. Kabak and Ülengin, 2011). In many cases, weightings of multiple criteria goal programming approaches are generated by means of qualitative evaluation through a decision maker (e.g. Amid *et al.*, 2011; Efendigil *et al.*, 2008), in some cases, even the weightings are computed through quantitative information within an optimization problem (e.g. Chan *et al.*, 2005; Chan *et al.*, 2006). Regarding item (3), several papers were found which use the term "supply chain", since it is a buzzword that increases academic impact. These papers were also excluded. We focus on publications that clearly contribute to SCM relevant research area, e.g. purchasing, distribution or collaboration, which consider inter-organizational aspects.

After eliminating irrelevant contributions, the papers were classified by publication year, journal of publication and whether or not a group decision approach or empirical results are included. Furthermore, we analyzed the MCDM category (MOMP, MAUT etc.), and the exact method (AHP, fuzzy set theory) of the paper. If a contribution uses more than one method, we identified the central method (first stated) and classified the papers considering up to three MCDM categories and methods. Additionally, we surveyed whether the approaches are integrated. In some cases, different methods are used side by side without interacting with each other. These approaches are classified as not integrated. The last attribute we categorized is the application area within SCM. The derivation of the different SCM application areas starts at the strategic decision level of *design*, followed by directly value adding areas, i.e. *purchasing*, *manufacturing*, *distribution* and *logistics*. We then considered supporting areas, i.e. *collaboration* and *performance management*. However, six publications were not assignable to these application areas and are therefore classified as *miscellaneous*. Moreover, the reviewed papers in each application area were assigned to the problem they consider (specific application area; e.g. complete network design, distribution network design, etc.).

B.3.2 General overview of multiple criteria decision making in supply chain management

In this section we present a general review of MCDM in SCM. The analyses focus on giving a compact insight on the development of the surveyed research field.

In *Table B-2,* the development of MCDM categories in SCM from 2000 to 2011 is depicted. In addition, the lower part of the table describes shares of papers that include integrated approaches, state case applications or group decision approaches. The number of applications has significantly increased in the last six years. In 2008, there is an abrupt rise that is hardly explainable by means of the obtained data in the literature review. One noticeable exception is, in this year eight single contribution journals (published only one article in the regarded research area and time frame) issued an article. However, even if the single contribution journals are neglected for this analysis, there is still a leap. Another peculiarity is the high number of publications in internationally not well recognized journals in 2008. If internationally less recognized journals are neglected for evaluation, there is still a peak, but a less significant one. On the other hand, for 2011, it is expected that the number of MCDM publications in SCM will exceed the number in 2008.

Regarding the method categorization, MAUT applications are clearly domi-

Table B-2: MCDM categories in SCM per year

Methods	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Total	2	3	3	7	5	7	15	13	25	14	15	15	124
Multi-attributive utility theory	2	3	3	3	4	5	5	11	20	9	12	7	84
Multi-objective mathematical programming				1	1	1	3		1	1	2	2	12
Non-classical				3		1	7	2	4	4	1	5	27
Outranking												1	1
Integrated approaches	0%	33%	33%	57%	60%	57%	47%	62%	48%	79%	67%	67%	57%
Case application	50%	0%	0%	29%	40%	14%	47%	54%	48%	50%	40%	40%	41%
Group decision approaches	50%	33%	0%	0%	20%	14%	7%	23%	8%	21%	7%	13%	13%

nant, certainly, due to the exclusion of purely quantitative methods. Nevertheless, even if purely quantitative methods would have been considered for the review, we expect that MAUT applications would still dominate the picture. Integrated approaches represented the greater part of the approaches already from 2003 to 2005.

Since 2009, integrated approaches constitute the bulk of contributions. Furthermore, we reviewed whether the articles integrated a case application of the proposed methodology to a real life problem. 41% of the papers integrate an actual case study and a further 11% of the articles incorporate a fictive example case (not stated in the table). Additionally, we surveyed the ratio of MCDM applications explicitly allowing for the consideration of more than one decision maker (group decisions). 13% of the reviewed papers represent a group decision methodology.

Table B-3 shows MCDM methods applied five or more times in the regarded time frame. The total number of applications exceeds the number of reviewed journals, since a utilization of two or more methods in a publication is considered. The methods AHP, fuzzy set theory and ANP represent 63% of all applications. Furthermore, like Sipahi and Timor (2010) and Wallenius *et al.* (2008) report in general, *Table B-3* presents for SCM a strong increase in AHP and ANP applications. Additionally, fuzzy set theory applications increased in recent years. In 46 articles one, in 58 articles two and in 20 articles three methods are applied. Occasionally, even four methods are employed. The increase in method applications per year presents the same picture as the number of contributions per year, a strong increase in 2006. However, the number of applications rises after 2006, instead of stagnating

Table B-3: MCDM methods in SCM per year

Method	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
AHP	2	3	1	5	3	5	5	10	19	8	8	6	75
Fuzzy set theory				3	1	1	7	5	9	7	5	10	48
ANP			1	1	1		2	1	2	2	5	2	17
Goal programming				1	2	1	1		2	3	2		12
DEA									1		2	2	5
Integer linear programming		1	1						1	1	1		5
Multi-objective linear programming							2		2		1		5
…	…	…	…	…	…	…	…	…	…	…	…	…	…
Total	2	4	4	11	9	13	24	24	45	28	30	28	222
Methods to article ratio	1.00	1.33	1.33	1.57	1.80	1.86	1.60	1.85	1.80	2.00	2.00	1.87	1.79

like the number of articles published. Furthermore, the methods to articles ratio (total number of applications per year divided by the total number of contributions per year) in the last row of *Table B-3* also indicates increasing application of two or more methods within an article.

Table B-4 shows the 13 journals and conference proceedings that published three or more articles in the regarded research area from 2000 to 2011 and the primary MCDM method category applied in the contribution. Overall, 49 journals contribute to the regarded research area. Most of the listed journals are internationally well-regarded and highly ranked, in journal rankings like "Association of Business Schools Academic Journal Quality Guide March 2010" and the "Association of Professors of Business in German speaking countries" VHB 2011. The articles in these journals account for 62% of all the contributions in this research field from 2000 to 2011. In the five most publishing journals of MCDM in SCM, the European Journal of Operational Research (EJOR), International Journal of Production Economics (IJPE), and International Journal of Production Research (IJPR) are known for their stronger connection to operations research topics. If purely quantitative approaches

Table B-4: Top 13 journals as well as conference proceedings and applied MCDM method category

Journal or conference proceeding		MAUT	MOMP	Non-classical	Outranking	Total
1	International Journal of Production Economics	11	1	6		18
2	International Journal of Production Research	8	5		1	14
3	Production Planning & Control	7		1		8
4	Supply Chain Management: An International Journal	5	1			6
5	European Journal of Operational Research	3		2		5
6	International Journal of Management & Decision Making	4				4
7	Benchmarking: An International Journal	3		1		4
8	Computers & Industrial Engineering	3				3
9	Computers in Industry	2		1		3
10	IIE Annual Conference. Proceedings	2	1			3
11	International Journal of Physical Distribution & Logistics Management	2		1		3
12	Journal of Cleaner Production	1	1	1		3
13	Journal of the Operational Research Society	1	1	1		3

would have been considered, too, it is assumed that EJOR would have been positioned at the third place or even higher. The contributions within the journals EJOR, IJPE, and IJPR correspond closely to their reputation. Thus, the focus lies on methodological aspects. Regarding the dominant methods in the top 2 journals, IJPE and IJPR, it is evident that, besides MAUT methods, IJPE mostly publishes mainly non-classical approaches. Therefore, IJPE mainly contributes to research streams that consider imprecise and incomplete information, like most non-classical MCDM methods do. On the other side, IJPR focuses on mathematical programming MCDM methods, which primarily treat optimization problems. The contributions in the journals Production Planning & Control and Supply Chain Management: An International Journal, are more concerned with content-related aspects.

The rows in *Table B-5* present the predominant method category as well as the exact method. The columns show the second method category in combined approaches and the exact method. The category "no MCDM" incorporates approaches like sensitivity analysis or balanced score card. Applications of three or more methods in one article are not considered in this analysis. The proportion of non-single approaches in *Table B-5* (78 / 124 = 63%) is higher than the proportion of integrated approaches in *Table B-2* (53%). This is due to the fact that in some cases, different single approaches are applied besides each other, but do not interact and are, therefore, not counted as integrated approaches. As apparent, AHP and ANP applications are the dominant methods within the reviewed articles, followed by fuzzy set theory and goal programming approaches. With respect to combined approaches, joint AHP and fuzzy set theory approaches are clearly dominant. These two methods also represent the approaches most often combined with other methods. The second ranked combination is AHP and goal programming, the top three method combination AHP and integer linear programming.

Table B-6 represents the number of applications to different application areas in SCM and the table lists the articles published in this area. The application areas map important functions in SCM based on the value adding process and supporting activities, as long as MCDM methods have been applied to this functions. The purchasing area is the most frequented area, followed by logistics and performance management.

Table B-5: MCDM method combinations in SCM

	MAUT						**MOMP**							**Non-classical**				**Out-rank-ing**		**Others**		**No MCDM**									**Single approach-es**	**Total**
	AHP	ANP	MACBETH	SMART	TOPSIS	Weighted average method	DEA	Dynamic programming	Goal programming	Integer linear programming	Linear programming	Multiple-objective integer linear programming	ming	Choquet integrals	Fuzzy set theory	Genetic algorithm	Grey relational analysis	ELECTRE	PROMETHEE	Entropy weight	QFD	Bi-negotiation agents	BSC	Interpretive structural modelling	Neural networks	Performance value analysis	Sensitivity analysis	Simulation	System dynamics	Taguchi loss function	Single approaches	
MAUT																																
AHP				1			1	1	6	4	1				18	1	1	1			1	1	2	1	1	1	1	1	1	1	21	67
ANP									1	1			1	1	2																9	15
MAUT															1																2	3
SMART																															1	1
TOPSIS															1																	1
Voting AHP																															1	1
MOMP																																
DEA		1			1														1													3
Goal programming	1	1													2																	4
Linear programming															1																	1
Multi-objective integer linear optimization	1																															1
Multi-objective linear programming															2																2	4
Non-classical																																
Choquet integral			1												1																	2
Fuzzy set theory	3				1	1						1									1										10	17
Genetic algorithm	1														1																	2
Grey relational analysis	1																															1
Outranking																																
ELECTRE																				1												1
Total	7	2	1	1	2	1	1	1	7	2	1	3	2	1	29	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	46	124

Table B-6: Application areas of MCDM in SCM

Application area	Papers	Total number
Design	[3], [10], [36], [43], [50], [53], [72], [76], [88], [96], [104]	11
Purchasing	[4], [5], [14], [16], [18], [19], [20], [23], [25], [27], [28], [30], [31], [40], [51], [55], [56], [57], [58], [60], [63], [64], [65], [66], [67], [70], [71], [73], [74], [75], [78], [81], [82], [83], [84], [85], [86], [87], [93], [95], [98], [100], [101], [103], [110], [111], [112], [115], [116], [117], [119], [120], [121], [123]	54
Manufacturing	[6], [7], [33], [54], [77], [90], [91], [102], [109]	9
Distribution	[22], [68]	2
Collaboration	[8], [9], [26], [35], [46], [69], [79], [80], [89], [107]	10
Logistics	[15], [17], [29], [32], [34], [37], [41], [42], [47], [48], [49], [52], [59], [62], [94], [106], [114], [122]	18
Performance management	[1], [2], [11], [12], [13], [21], [24], [38], [44], [45], [99], [105], [108], [113]	14
Miscellaneous	[39], [61], [92], [97], [118], [124]	6
Total		124

B.4 Review of multiple criteria decision making with respect to application areas in supply chain management

In this section, we provide a detailed analysis of MCDM utilizations to SCM application areas. For every application area, we present a table giving an overview of the contributions within specific application areas (decision problems), the most applied method or method combination, the share of integrated approaches and the share of contributions including a case study.

B.4.1 Design

Table B-7 represents the application area *design* summary. There is no predominant specific application area. Complete networks, as well as distribution and manufac-

Table B-7: Overview SCM application area *design*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Distribution network	3	AHP	67%	67%
Complete network	3	AHP, AHP & integer linear programming	67%	0%
Manufacturing network	3	AHP, AHP & integer linear programming	33%	33%
Reverse logistics network design	2	AHP	100%	100%
Total	11	AHP, AHP & integer linear programming	55%	45%

turing networks, are all considered with three publications. The reviewed papers regarded only supply networks in holistic approaches (complete networks); supply networks are not listed in *Table B-7*. The most applied method combination,
AHP and integer linear programming occurs due to the frequent optimization problems in this area. In comparison with other application areas, the AHP method takes a dominant position within the design area only comparable to the purchasing area. The share of integrated approaches and papers with case studies differ only slightly from the averages of the whole population. The journal with the highest number of contributions from 2000 to 2011 is the International Journal of Management & Decision Making (2 / 11).

B.4.2 Purchasing

Table B-8 represents the summary of the application area *purchasing*. In the application area purchasing, supplier selection is the predominant specific application area with 44 of 54 papers devoted to this topic. The prevalent method and method combination do not deviate significantly from the population although AHP plays a key role. However, the share of integrated approaches (67%) is significantly higher compared to the population of surveyed articles (57%). This indicates, that approaches within this application area are more sophisticated than the average approach in the population. The most frequently contributing journals in purchasing are the International Journal of Production Economics (9 / 54) and the International Journal of Production Research (9 / 54).

Table B-8: Overview SCM application area *purchasing*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Supplier selection	44	AHP & Fuzzy set theory	70%	36%
Supplier evaluation	6	AHP	33%	17%
Software selection	2	AHP	100%	50%
Supplier risk assessment	2	AHP	50%	50%
Total	54	AHP, AHP & Fuzzy set theory	67%	35%

B.4.3 Manufacturing

Table B-9 represents the summary of the application area *manufacturing*. Regarding the specific application area in manufacturing, the focus of MCDM applications is in outsourcing and production planning. The two main methods are AHP and goal programming. The latter is an indicator for a high number of optimizations concerning production planning. A very mixed application of methods is quite striking within the manufacturing area. The share of integrated approaches is significantly lower and the share of papers with case studies is noticeably higher than in the population. The journals with the highest number of contributions are again the International Journal of Production Economics (2 / 9) and International Journal of Production Research (2 / 9).

B.4.4 Distribution

Table B-10 represents the summary of the application area *distribution*. Only two contributions of all 124 reviewed articles concern distribution problems. Both consider distribution planning problems. Certainly, more MCDM applications may be found in this area. However, they are often purely quantitative and therefore not considered in this review. Both articles chosen reveal a different methodological approach. Among journals contributing to this area, the International Journal of Computer Integrated Manufacturing and the International Journal of Production Research published each one article in this SCM application area.

Table B-9: Overview SCM application area *manufacturing*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Outsourcing	3	Goal programming & ANP, Smart	33%	33%
Production planning	3	AHP, ANP, Goal Programming	33%	100%
Collaborative production planning	1	Multi-objective linear programming	0%	0%
Service and manufacturing optimization	1	AHP & System dynamics	100%	0%
Sustainability	1	Fuzzy set theory	0%	100%
Total	9	AHP, Goal programming	33%	56%

Table B-10: Overview SCM application area *distribution*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Distribution planning	2	Multi-objective linear programming & Fuzzy set theory, AHP & Genetic algorithm	50%	50%
Total	2	Multi-objective linear programming & Fuzzy set theory, AHP & Genetic algorithm	50%	50%

B.4.5 Collaboration

Table B-11 presents the summary of the application area *collaboration*. Besides information sharing, horizontal collaboration between supply chains is the specific application area with the highest number of contributions. Since collaboration is a rather soft and intangible application area, AHP as well as AHP in combination with fuzzy set theory emerge unsurprisingly as the most applied method. Again, the share of integrated papers incorporating case studies does not significantly deviate from the population, although it is slightly higher in both categories. The journals with the highest number of contributions in this area are the International Journal of Production Economics (2 / 10) and Production Planning & Control (2 / 10).

B.4.6 Logistics

Table B-12 represents the application area *logistics* summary. Like in the purchasing area, in the application area logistics, partner selection in form of 3PRLP (third party reverse logistics provider) and 3PL selection are dominating the field. The selection of partners is often strongly dependent on intangible, qualitative criteria. Therefore, the most applied method (combination) AHP as well as integrated AHP

Table B-11: Overview SCM application area *collaboration*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Information sharing	4	AHP & Fuzzy set theory	100%	25%
Horizontal collaboration	3	AHP	33%	67%
Agile partnerships	1	Fuzzy set theory	0%	100%
Integration	1	Fuzzy set theory	0%	100%
Process transformation	1	AHP & QFD	100%	100%
Total	10	AHP, AHP & Fuzzy set theory	60%	60%

Table B-12: Overview SCM application area *logistics*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
3PRLP selection	6	AHP & Fuzzy set theory	67%	17%
3PL selection	5	AHP	20%	40%
Agile SC	2	ANP, Fuzzy set theory	0%	50%
4PL evaluation	1	Choquet integral	100%	0%
Customer service management	1	Fuzzy set theory	100%	100%
SC effectiveness	1	ANP	0%	100%
Selection of global logistics strategy	1	AHP & Fuzzy set theory	100%	100%
Supply chain development	1	AHP	0%	0%
Total	18	AHP, AHP & Fuzzy set theory	44%	39%

and fuzzy set theory approaches do not surprise. However, the share of integrated approaches and the share of papers including case studies are significantly lower than in the population. The International Journal of Production Economics (3 / 18) has the highest number of contributions in the area of logistics.

B.4.7 Performance management

Table B-13 presents the summary of the application area *performance management*. In this application area, most contributions have no special focus and consider supply chain performance management generally. Hence, the methods applied set out a heterogeneous picture. As far as the share of integrated approaches and papers including case studies, no significant deviations from the population are apparent: both stay slightly above average. The most contributing journals in this area are Production Planning & Control (2 / 14) and Supply Chain Management: An International Journal (2 / 14).

Table B-13: Overview SCM application area *performance management*

Specific application area	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
No special focus	9	AHP, AHP & BSC	67%	33%
Sustainability	3	MAUT	33%	33%
Benchmarking of SCs	1	DEA & PROMETHEE	100%	100%
Reverse logistics	1	AHP & DEA	100%	100%
Total	14	AHP, AHP & BSC	64%	43%

B.4.8 Miscellaneous

Table B-14 presents the summary of MCDM applications not assignable to other application areas. The papers subsumed under *miscellaneous* either do not represent a typical task in SCM, or are numbered too low to build an application area of their own in this literature survey. A general description is not very meaningful, since the problems presented differ strongly from each other. The AHP method is clearly dominant.

B.5 Discussion

In this section we will discuss limitations of our literature study, summarize the findings of the earlier sections and derive possible trends of MCDM applications in SCM.

Regarding limitations of our literature survey, the review was restricted to academic peer-reviewed articles. Textbooks, master theses and doctoral dissertations were thus not selected; furthermore, only articles in English were considered. Additionally, our literature study of MCDM methods is restricted to approaches applied in a SCM context. Therefore, applications used in distribution, manufacturing or purchasing without SCM connection have not been examined in our study. Moreover, our investigation is based on a keyword search in the databases EBSCO Host (Business Source Premier, EconLit, Computer Source) and ABI/INFORM Complete (ProQuest). Hence, it is possible that some relevant articles did not match our search terms or were not listed in the searched databases. However, we are quite confident about the thoroughness of our study. Finally, we scrutinized only methods that explicitly allow for the consideration of qualitative or intangible information

Table B-14: Overview SCM application area *miscellaneous*

	Paper count	Most applied method or method combination	Share of integrated approaches	Case studies (share of total no.)
Project selection	3	ANP	33%	0%
Risk management	1	AHP	0%	100%
SC competitiveness positioning in shipbuilding	1	AHP & Fuzzy set theory	100%	0%
SC quality management	1	AHP	0%	100%
Total	6	AHP	33%	33%

within the decision process. Therefore, purely quantitative methods, as well as methods using only qualitative information for the estimation of uncertainties for an input variable (e.g. fuzzy demand) are excluded.

For the derivation of future trends of MCDM in SCM, two triggers can be distinguished:

(a) current SCM research offers application areas not thoroughly considered yet as well as future trends in SCM research provide new application areas, and
(b) the evolution of MCDM methods may offer new application opportunities in SCM.

The methodological proceeding for the derivation of research gaps and future trends follow; first, we evaluated the results of our literature analysis and deduced research gaps. Independent from future developments in SCM or MCDM, these gaps need to be closed and require further academic attention. Second, we considered future developments in SCM and resulting new application areas or areas which may experience a strong shift in its needs, or criteria that must be considered. This investigation yields possible future trends of MCDM in SCM arising from alterations in SCM research. Third, we regarded new MCDM methods which may be useful to SCM research.

In the following we will briefly analyze which future trends of MCDM applications in SCM may emerge from these two triggers, considering the results from the literature review.

B.5.1 Current state and future developments in SCM research

After considering current and future developments in SCM, we first summarize our findings from the previous section and show research gaps in current and future SCM research. We support and augment our line of argument through a literature review of current SCM research (Giunipero *et al.*, 2008) and a Delphi study on future SCM trends (Melnyk *et al.*, 2009).

The general overview of MCDM methods in SCM shows that this research field is rapidly growing. In 2011 we expect about 30 publications on MCDM in SCM (15 articles were already available by the end of April), exceeding the highest number in 2008 (25 publications). Furthermore, we assume that the trend toward combining methods will increase, especially among approaches that combine conveniently with others. As far as the results from the literature review show, this applies particularly to AHP, ANP and fuzzy set theory.

As for methodological tendencies of individual application areas, it is no surprise that with logistics' particular focus on optimization, purchasing focuses more on methods allowing for the consideration of qualitative and imprecise information. The share of integrated approaches is an indicator of the approaches' sophistication and varies between the application areas. Purchasing is the most highly developed application area when ranked by number of publications and share of integrated approaches. In contrast, the application area distribution is largely ignored by academia. Overall, only five contributions are concerned with distribution (counting three papers on distribution network design, assigned to the application area design). This is surprising, since combinations of MOMP and MAUT or outranking approaches may offer significant advantages over purely quantitative approaches in this area. However, most of the specific application areas (decision problems) are not analyzed in great detail by means of MCDM applications. Only topics like supplier selection and evaluation, 3PL and 3PRLP selection – and general performance management – are surveyed by high numbers of contributions. Particularly surprising is the lack of papers on risk management. Overall, there are only three articles, two on supplier and one on general risk management. Risks are hard to identify and even harder to quantify. Therefore, AHP, ANP and fuzzy set theory approaches are expected to offer great potential for application in this area.

To support and complement our argument, we use results from the most recent and comprehensive SCM literature review available. Giunipero *et al.* (2008) survey 405 articles from nine SCM peer-reviewed journals. However, their evaluation of future developments in SCM research focuses on research methods that have to be employed to advance the state of knowledge in SCM. Therefore, we refer to Melnyk *et al.* (2009) on future trends in SCM research. Based on a literature review, they conduct a Delphi study, integrating academics as well as practitioners. Appropriate practitioners are identified using the AMR research list of the top 25 supply chain firms; academics are selected from North American universities with a good reputation in SCM.

Giunipero *et al.* (2008) state that the most frequented SCM research area is SCM strategy. They describe it as "strategic alignment between the supply chain and the focal firm", and refer to content like competitive advantage and risk management. Risk management was already identified as an underrepresented area. Melnyk *et al.* (2009) report "supply chain disruption risk" as the single most important area with respect to future SCM. Therefore, further MCDM approaches for risk management, focused on the supply side or not, would be helpful for SCM research.

Aligning various supply chain strategy areas within the supply chain as well as competitive positioning (advantage) are completely neglected by MCDM research. The importance of this area is also stated by Melnyk *et al.* (2009). They find that SCM is still mainly concerned with efficiency related topics (e.g. cost minimization), but that effectiveness will increasingly become the focus of SCM and strategy related issues. For example, selection of an inter-organizational supply chain strategy, including a group decision-making approach might be a possible application area for MCDM. Furthermore, the developing trend of supply chain differentiation (cf. Hilletofth, 2009) will increase the importance of topics like supply chain strategy and competitive positioning. Supply chain differentiation concerns the concurrent operation of several parallel supply chains, effectively and efficiently satisfying customer needs. Firms like AT Kearney (Mayer *et al.*, 2009), McKinsey & Company (Malik *et al.*, 2011) and Gartner (Davis, 2010) report how this strong trend finds its way into SCM. Issues that might arise here include the right (optimal) number of supply chains a company should operate. One paper in the review examines competitive positioning in the shipbuilding industry (Zangoueinezhad *et al.*, 2011). Supply chain strategy, including topics like supply chain differentiation, alignment of supply chain strategy and competitive positioning, represents an application area for further MCDM approaches.

Supply chain performance management is an application area currently given “average” attention (14 papers). Certainly, at a first glance, one would deduce that this area is well covered and does not provide – per se – potential for further MCDM applications. However, the trend of supply chain differentiation will demand new performance management systems. Agarwal *et al.* (2006) offer a first suggestion how such performance management systems might be built. However, this approach would have to be adapted to the needs of a differentiated supply chain. Performance management presents an area where further MCDM approaches might be needed.

In summary our analysis revealed two research gaps in MCDM applications in SCM requiring further consideration:

i. Distribution in a supply chain context, including distribution network design as well as (collaborative) distribution planning, and
ii. Supply chain risk management, including a pure focus on the supply side.

Furthermore, present trends in SCM research may initiate a need for new MCDM applications in these areas:

iii. Supply chain strategy, including supply chain differentiation, competitive positioning and alignment of supply chain strategy, and
iv. Supply chain performance management, especially for the performance management of several parallel supply chains.

B.5.2 Evolution of MCDM methods

As described in section 2.1, research on MCDM is growing rapidly; new methods and innovative applications of existing methods are common. In this paragraph, we will discuss which new SCM applications could be offered by future MCDM developments. We support our argument using a meta review of developments in MCDM (Wallenius *et al.*, 2008).

Mental models, sometimes also referred to as decision maps, offer good prospects for further MCDM research (cf. Comes *et al.*, 2011; Wallenius *et al.*, 2008). Mental models attempt to measure the perception of a decision maker and how different attributes of a solution alternative may affect an objective. The model estimates how attributes of different solution alternatives might impact specific consequences related to value concepts. Mental models may introduce a new era in decision making in SCM. Where current decisions are formulated solely to a specific problem, mental models focus on the effect of the selected solution on a higher objective level. For example, current decision problems with supply chain network design focus, in most cases, on cost minimization. A mental model would be formulated considering a higher objective level, e.g. maximize the possible achievable customer satisfaction while holding costs at a reasonable level. Supplier selection problems might not be formulated as "which supplier meets our requirements" but as "which supplier has the most positive impact on the overall quality and on revenues as well as profit." An example for such a model is Montibeller *et al.* (2008). These approaches are very general and are therefore applicable to a wide range of decision problems. We expect that we will see first applications of mental SCM models in the near future.

A further recent research area in MCDM is revisiting targets, which is especially suitable for decision problems concerning achievement of a specific target value (cf. Tsetlin and Winkler, 2007; Wallenius *et al.*, 2008). Such approaches are especially interesting for supplier selection. Certain criteria may be interpreted as qualifying criteria and therefore represent a binary criteria (possible values 1 and 0), where the supplier is evaluated with a 1 if he satisfies the criteria and a 0 if he does not. Combined with other criteria, which measure the actual goal attainment, this might be a worthwhile approach and could also function for other areas like supply chain design: i.e. does a location match certain binary criteria, or how high is the goal attainment of other criteria. Revisiting targets are implementable in currently existing approaches and thereby represent a methodological advancement. Also in this area, first implementations in SCM can be expected soon.

Wallenius *et al.* (2008) state that due to the progress made in computer design with respect to computing power, optimization problems with high computational requirements will be an interesting MCDM research area. Quadratic and stochastic programming are such areas. In this optimization class, one or two objective functions may be quadratic and quadratic objective functions may also represent variance and thus uncertainty. Such problems are not computable yet, but will be in the near future (cf. Ehrgott *et al.*, 2009). Like revisiting targets, this trend represents a methodological advancement. However, it is only implementable in MOMP approaches and therefore not as broadly applicable as revisiting targets; it might only be utilized in SCM application areas where optimization approaches are common. These application areas include supply chain design, distribution and manufacturing planning. Nevertheless, this further development of optimization approaches might be useful for these application areas.

Further mathematical developments with good prospects in MCDM research are evolutionary multi objective optimization approaches, which are search algorithms (heuristics) that basically imitate natural evolution (cf. Rachmawati and

Srinivasan, 2010; Wallenius *et al.*, 2008). Genetic algorithms are a very common approach in this area. Three articles on genetic algorithms have been considered in our study. Chan and Chung (2004) regard distribution planning problem, Ohdar and Ray (2004) present an approach for supplier evaluation in the application area purchasing, and Sha and Che (2006) introduce a procedure for supply chain design of a complete network. Since genetic algorithms are heuristics for quantitative problems, they are especially suitable for the application areas of supply chain design, distribution and manufacturing planning, like quadratic and stochastic programming.

To summarize: in MCDM research advancements, we expect significant impact on MCDM approaches in SCM, especially from two areas:

i. Mental models and
ii. Revisiting targets.

Due to their wide adaptability, these MCDM methods offer high potential for application to SCM research. Certainly, quadratic and stochastic programming, as well as evolutionary multi objective optimization, will be utilized in SCM. However, mental models and revisiting targets, particularly in combination with other MCDM methods, offer higher potential for application in SCM and better opportunities for initiating MCDM research trends in SCM.

B.6 Conclusion

This paper is a literature survey on MCDM applications in SCM. MCDM and SCM are both rapidly growing research fields. However, a structured analysis with respect to MCDM approaches in SCM is not yet available. We focused on approaches allowing for the consideration of qualitative information. Overall, 334 articles matched our search criteria in the time frame from 2000 to 2011. We categorized these papers according to the year and publishing journal, analyzed SCM application areas, classified the MCDM methods and studied whether two or more methods were combined, group decision procedure was incorporated, or if a case study application provided support. The main conclusion of our analysis is: publications on MCDM in SCM are rapidly growing, especially combined approaches. Based on our findings, we suggest further research, especially in the application areas of distribution in SCM context, supply chain risk management, strategy and performance management. Looking to the future of MCDM research, we expect that mental models and revisiting targets have the potential for establishing a new trend of MCDM applications in SCM. For business practice as well as for academia, this article offers a valuable overview regarding MCDM methods for SCM decision problems.

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C Designing differentiated supply chain strategies – A multiple criteria decision making approach

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Abstract
Supply chain management (SCM) developed in the last decade from a mere efficiency and optimization driven topic to a field of strategic importance. Companies nowadays recognize the opportunity within SCM to differentiate themselves from their competitors. A strong upcoming trend in SCM is the concurrent operation of several supply chains (SC), supply chain differentiation (SCD). Decisions on an ideal differentiated SC design are strategic in nature and subject to quantitative as well as qualitative, imprecise and uncertain information. Approaches in multiple criteria decision making (MCDM) are especially well suited to tackle such decision problems. The paper at hand offers an approach and a model for such decision problems. We present a set of relevant criteria for decisions on SCD and integrate these criteria in an analytic hierarchy process (AHP). On the basis of a real life decision on SCD, we present an illustrative application example of the AHP. We check the robustness of the AHP solution by means of a sensitivity analysis. The research results indicate a well applicability of the AHP and turn out to be robust against deviations in the importance of different criteria. Based on the magnitude of decisions on SCD, future research should offer further approaches to solve these decision problems.

Keywords: *Supply chain management, supply chain differentiation, strategic decisions, multiple criteria decision making, analytic hierarchy process, sensitivity analysis*

C.1 Introduction

SCM moved from an efficiency and optimization focus to a matter of strategy (cf. Hofmann, 2010). In fact, modern approaches to SCM offer a source of competitive advantage (cf. Thomas *et al.,* 2011). A research stream in SCM that earns increasing interest by academia and business practice is the customer-oriented approach of differentiated SCM. Supply chain differentiation (SCD) is the concurrent operation of several SCs incorporating the adoption of different SC strategies. SCD offers companies an opportunity to increase customer proximity through a differentiated customer approach, since it delivers products and services effectively through several SCs to a market and may increase the overall efficiency of SCM (cf. Christopher *et al.,* 2009; Davis, 2010; Beck *et al.,* 2012).

Apart from production and distribution optimization problems, SCM incorporates decisions that are not reversible in the short run, e.g. supplier selection, network design and especially decisions on SCD. Misdeterminations in these strategic decisions are at least costly or may even contribute to the failure of a company. Hence, decision support for strategic decisions in SCM is highly relevant to managers and business practice. Strategic decisions have to consider multiple conflicting criteria and normally incorporate qualitative as well as incomplete information besides quantitative data. The consideration of multiple criteria that are of qualitative and quantitative nature, demand for a certain class of decision support, methods in multiple criteria decision making (MCDM). Methods in MCDM offer a particularly suitable decision support for strategic decisions (cf. Montibeller and Franco, 2011), since these methods are designed for integrating multiple conflicting, incomplete and qualitative criteria (cf. Ram *et al.,* 2011). One focal support provided by MCDM is the structured analyses of a decision problem, including the accurate examination of relevant criteria and their influence on the outcome of possible solution alternatives as part of the decision process (cf. Wallenius *et al.,* 2008).

MCDM research is one of the fastest growing research areas in general (cf. Bragge *et al.,* 2010). Particularly publications on MCDM applications in SCM have grown exponentially in recent years (Beck and Hofmann, 2012). Yet, no method in MCDM has been employed to decisions on SCD. The goal of this paper is to provide a suitable MCDM method, more precisely an AHP, for decisions on SCD. Thereby we tackle the following research question (RQ).

RQ: How may a SCD-decision be supported by means of a multiple criteria decision making methodology?

The contribution of our paper is twofold. (i) For academia we present an innovative application of a MCDM methodology for decisions on SCD. We use an AHP due to its great flexibility with respect to the incorporation of quantitative and qualitative information. Regarding the quantitative criteria, we integrate a set of variables for analyzing demand and product characteristics, which is also known as DWV^3 model (Childerhouse *et al.,* 2002) and variables that measure positive (e.g. increasing revenues) and negative (e.g. costs incurred by SCD) effects of a differentiated SC strategy. The qualitative criteria mainly focus on customer interaction and the importance weightings of all considered criteria. Moreover we integrate a sensitivity analysis for ensuring the robustness of our solution. (ii) For managers and business practice we offer decision support for SCD-decisions with respect to relevant criteria and variables and an appropriate MCDM application. The decision support methodology presented in this paper is a stepwise approach to SCD-decisions. First, the input information is analyzed. Second, distinct SC design scenarios are derived based on the results from the input information analysis. Third, the AHP is used to select the most appropriate SC design.

Our research methodology is as follows. Based on a literature review we developed a conceptual decision model. For the verification of the conceptual decision model, we employ a case study design with embedded unit of analysis (Yin, 2007) through the analysis of a case company. For data collection we conducted semi-structured interviews. From the verified conceptual decision model we generated a mathematical model in form of an AHP for decisions on SCD. The mathematical model is tested by means of an illustrative example, based on the statements of the case company.

The paper is structured in the following manner. Section two presents a brief literature review of decisions on SCD and on MCDM in SCM. Section three states our decision model. We present a comprehensive application example in section four. Section five discusses our findings and states areas for future research.

C.2 Literature review

C.2.1 Supply Chain Differentiation

Criteria and variables for the development of differentiated SC strategies, or the synonymously used term segmented SC strategies, stem from various research streams in logistics and SCM research. Early contributions in logistics research deal with the differentiation of logistics service levels according to diverse requirements of customer segments (for example Fuller *et al.,* 1993; Gilmour *et al.,* 1977). Furthermore, the discussion of lean vs. agile SCs provided criteria and variables for selecting an appropriate SC strategy by considering product characteristics (Shapiro, 1984; Fisher, 1997; Lee, 2002). The introduction of decoupling points in logistics literature (Bucklin, 1965; Hoekstra *et al.,* 1992), which was adopted by SCM research by means of hybrid SC strategies (Naylor *et al.,* 1999; Mason-Jones *et al.,* 2000; Olhager, 2003), is an additional source for criteria and variables for differentiating SCs. Related to hybrid SC strategies and decoupling points is the literature on postponement (Pagh and Cooper, 1998) and mass customization (Liu and Deitz, 2011).

The first and most known model for the design of differentiated SC strategies is the so called DWV^3 model, introduced by Christopher and Towill (2000). They integrate five variables (duration of product life cycle, time window for delivery, demand volume, product variety and demand variability) for assigning products to different types of SCs (e.g. make-to-stock of make-to-order) according to the demand and product characteristics. These five variables are no strangers to the discussion of suitable SC strategies for given product characteristics, since they mainly date back to the briefly above represented discussion of lean, leagile and agile SC strategies. Childerhouse *et al.* (2002) present a comprehensive overview of these variables and their sources in literature. Furthermore, Childerhouse *et al.* (2002) validate the DWV^3 model by means of a case study of an UK based lighting manufacturer. Further contributions discuss different aspects of the DWV^3 model and validate the model (Aitken *et al.,* 2003; Aitken *et al.,* 2005; Christopher *et al.,* 2006). Christopher *et al.* (2009) and Godsell *et al.* (2011) state that it depends on the case and the regarded companies, which variables of the DWV^3 model are relevant in a specific decision on a differentiated SC design. Lovell *et al.* (2005) presents a model very similar to the DWV[3] model.

C.2.2 Multiple criteria decision making

MCDM applications to SCM are a fast growing research stream. Beck and Hofmann (2012) reviewed 124 MCDM applications to SCM over the time period from 2000 to 2011. They report a strong increase of publications on multiple criteria decision support for SCM. MCDM applications in SCM are most often found in the area of purchasing, especially on supplier selection (e.g. Wu *et al.,* 2009; Kuo *et al.,* 2010; Amid *et al.,* 2011). Other applications to strategic decisions are particularly on network design problems (e.g. Dotoli *et al.,* 2005; Kinra and Kotzab, 2008) and outsourcing (e.g. Platts *et al.,* 2002; Kirkwood *et al.,* 2005). In the area of logistics, several publications consider the selection of a suitable logistics service providers through a MCDM approach (e.g. Göl and Çatay, 2007; Chen *et al.,* 2011). Cabral *et al.* (2012) present an ANP for the selection of lean, agile, resilient and green SC paradigms as well as for the selection of appropriate KPIs, which is the most related publication with respect to our research goal.

Even if research on MCDM in SCM is fast growing, the decision problem of designing a differentiated SC strategy with respect to demand and product characteristics as well as customer interaction, has not been considered yet in this research area. Beck and Hofmann (2012) state a deficit of MCDM applications in the area of SC strategy. Furthermore, they point out that current customer-oriented SCM approaches, i.e. SCD, have not been considered in MCDM research on SCM. Furthermore, Subramanian and Ramanathan (2012) review 291 AHP applications to operations management. 27% of the surveyed AHP applications focus on decision problems in SCM. The authors list the criteria considered for the analyzed AHPs. None of the reviewed approaches integrates product and demand characteristics or customer interaction, for deciding on differentiated SC strategies. Due to the importance of such decisions, this research gap is severe. This gap is even more surprising since research on relevant criteria has been conducted, as presented in Section C.2.1.

C.3 SCD-decision model

Mentzer *et al.* (2001, p. 15) state that "SCM is concerned with improving both efficiency (i.e., cost reduction) and effectiveness (i.e., customer service) in a strategic context (i.e., creating customer value and satisfaction through integrated supply chain management) to obtain competitive advantage that ultimately brings profitability." SCD is a modern and customer responsiveness driven SCM approach. The main goal of SCD is to deliver customers exactly what they want and thereby guarantee effectiveness of SCM. These considerations are incorporated in the first component of our model, the effectiveness ensuring part. However, effectiveness without efficiency is a pointless venture, since doing what customers want while lacking profitability is no sustainable business model. Therefore, the second part of our model integrates an efficiency constraint, which requires the positive effects from SCD not to be overcompensated by the costs incurred by SCD.

The here proposed SCD-decision model incorporates three steps: (I) Conduct analyses of effectiveness ensuring part, which encompasses customer interaction as well as product and demand characteristics. (II) Based on the results from these analyses, derive distinct SC design scenarios that incorporate standardized SC design components. (III) Select the most suitable SC design scenario by means of an AHP, which incorporates the effectiveness ensuring part and the efficiency constraint (positive effects of SCD and SCD costs). *Figure C-1* illustrates the application process of the SCD-decision model.

C.3.1 Effectiveness ensuring part

Since effectiveness is occupied with satisfying customer requirements, this part of our model starts with analyzing the demanded customer interaction with respect to SCM.

Customer interaction

Academia increasingly proposes that a company is not able to create value but only to offer a value proposition (cf. Vargo and Lusch, 2004). Value in use of a product and/or services are always based on value co-creation of the manufacturer and the customer following service-dominant logic (cf. Vargo and Lusch, 2008). Through the interaction with the manufacturer the customer is able to influence the value in use, which the product and/or the service provide. Several indicators are available to

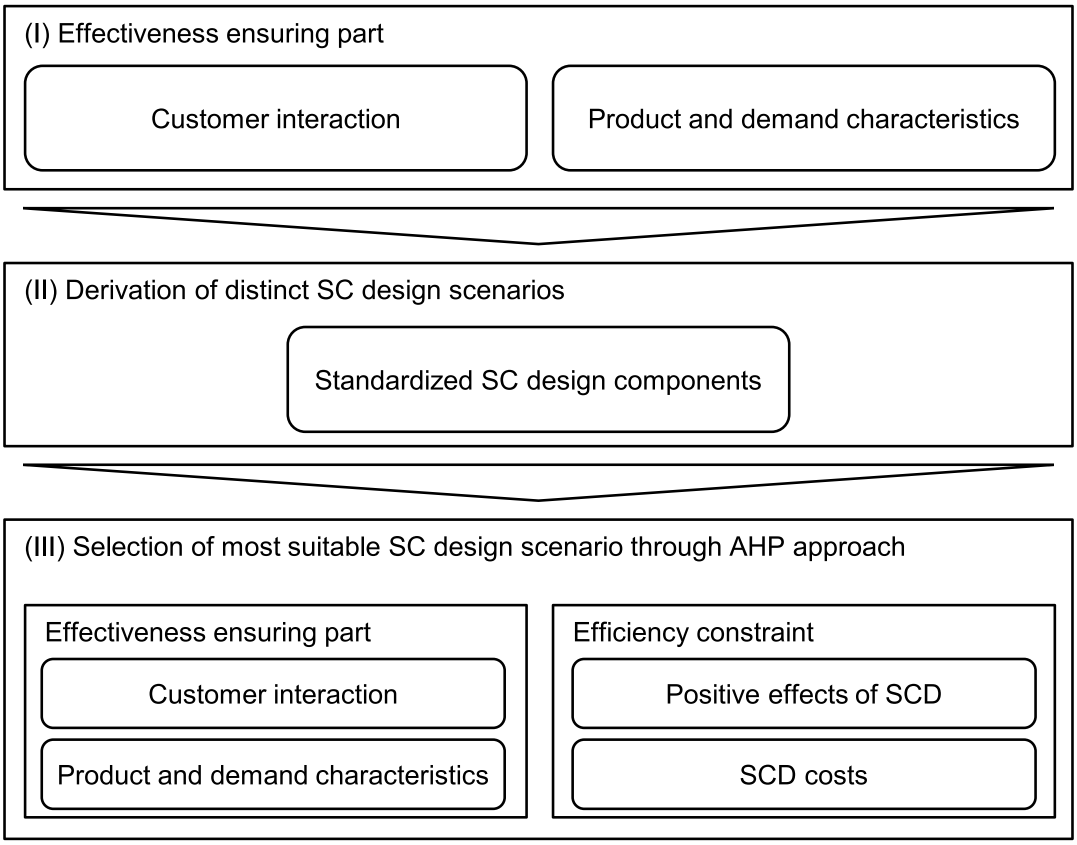

Figure C-1: Application process of the SCD-decision model

measure this interaction. The first and most general indicator is the level of information sharing. A high level of information sharing between the customer and the manufacturer is a sign for some kind of customized product or customized service provision. No information sharing at all indicates that the customer is satisfied with the standard product and/or the standard service. For a more detailed view on demanded customer interaction, we divide possible areas the customer might influence, namely distribution, manufacturing and purchasing. Distribution was one of the first value adding areas that adopted differentiated approaches as early publications on service level differentiation with respect to the requirements of distinct customer segments suggest (e.g. Gilmour *et al.,* 1977). Customers often have specific needs regarding the way the product is delivered to them. Therefore, the demanded influence on distribution is a relevant indicator and variable for customer interaction. The central value adding area, manufacturing, has become subject to customization and differentiated approaches too, through approaches like postponement (cf. Pagh and Cooper, 1998) and mass customization (cf. Pine, 1992). Companies adopt increasingly approaches in which the production of standard products and customized products are combined, e.g. sports article and shoe manufacturer Adidas (Berger and Piller, 2003) and computer manufacturer Dell (cf. Beck *et al.,* 2012). Thereby these companies integrate a differentiated customer approach by efficiently manufacturing standard products while effectiveness is ensured through the line of customized products. Hence, information on demanded influence on manufacturing is worthwhile for describing customer interaction. The area of purchasing is in recent years also subject of customer interaction. Especially in business to business markets, the interest of customers to influence purchasing decisions of the manufacturer raises (cf. Choi and Linton, 2011). This variable should also be integrated in the description of customer interaction.

Product and demand characteristics

As stated in the literature review, the so called DWV^3 model based on Christopher and Towill (2000) and Childerhouse *et al.* (2002) is a well discussed and tested set of five variables for analyzing product and demand characteristics. We integrate these five variables in our model and briefly explain the single variables in the following. The duration of product life cycle is an indicator for storage capability of a product. If products are of high technological nature, long storage times might be not possible due to the loss in value of the product. The window for delivery represents the lead time demanded by customers. Some groups of customers expect lead times that do not allow for a production after the customer placed its order. In such cases products must be pre-manufactured and stored for immediate satisfaction of the customer order. The two variables demand volume and variability are classical criteria for deciding whether products should be provided to market via push or pull strategy (cf. Vitasek *et al.,* 2003). Finally product variety is also an indicator for favorable push of pull manufacturing of products. A high number of product variants suggest low volume and high variability for the single product variant. However, this variable gets obsolete if the analysis of demand volume and variability is carried out on the level of stock keeping units (SKU) (cf. Godsell *et al.,* 2011).

Concluding we want to emphasize that the relevance of the single variables in both areas, customer interaction as well as product and demand analysis, depends on the considered company and the specific case (cf. Christopher *et al.,* 2009; Godsell *et al.,* 2011).

Standardized SC design components

On the basis of the above introduced criteria and variables in the effectiveness ensuring part, SC design scenarios are derived. To describe the SC design scenarios, we introduce SC design components, which are common in SCM research and therefore guarantee a high level of generalizability. Due to the complexity of the proposed model, we restrict the included decision variables (SC design components) to a minimum. Certainly, the number of considered decision variables may be extended if needed. Besides the number of SCs for a differentiated SC, we include distribution channels, SC strategies and types of SCs. As possible configurations of the distribution channel we incorporate indirect, multi-channel and direct distribution. The regarded manifestations of generic SC strategies are lean, leagile and agile. Finally, with respect to the type of SCs used in a differentiated SC design we consider make-to-stock (MtS), assemble-to-order (AtO), and make-to-order (MtO) SC types. The SC type could be also referred to as manufacturing strategy. The introduced variables of the effectiveness ensuring part and the standardized SC design components are summarized in *Figure C-2*.

C.3.2 Efficiency constraint

The efficiency constraint makes certain that the positive effects of SCD are not overcompensated by the costs incurred by the differentiated SC design. This implies a listing of expected positive effects as well as costs and a comparison of these effects. Possible positive effects from SCD spread widely in related literature. Childerhouse *et al.* (2002) report reductions of manufacturing costs and delivery lead times. Davis (2010) states cost reductions due to complexity decreases and mentions also an increased customer proximity, which may yield a higher revenue. Furthermore, a revenue increase may also be due to higher prices for customized products that are offered in the course of differentiating a push oriented SC (cf. Berger and Piller, 2003). We consider in our model the following possible positive effects of SCD: (a) revenue increase, (b) higher customer proximity, (c) complexity decrease, (d) decrease of delivery lead time, and (e) differentiated customer approach.

Even if some academics claim cost reductions of a differentiated SC design over a “one size fits all” SC design, this must be observed carefully. Therefore, we suggest a thorough estimation of cost developments in the course of implementing

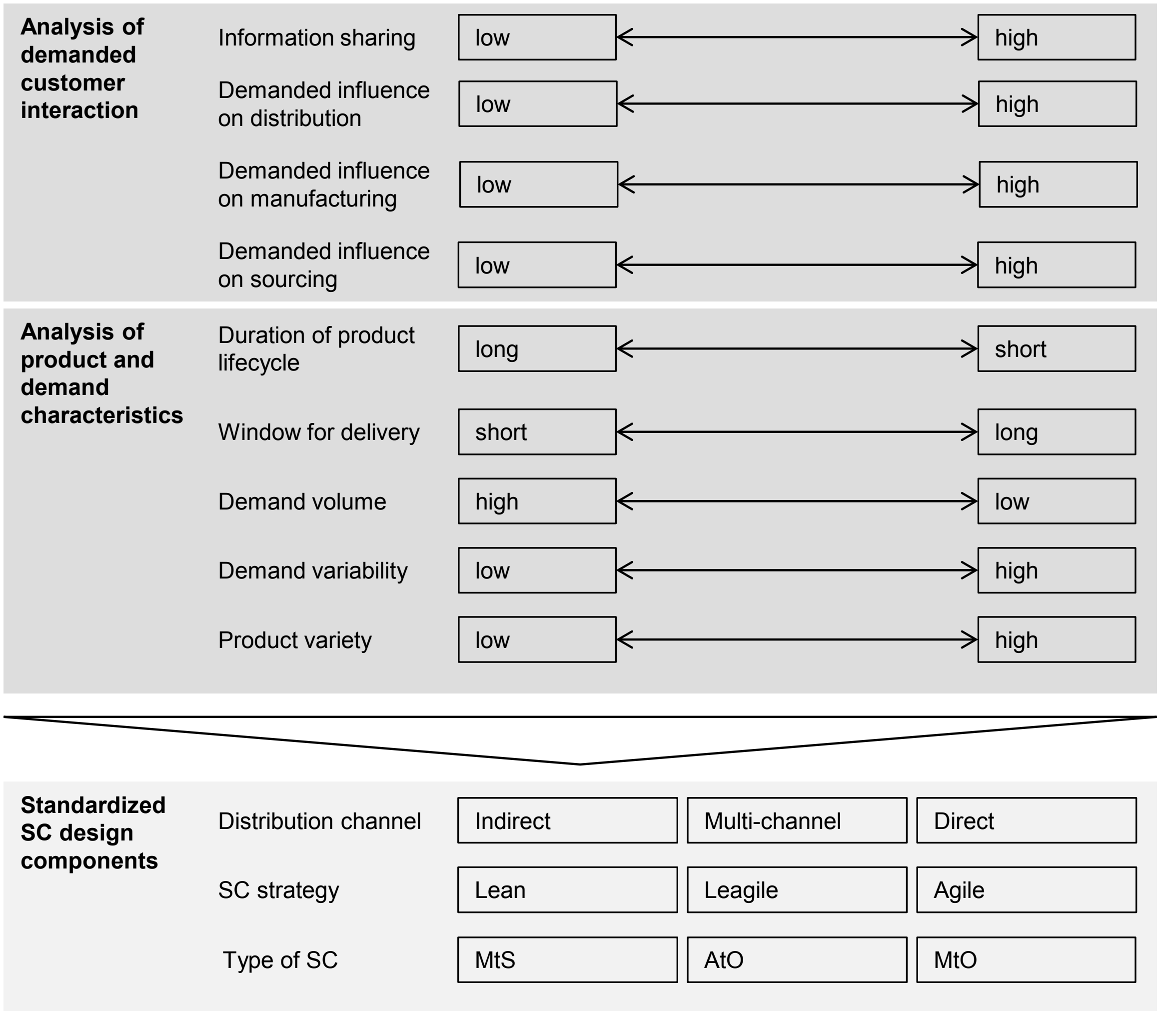

Figure C-2: Criteria categories and variables for SCD-decision and standardized SC design components

SCD. Recently Pettersson and Segerstedt (2012) introduced a framework for measuring SC costs, which might be supportive for estimating cost developments incurred by SCD. They distinct six different categories of SCM costs: (i) manufacturing cost, (ii) administration cost, (iii) warehouse cost, (iv) distribution cost, (v) capital cost, and (vi) installation cost.

C.3.3 Analytic hierarchy process for decisions on supply chain differentiation

The model we propose requires a MCDM method that is flexible with respect to the consideration of qualitative and quantitative input data. The AHP, a method for quantifying decision makers preferences by means of pair-wise comparisons based on Saaty (1980), is such a flexible method. Subramanian and Ramanathan (2012) state that the AHP is mostly utilized if qualitative and quantitative information have to be considered. AHPs are especially applied in situations where input information is hardly quantifiable and expert judgments have to be objectified and expressed numerically. The method guarantees consistency of decision makers preferences by means of a consistency indicator. Furthermore, group decisions are easily implementable in an AHP (cf. Saaty, 2008). An AHP is particularly well suited for complex decision problems, since it structures the decision problem hierarchically into sub problems and thereby fosters a better understanding of the overall decision problem (cf. Bhagwat and Sharma, 2009). A major criticism of the method is due to the problem of rank reversal. This means, if further decision alternatives are added the ranks of the old alternatives might change. However, academics have not reached a consensus regarding whether this is actually a fundamental problem in the application of the method (cf. Wang and Elhag, 2006). Hence, we will ignore this criticism.

According to Saaty (2008) an AHP application incorporates the following steps:

i.) The problem and the relevant information are defined.

ii.) The decision is hierarchically structured including the statement of the decision problem on the top of the hierarchy and the introduction of the relevant criteria (first level criteria and sub-criteria to the lowest level of criteria).

iii.) Thereafter the decision makers compare the solution alternatives to each other by pairwise comparisons of each alternative with respect to each criterion on the lowest level of the hierarchy. These pairwise comparisons are also conducted for the criteria on the higher levels.

iv.) The last step summarizes the priorities created on each level until the rank of the solution alternatives is obtained.

The AHP is a method for the comparison of different solution alternatives for a decision problem. In our case the solution alternatives are the distinct SC design scenarios. By means of the variables in the effectiveness ensuring part of our model, these SC design scenarios are derived.

Figure C-2 states the differentiation variables of the effectiveness ensuring part of the model and the standardized SC design components. Through the qualitative analysis of customer interaction and the quantitative analyses of demand and product characteristics, the decision makers are able to derive suitable SC design scenarios for their business environment. These steps before the application of the AHP also provide a better understanding of the differentiation variables in the effectiveness ensuring part and their influence on possible differentiated SC designs by the decision maker.

Having derived the SC design scenarios, the differentiation variables of the effectiveness ensuring part and the efficiency constraint have to be integrated in an AHP. Therefore these variables must be structured hierarchically. In our case it seems natural to apply the already existing hierarchy of the model. Hence, the decision problem we seek to solve is “which is the most suitable SC design for the regarded market?” The first level criteria for solving this problem are the effectiveness and the efficiency part. The level two criteria are customer interaction as well as product and demand analysis, subsumed in the effectiveness part, and positive effects of SCD and costs incurred by SCD, in the efficiency constraint. The third level criteria of our AHP consist of the variables introduced earlier in this section. *Figure C-3* presents the AHP criteria hierarchy.

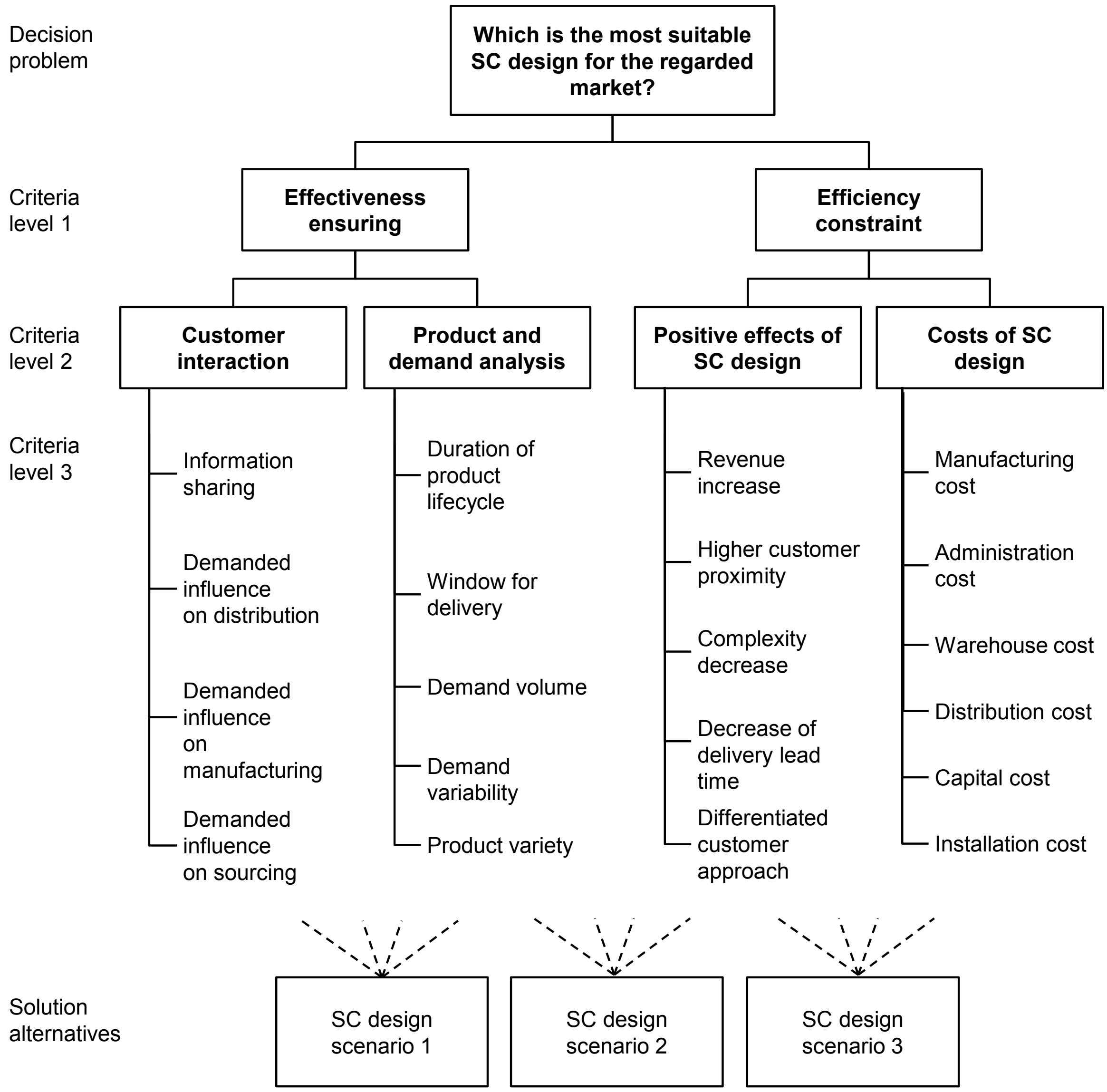

Figure C-3: Analytic hierarchy process for decisions on SCD

C.4 Illustrative example

On the basis of our case study we present an exemplary application of the model in this section. The case company is a multi-national manufacturer of wiring and wiring devices for communication solutions sited in Switzerland. In 2011 they counted 600 employees and made a revenue of approximately 210 million US $.

C.4.1 Derivation of supply chain design scenarios

In our case example we consider five different customer segments, which the company serves, and 300 SKUs. The five customer segments are large scale installers, system integrators, value adding resellers, normal resellers and small scale installers (e.g. electricians). These customer segments show varying attributes regarding customer interaction. According to their demands with respect to information sharing as well as influence on distribution, manufacturing and sourcing, two mainly homogenous customer groups are formed. The customer segments large scale installers and system integrators are combined in customer group 1 (CG1) with a high demand for customer interaction. The customer segments value adding resellers, normal resellers and small scale installers are consolidated in customer group 2 (CG2) with a low demand for customer interaction. *Table C-1* summarizes the demanded customer interaction of the single customer segments and the customer groups.

Unfortunately companies are very reluctant to provide their sales figures on SKU basis for research purposes. Therefore, we had to generate the attributes of the exemplary SKUs on basis of the regarded industry. We used random number generators for creating average demand volumes, the variabilities of demand and the windows for delivery with respect to each SKU. The average yearly demand (μ) is generated by a random variable with a uniform distribution between 0 and 10. The variability, in form of a standard deviation (σ), is generated with a random number generator using a uniform distribution between 0 and 5. However, the variability was defined to slightly decrease as the average demand increases. In real life the window for delivery for products often increases as the variability of the product increases, e.g. a product with a high degree of customization is ordered very irregu-

Table C-1: Customer interaction in different customer segments and groups

	Demanded customer interaction			
Customer segments/ groups	Information exchange	Distribution	Manufacturing	Sourcing
Large scale installers	high	high	medium	low
System integrators	high	high	high	high
Resellers	low	low	low	low
Value adding resellers	medium	low	medium	low
Distributers (e.g. electricians)	medium	low	low	low
Customer group 1	high	high	high	medium
Customer group 2	medium	low	low	low

larly and the customer is prepared the wait a longer time since he gets exactly the product he wants. We integrate this assumption in the computation of our window for delivery. The window for delivery (W) depends on the coefficient of variation of demand ($CV = \sigma/\mu$) multiplied by a random number incorporating a uniform distribution between 0 and 1. Thereby it was ascertained that SKUs with a high CV normally have a long W but it was also allowed for outliers, i.e. SKUs with high CV and short W. W assumes the values 1 (short), 2 (medium) and 3 (long). Since we conduct the analysis on SKU level, the variable product variety is not relevant in our example. Furthermore, the duration of product life cycle is rather long for all SKUs. Hence, this variable is also irrelevant in our example. *Figure C-4* presents the demand volume and variability of all considered SKUs.

After the generation of the exemplary SKUs and their attributes, we created three product clusters, based on information from the case company. The SKUs were assigned to the product clusters (PC) under the following conditions:

- PC1: $\mu \geq 5$ AND $\sigma \leq 3$ OR $W = 1$
- PC2: $\mu \geq 2$ AND $\sigma \leq 3$ AND $W \geq 2$ OR $W = 2$
- PC3: $\mu < 2$ AND $W = 3$

Hence, PC1 incorporates SKUs with high volume and low variability as well as

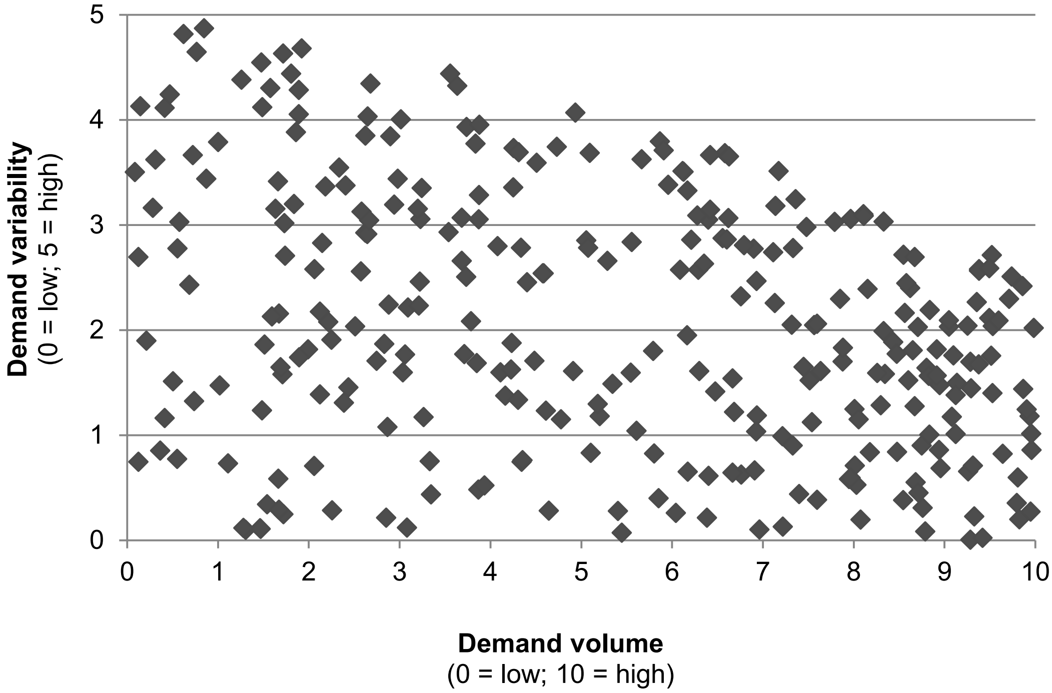

Figure C-4: Demand volume and variability of considered SKUs (random numbers) units that do not match the previous criteria but have a short lead time. PC2 integrates all SKUs with medium volume and variability as well as units with a medium lead time. PC3 incorporates all other units. *Table C-2* summarizes the attributes of the total SKU sample as well as the attributes of PC1 to PC3. Further important information is that the SKUs in PC1 are mainly demanded by CG2 and the SKUs in PC2 and PC3 are mainly demanded by CG1. This is coherent with the fact that CG1 demands a high influence on manufacturing. Therefore these SKUs have a lower demand and a higher volatility in demand.

As presented above we determined two different customer groups with varying demanded customer interaction. Furthermore we categorized the SKUs in three mostly homogenous product clusters. The SC design scenarios are derived according to several possibilities to serve these customer groups and to provide the SKUs within the product clusters.

SC design scenario 1 considers a single SC design to serve the customer groups. Since the customer groups vary regarding their demand for information exchange the company must offer them various possibilities to submit their orders. Therefore, the company would adopt a multi-channel distribution strategy. Most of the SKUs within the sample (PC1, with 188 SKUs) are suited to be manufactured via a lean SC strategy. Hence, it seems appropriate to adopt a lean approach in a

Table C-2: Description of total SKUs and product clusters

		μ	σ	W
Total (300 SKUs)	Minimum	0.0876	0.0033	1
	Average	5.3556	2.0746	1.5700
	Maximum	9.9851	4.8708	3
PC1 (188 SKUs)	Minimum	1.2832	0.0033	1
	Average	6.9034	1.5610	1.0904
	Maximum	9.9851	3.7421	2
PC2 (71 SKUs)	Minimum	0.5570	0.5856	2
	Average	3.5243	2.7105	2.0141
	Maximum	8.3304	4.6772	3
PC3 (41 SKUs)	Minimum	0.0876	0.7446	3
	Average	1.4292	3.3286	3
	Maximum	3.8801	4.8708	3

single SC design and to implement a MtS SC. However, to fulfill the demand for a high customer influence on manufacturing, the company would be forced to produce even the SKUs in PC3, with low demand and high variability, by means of MtS SC. This may incur extensive costs for storing these units.

SC design scenario 2 adopts a differentiated SC strategy with two SCs. With respect to the CGs an implementation of two differentiated SCs seems meaningful. CG1 has very high demand for interaction in the categories information sharing, influence on distribution and manufacturing. On the other side, the customers within CG2 are prepared to accept much less interaction. If a company wants to serve both customer segments effectively but still make use of the possibility to serve the SKUs within PC1 by means of a cost efficient approach, a differentiation of their SC seems meaningful. In this case CG1 would be mainly served by an agile SC2 integrating a MtO SC, which would provide the SKUs within PC2 and PC3. The high volume low volatility SKUs, which are mainly demanded by CG2, are manufactured via a lean SC1. Furthermore, SC1 would implement multi-channel distribution while SC2 would operate direct distribution.

SC design scenario 3 incorporates the set up of three differentiated SCs. Three SCs seem to be most adequate to deal with the varying requirements of the SKUs within PC1 to PC3. SC1 would adopt a lean SC strategy and operate a MtS SC, very much like SC1 in design scenario 1, and provide the SKUs within PC1 to CG2. The distribution would follow a multi-distribution strategy. SC2 would implement a leagile SC by means of an AtO SC. It would manufacture the SKUs in PC2, which are mainly demanded by CG1. SC3 would use an agile SC strategy through a MtO SC and produce the SKUs within PC3, again mainly for CG1. SC2 and SC3 would use a direct distribution strategy. The position of the PCs and CGs within the relevant criteria and variables as well as the SC design scenarios are summarized in *Figure C-5*.

C.4.2 AHP application for the evaluation of supply chain design scenarios

Having derived three design scenarios by means of our framework, we will now use an AHP to select the most appropriate SC design for the regarded case company. We use the criteria hierarchy presented in *Figure C-2*, except for the not relevant variables duration of product life cycle and product variety (see previous

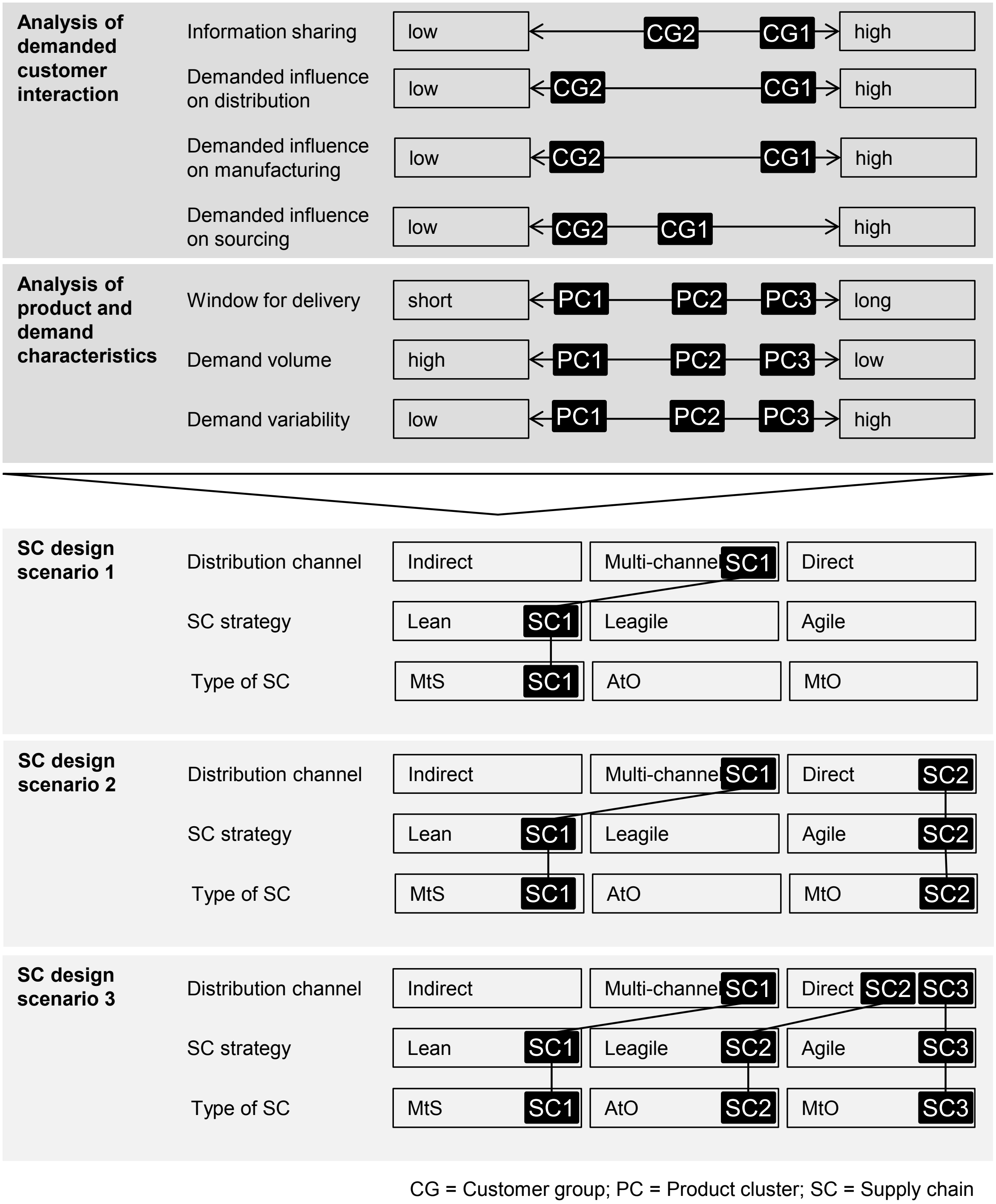

Figure C-5: Relevant SCD-decision criteria and SC design of the case company

subsection). On basis of the statements of the case company, we do pairwise comparisons of criteria levels 1 to 3 and the solution alternatives. Overall 25 matrices are filled in. For the calculation of the eigenvalues and the eigenvector we use the arithmetic mean method, proposed by Saaty (1980). For each matrix of pairwise comparison we make sure that the consistency ratio is smaller than 0.1 (see Saaty, 1980). *Table C-3* presents the results of the AHP analysis.

As presented in *Table C-3*, we prioritize, in accordance with statements of the case company, the efficiency constraint higher than the effectiveness ensuring part, since costs within the efficiency constraint are quantifiable and therefore should be considered with a higher weight. Customer interaction and product and demand are of equal importance. Within the sub-criteria of customer interaction, the influence on manufacturing is the most important criteria. In the area of product and demand analysis the criterion demand volume has the highest weight. In the efficiency constraint, again the simpler quantifiable costs are higher weighted than the more difficult to estimate positive effects of SCD. A possible revenue increase is the most important criterion within the positive effects of SCD. For the criteria subsumed under SCD costs we used pairwise comparisons of estimated costs for the different SCD design scenario.

Table C-3: Results of the AHP application

				SC design scenario 1	SC design scenario 2	SC design scenario 3
Effectiveness ensuring	Customer interaction	Information sharing	0.2433	0.2000	0.4000	0.4000
0.3333	0.5000	Influence on distribution	0.1466	0.1976	0.3119	0.4905
		Influence on manufacturing	0.5115	0.1263	0.4577	0.4160
		Influence on purchasing	0.0986	0.1638	0.5390	0.2973
		Sub-priorities customer interaction		*0.1584*	*0.4303*	*0.4113*
	Product and demand	Demand volume	0.5571	0.1698	0.3873	0.4429
	0.5000	Demand variability	0.3202	0.1263	0.4160	0.4577
		Window for delivery	0.1226	0.3333	0.3333	0.3333
		Sub-priorities product and demand		*0.1760*	*0.3899*	*0.4342*
	Sub-priorities effectiveness ensuring			**0.1672**	**0.4101**	**0.4227**
Efficiency constraint	Positive SCD effects	Revenue increase	0.4723	0.1698	0.3873	0.4429
0.6667	0.2000	Higher customer proximity	0.0846	0.1698	0.3873	0.4429
		Complexity decrease	0.1981	0.3333	0.3333	0.3333
		Decrease of delivery lead time	0.1568	0.2000	0.4000	0.4000
		Differentiated customer approach	0.0882	0.2000	0.4000	0.4000
		Sub-priorities positive SCD effects		*0.2096*	*0.3797*	*0.4107*
	SCD costs	Manufacturing cost	0.5640	0.3771	0.3205	0.3024
	0.8000	Administration cost	0.0698	0.3925	0.3271	0.2804
		Warehouse cost	0.0950	0.1892	0.4730	0.3378
		Distribution cost	0.1647	0.3750	0.3125	0.3125
		Capital cost	0.0640	0.3039	0.3646	0.3315
		Installation cost	0.0426	0.7143	0.1429	0.1429
		Sub-priorities SCD costs		*0.3697*	*0.3294*	*0.3009*
	Sub-priorities efficiency constraint			**0.3377**	**0.3395**	**0.3229**
			Priorities	**0.2808**	**0.3630**	**0.3562**
			Normalized	**0.7737**	**1.0000**	**0.9812**

Table C-4 states the estimated costs of cost category *i*, e.g. manufacturing cost, and SC design scenario *j*. The single cost component is denoted by c_{ij}. The weighting for cost category *i* (WCC_i) is calculated as follows:

$$WCC_i = \frac{\sum_{j=1}^{3} c_{ij}}{\sum_{i=1}^{6}\sum_{j=1}^{3} c_{ij}}$$

The priorities regarding SC design scenarios with respect to the different cost categories were computed according for the following example. The example shows the calculation of priorities of the SC design scenarios for the cost category manufacturing cost (*j = 1*). This kind of priority calculation always returned a consistency ratio of zero.

$$\begin{pmatrix} 1 & \frac{c_{12}}{c_{11}} & \frac{c_{13}}{c_{11}} \\ \frac{c_{11}}{c_{12}} & 1 & \frac{c_{13}}{c_{12}} \\ \frac{c_{11}}{c_{13}} & \frac{c_{12}}{c_{12}} & 1 \end{pmatrix} = \begin{pmatrix} 1 & \frac{100}{85} & \frac{106}{85} \\ \frac{85}{100} & 1 & \frac{106}{100} \\ \frac{85}{106} & \frac{100}{106} & 1 \end{pmatrix}$$

The priorities of the SC design scenarios with respect to the other criteria were computed by means of pairwise comparisons, i.e. how well would each SC design scenario cover the differing needs of the customer groups or the product clusters in the effectiveness ensuring part. The same was done for the positive effects of SCD within the efficiency constraint. As apparent from *Table C-3*, the most favored SC design scenario varies for the criteria level one to three. For example, within the area of customer interaction SC design scenario 2 is the highest prioritized solution. The criteria within product and demand prefers SC design scenario 3 and the criteria

Table C-4: Costs for SCD per cost category and SC design scenario

	SC design scenario 1	SC design scenario 2	SC design scenario 3	Total	Weights
Manufacturing cost	85	100	106	291	0.56395
Administration cost	10	12	14	36	0.06977
Warehouse cost	25	10	14	49	0.09496
Distribution cost	25	30	30	85	0.16473
Capital cost	12	10	11	33	0.06395
Installation cost	2	10	10	22	0.04264
Total	159	172	185	516	

for SCD costs positions SC design scenario 1 on the highest rank.

C.4.3 Sensitivity analysis of the AHP results

Since the sub-priorities of the AHP favor different solutions, we conduct a sensitivity analysis for the evaluation of the robustness of the AHP result. We integrate all criteria on level one and two of the AHP criteria hierarchy, since the weightings of these criteria have the highest influence on the overall outcome of the AHP. Furthermore, we incorporate the criteria with the highest weightings from criteria level 3, i.e. information sharing, influence on manufacturing, demand volume, revenue increase, manufacturing and distribution cost. We calculate which weights change the overall outcome of the AHP, with positive and negative deviations, resulting in upper bounds and lower bounds for the AHP solution. For the criteria on level one and two, we only calculated the deviations for one of the factors. This is due to the fact that the level one and two criteria are always in pairs, i.e. effectiveness ensuring vs. efficiency constraint. This means that the weight of one criterion directly determines the weight of the other criterion (weight of effectiveness ensuring = 1 – weight of efficiency constraint). We integrate this relationship in the sensitivity analysis. In case of information sharing, influence on manufacturing, demand volume and revenue increase we divide the deviation evenly between the other relevant sub-criteria. We stopped the sensitivity analysis if one of the criteria exceeds the weight of one or gets under zero, e.g. sensitivity analysis for information sharing stopped at 0.5389 since the criterion influence on purchasing falls below zero. With respect to the considered cost categories we calculated deviations in cost that would change the overall outcome of the AHP. However, we stopped the sensitivity analysis at 200% deviation or if the cost factor falls under zero.

Table C-5 shows the outcomes of the sensitivity analysis. The column “changing weight” states the value at which the overall AHP solution is altered. The column “relative deviation” states the variance in % from the original value to the changing weight and NA means that no change occurred. As presented, the results of the AHP are relatively robust. For the level one and level two criteria, high deviations are necessary to change the overall outcome of the AHP. Regarding the criteria information sharing, influence on manufacturing, demand volume and revenue increase no change occurs at all. However, deviation in manufacturing and distribu-

Table C-5: Results of the sensitivity analysis for the AHP

			Changing weight	Relative deviation	Priorities		
					SC design scenario 1	SC design scenario 2	SC design scenario 3
1	Effectiveness ensuring	ub	0.5666	70%	0.6353	0.9999	1
		lb	0	NA	0.9947	1	0.9512
2	Customer interaction	ub	1	NA	0.7517	1	0.9530
		lb	0.1764	65%	0.7883	0.9999	1
3	Positive SCD effects	ub	0.3723	86%	0.7117	0.9999	1
		lb	0	NA	0.8481	1	0.9586
4	Information sharing	ub	0.5389	NA	0.7826	1	0.9859
		lb	0.0000	NA	0.7664	1	0.9774
5	Influence on manufacturing	ub	0.8072	NA	0.7612	1	0.9785
		lb	0	NA	0.7955	1	0.9859
6	Demand volume	ub	0.8024	NA	0.7658	1	0.9851
		lb	0	NA	0.7916	1	0.9722
7	Revenue increase	ub	0.8106	NA	0.7660	1	0.9864
		lb	0	NA	0.7843	1	0.9739
8	Manufacturing cost for SC design scenario 1	ub	255.0100	NA	0.5166	1	0.9809
		lb	38.0900	55%	1	0.9999	0.9828
9	Manufacturing cost for SC design scenario 2	ub	107.4020	7%	0.7913	0.9999	1
		lb	0	NA	0.3535	1	0.5315
10	Manufacturing cost for SC design scenario 3	ub	318.0010	NA	0.8100	1	0.7447
		lb	98.4040	7%	0.7709	0.9999	1
11	Distribution cost for SC design scenario 1	ub	75.0010	NA	0.6781	1	0.9854
		lb	0.0000	NA	0.9369	1	0.9779
12	Distribution cost for SC design scenario 2	ub	37.9050	26%	0.7908	0.9999	1
		lb	0	NA	0.6370	1	0.8318
13	Distribution cost for SC design scenario 3	ub	90.0000	NA	0.7890	1	0.8913
		lb	23.0610	23%	0.7707	0.9999	1

ub = upper bound; lb = lower bound

tion costs easily lead to changes in the overall outcome. Hence, the AHP result is very sensitive with respect to manufacturing and distribution costs in this example. A decision maker should bear that in mind before selecting the final SC design.

C.5 Discussion and conclusion

Applications of methods in MCDM on strategic contexts, especially in SCM, are rare (cf. Beck and Hofmann, 2012; Subramanian and Ramanathan, 2012). This fact is especially surprising since MCDM methods seem very well suited for tackling strategic decision problems that involve both, qualitative and quantitative information.

The paper at hand picks up a currently discussed problem in strategic SCM research, the design of differentiated SCs. It contributes thereby to academia through integrating SCD in a MCDM approach for the first time. Furthermore, we offer a comprehensive spectrum of relevant criteria with respect to decisions on SCD. For managers the paper offers a methodology for addressing such decision problems and guidance in doing so. The extensiveness of a real world application of the proposed model is variable. All inputs may be pure subjective estimations of a decision maker, which would be the minimum magnitude of application. The maximum extent of application would require as objective as possible estimation based quantitative analyses, for example the incurred costs may be evaluated through a project of several months. Apparently, thorough analyses of all relevant variables yield higher objectified results that represent the reality more accurately.

Regarding limitations of our proposed model, an application is only conducted to an illustrative example. Yet, our experience during collecting the information for the creation of our model and several workshops and interviews with decision makers suggests that applicability to real life problems is given. Furthermore, even if our research for deducting the model was thorough and comprehensive, it is not possible to rule out that further criteria should be integrated in the model. Additionally, we incorporated a company from the plant and machinery building industry to derive the decision model. Companies from the plant and machinery building industry normally are located downstream in their SCs. Therefore, it might be that companies, which are located upstream in their SCs, like manufacturers of chemicals, have to consider other criteria.

Future research directions are distinguishable in two sub-domains: research on relevant criteria for decisions on SCD and research in further developing MCDM approaches for decisions on SCD. With respect to SCD-decision criteria future research should ensure completeness of relevant criteria for such decisions. Therefore, further real life decisions on SCD should be analyzed thoroughly, e.g. by means of case studies or action research. Research on MCDM methodologies for such decision problems should find ways to integrate this hopefully complete set of criteria by means of suitable approaches. The qualitative often with uncertainty charged criteria of such problems might suggest an integration of fuzzy logic to these problems. The quantitative factors, like costs and available information on product and demand characteristics, might even allow for a meaningful application of multi-objective programming for optimizing the assignment of SKUs to different product clusters.

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