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Hrsg.: Frank Straube, Helmut Baumgarten, Raimund Klinkner

Benjamin Nitsche

Development of an Assessment Tool to Control Supply Chain Volatility

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Prof. Dr.-Ing. Frank Straube,
Prof. Dr.-Ing. Raimund Klinkner,
Prof. Dr.-Ing. Dr. rer. pol. h.c. Helmut Baumgarten

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E-Mail: publikationen@ub.tu-berlin.de

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Content Overview

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List of Abbreviations

AHP	Analytical Hierarchy Process
B2B	Business to business
B2C	Business to consumer
BWE	Bullwhip-effect
CR	Consistency Ratio
ETA	Estimated time of arrival
ETD	Estimated time of departure
ETO	Engineer to order
MAPE	Mean absolute percentage error
MTO	Make to order
MTS	Make to stock
NGT	Nominal Group Technique
OTDR	On-time delivery rate
RO	Research objective
RO	Research question
S&OP	Sales and operations planning
SC	Supply chain
SCM	Supply chain management
SCV	Supply chain volatility
SLR	Systematic literature review

1. Introduction

1.1 Motivation and Background

Coping with volatility is one major challenge of modern supply chains (SC). While facing tremendous turbulence on both the supply and demand sides, SC managers acknowledge the increasing importance of volatility and are forced to adjust and redesign their SC and operational structures on a regular basis (Handfield et al., 2013). Christopher and Holweg (2011) further predicted an upcoming era of volatility that will hurt the performance of SCs, leading to stock-outs, inefficient inventory levels and poor capacity utilization; a trend that is still present in their revised version of this article (Christopher and Holweg, 2017). Consequently, volatility ranks among the most important future research topics that need more attention from academia (Wieland et al., 2016).

Nevertheless, volatility itself is not a novel phenomenon in SCM. Indeed, it has already been challenging companies for decades. On the one hand, there are traditional inducers of volatility that have been intensively investigated by academia, although a lot of companies still struggle to deal with them (e. g., unpredictable customer demand, the bullwhip effect, missing SC visibility and others). On the other hand, there are comparatively new factors that potentially impact the volatility of material flows additionally. First, the trend of globalization paired with increasing rates of outsourcing, especially emerging market sourcing, is still present in modern SCs. This trend makes SCs prone to political, legal and currency instabilities that induce volatility often coming from the supply side. Second, after years of relative stability, increasing market volatility can be observed (Christopher and Holweg, 2011, 2017). In particular, the transport and logistics market faces growing volatility in transport volumes. A study among 229 German manufacturers, retailers and logistics service providers stressed that, especially for international transport, volume fluctuations are steadily accelerating. Practitioners agree that this leads to higher logistics costs due to expenses for covering peaks or unutilized capacities (Wittenbrink and Gburek, 2013). Third, in the spotlight of digitalization, new customer requirements potentially change the volatility of demand. Selling a growing variety of individual products through a high number of sales channels, coupled with shorter and shorter product life cycles, could pose new challenges for logistics managers.

In general, to manage unintended changes in the material flow in your SC, you basically need to: (1) identify and understand the root causes; (2) measure and assess the impact these sources have on your particular SC; (3) set up mitigation measures to deal with it; (4) monitor the changes in volatility and reevaluate the measures you introduced. A model of the adaptation of the business continuity planning cycle to prevent supply discontinuity developed by Zsidisin et al. (2005) is shown in Figure 1.

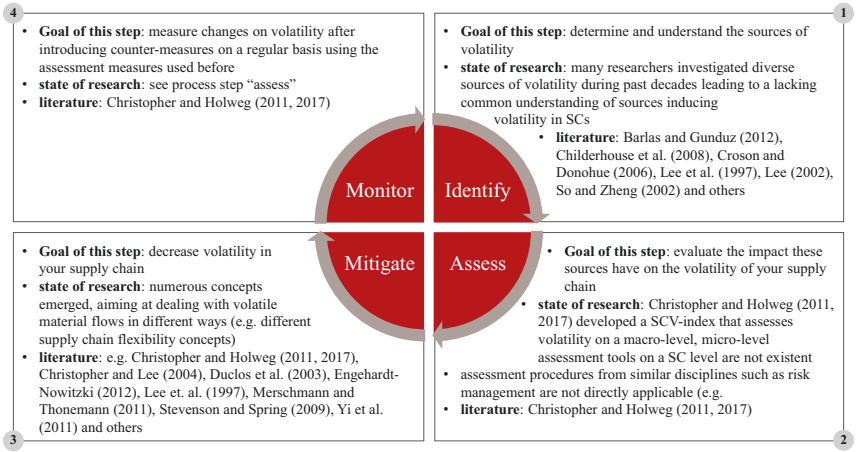

Figure 1 – Volatility management cycle and state of research

Due to the importance of the volatility phenomenon to SCM, different practices for dealing with it emerged, aiming at providing solutions to *step 3*. For example, SC flexibility (Engelhardt-Nowitzki, 2012; Yi et al., 2011) and SC agility (Gligor and Holcomb, 2014; Qrunfleh and Tarafdar, 2013) are management concepts that aim at efficiently responding to volatile changes in upstream or downstream material flows. However, it is remarkable that, although there are numerous studies about how to react to volatility (*step 3*), nevertheless other aspects of this management cycle have previously received less attention.

First, a well-founded theory about the root sources of volatility is still not existent (*step 1*). Although various sources of volatility have been examined in the past, the literature is widely spread and often focuses on single sources instead of aiming at explaining the phenomena of volatility in a comparatively holistic way. This is astonishing, considering that a profound understanding of the sources and their impact on volatility should be the basis of developing new strategies for dealing with it. Second, and equally important, companies lack a systematic

procedure concerning how to measure and assess the volatility of a SC (*step 2*) and how to monitor the changes in volatility over a period of time after introducing certain measures (*step 4*). This being said, the following thesis aims at closing this management cycle by providing a clear contribution to steps 1, 2 and 4 in order to manage volatility more efficiently. It specifically seeks to provide a management instrument that enables SC managers to assess the impact of different volatility sources on the volatility of a particular SC. It aims at assisting the monitoring and evaluation process of introduced measures. The thesis thereby tries to extend the current understanding of volatility in SCs in order to set up more suitable mitigation strategies. Additionally, management strategies for dealing with volatility will be given, in order to control supply chain volatility (SCV). Consequently, a SCV assessment tool will be provided that assists managers in measuring the volatility of a product's supply chain, finding suitable mitigation strategies and monitoring the changes in volatility over time.

1.2 Research Objective, Approach and Outline of the Thesis

It has been explained that the volatility management cycle proposed above still shows some gaps that need further investigation. In order to narrow these gaps and to develop recommendations on how to set up a SCV management system, this thesis follows an iterative, cumulative approach. It will consist of an introduction that outlines thesis objectives, approaches and delimitations; three consecutive articles that build upon each other; followed by an outlook that synthesizes the thesis's findings and puts them together into a SCV management tool that aims at controlling SCV. The thesis procedure, including methodologies applied, is outlined in Figure 2. In the following, research objectives and approaches of the three articles as well as the outlook section will be described.

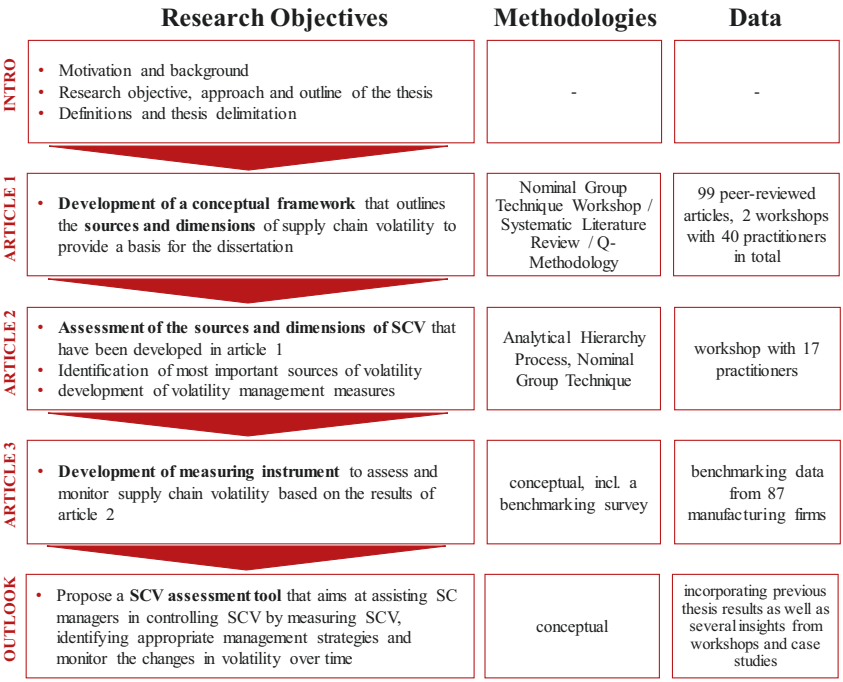

Figure 2 – Research procedure of the thesis

Article 1

The first article of this thesis aims at outlining the sources and dimensions of SCV. Explaining the emergence of volatility in material flows has been the focus of many researchers over the decades. This article strives to unify and extend research on this topic by proposing a framework of SCV that explains the dimensions, sources and possible moderators of the sources–SCV relationship. To ensure comprehensiveness, a data triangulation is applied combining a systematic literature review (SLR) with a moderated group exercise among 23 SC managers. The SLR incorporates two distinct literature search procedures. Titles and abstracts of a total of 2,789 articles have been read, identifying 99 studies relevant for further investigation. The first group exercise was based on the Nominal Group Technique (NGT, Van de Ven and Delbecq, 1971) and was conducted to widen practical insights into the topic as well as to limit the possibility of missing important aspects by solely relying upon literature. Additionally, a second group exercise was conducted in order to build propositions aiming at outlining the dimensions of SCV according to three SCV-affecting characteristics.

Subsequently, through a structured synthesis leaning on the Q-methodology (cf. Ellingsen et al., 2010), a synthesized set of 20 SCV meta-sources has been synthesized. Based upon the sources, five dimensions of SCV and two moderators of the sources–SCV relationship have been proposed by involving researchers and practitioners in the synthesis process. With the assistance of a second group exercise among 17 SCM practitioners, 15 propositions are developed that outline different SCV-affecting characteristics of the SCV dimensions.

> **RO1.1**: Development of a conceptual framework that depicts sources, dimensions and potential moderating variables in the sources–SCV relationship.

Article 2

The second article strives to assess the impact of different sources of SCV in order to efficiently guide SCV management. Therefore, an Analytical Hierarchy Process (AHP) will be performed through a moderated workshop among 17 representatives of manufacturing firms covering different industry types. By doing this, the author will give insights on the most pressing sources of SCV, acknowledging the idiosyncrasies of different types of manufacturers (especially with regard to their SC position, production strategy and total lead time). Following the AHP, a Nominal Group Technique workshop with the same group of company representatives will be conducted in order to develop management strategies for dealing with the most important sources of SCV.

> **RO2.1**: Identification and assessment of the most important sources of SCV.
> **RO2.2**: Development of strategies that seek to manage the most important sources of SCV.

Article 3

Based on the first two articles, a measuring instrument will be implemented that strives to measure the volatility of a particular SC. More specifically, the instrument will measure an SCV score that breaks down to different sub-scores building on the sources and dimensions of SCV. By using this instrument, a practitioner will be able to measure the impact of certain sources of volatility on the volatility of their SC. Consequently, they will be enabled to identify concrete needs for action from this case-based assessment. The measuring instrument will consist of a weighted scoring model that processes several qualitative and quantitative data (supplier-

specific, product-specific, company-specific and market-specific input) and benchmarks the data from companies coming from manufacturing industries. The benchmark is based on a large-scale online survey with feedback from 87 manufacturing firms.

RO3.1: Identify appropriate measures to assess the state of SCV of a product's SC.
RO3.2: Propose a benchmarking instrument that assesses the state of SCV of a product's SC and benchmarks it against competitors.
RO3.3: Analyze the current state of SCV management.

Outlook

In the outlook section the results of the first three articles will by synthesized aiming at proposing a SCV assessment tool. This will combine the SCV measuring instrument, proposed in the previous article, with a SCV management framework that outlines the core principles of efficiently managing volatility. The management framework will incorporate insights from several workshop and case study exercises conducted in the research project "Navigator for German Chinese logistics networks."

RO4.1: Development of a SCV assessment tool that combines the SCV measuring instrument with a SCV management framework to assist managers in controlling SCV.

The outlook section closes with a summary of results as well as a critical discussion of the thesis limitation and areas for future research. Figure 3 outlines a schematic representation of the intended SCV assessment tool and how the different parts of this thesis contribute to the assessment tool.

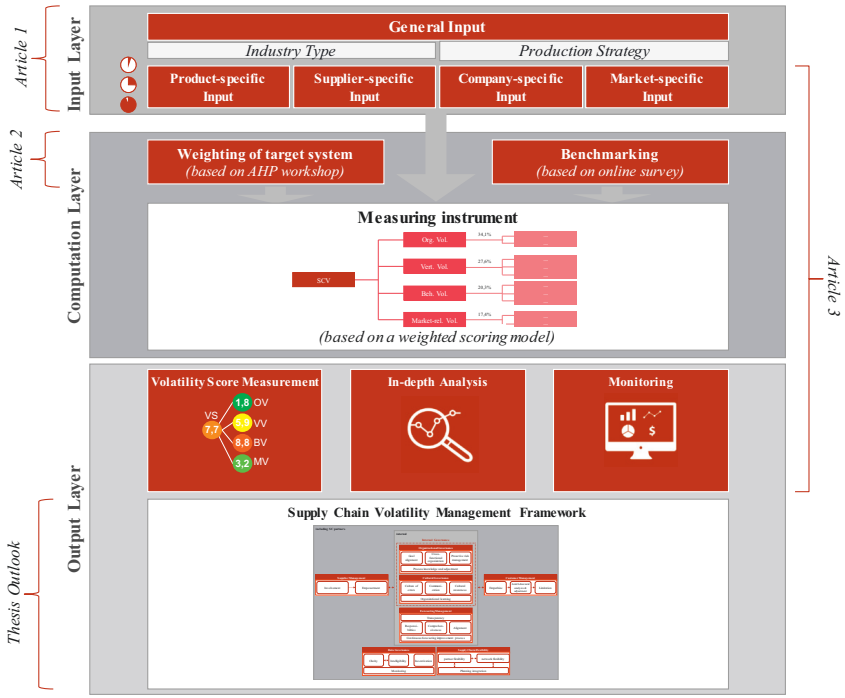

Figure 3 – Contribution of articles to the intended SCV assessment tool

(for copyright declaration see p. 161)

1.3 Definitions and Thesis Delimitation

1.3.1 Logistics and Supply Chain Management

Due to the importance of logistics and SCM in management research, numerous definitions emerged that seek to outline their specific characteristics. Although it is not intended to describe the evolution of those definitions over the past decades, it has to be stated that terminologies and understandings have changed over recent decades. Table 1 provides an excerpt of widespread and widely accepted logistics and SCM definitions. Independent from the definition, it becomes obvious that the definitions overlap with regard to different aspects. Whether one is taking a logistics or a SC perspective, both involve the planning, execution, control and monitoring of activities within a network of companies with the aim of fulfilling a customer order.

Due to the long debate on the commonalities and differences between logistics and SCM, Larson and Halldorsson (2004) investigated different perceptions on those two terms involving researchers as well as practitioners, leading to four different perspectives: *traditionalists*, *re-labelers*, *unionists* and *intersectionists*. While *traditionalists* view SCM as a part of logistics, *unionists* take the opposite perspective and view logistics as a part of supply chain management because, from their point of view, logistics is limited to, among others, transportation and warehousing, while SCM includes additional, strategic activities. The *re-labeler* school, which is widely accepted among researchers, merely changed the term from logistics to SCM to draw further attention to the network aspect of logistics management. *Intersectionists* see an overlap between logistics and SCM, but acknowledge both as different business functions.

Table 1 – Excerpt of definitions of logistics and supply chain management

Author	**Definition of Logistics and Supply Chain Management**
Straube (2004), p. 31	"**Logistics** comprises the planning, control, execution and monitoring of all information and material flows within and between companies from customers to all suppliers and sub-suppliers and other value-added partners."
Pfohl (2010), p. 12	"**Logistics** includes all activities through which the transformation of goods over time and space and the associated transformations with regard to the quantities and types of goods, the characteristics of goods handling and the logistical determinacy of the goods are planned, controlled, realized or monitored. Through the interaction of these activities, a flow of goods is to be set in motion that connects a delivery point with a receiving point as efficiently as possible."
Mentzer et al. (2001), p. 18	"**Supply chain management** is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."
Simchi-Levi et al. (2004), p. 2	"**Supply chain management** is a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize systemwide costs while satisfying service-level requirements."

For the remainder of this thesis, the terms logistics and supply chain management will be used synonymously without any differentiation. Other important definitions for the thesis, especially with regard to the term "supply chain volatility" as well as its difference from risk management, will be discussed in the first article (chapter 2).

1.3.2 Thesis Delimitations

In order to clarify the focus of this research, Figure 4 outlines the thesis delimitation. To set the conceptual constraints of our study, it is of importance to elucidate the unit and level of analysis. According to Yurdusev (1993), the unit of analysis stresses the entity that is studied, while the level of analysis refers to the context the unit of analysis is placed in. Consequently, in this study the focal firm is investigated as the unit of analysis, in terms of how it is affected by volatility. Leaning on the classification of levels of analysis in SCM research by Halldórsson and Arlbjørn (2005), the context the investigated focal firm is operating in (level of analysis) is its SC including all directly linked organizations and people. The focal firms that will be investigated are manufacturers, more specifically, the material flow of manufacturing firms excluding the flow of services.

Category	**Manifestation**				
Unit of analysis	function	firm	dyad	chain	network
Level of analysis	function	firm	dyad	chain	network
Firm unit	manufacturer	retailer	service provider	others	
Event	disruptive		recurrent		
Origin	internal	endogenous to the SC	exogenous to the SC		
Volatility management process	identification	assessment	mitigation	monitoring	
Management level	operational	tactical	strategical		

Figure 4 – Thesis delimitations

According to Chopra et al. (2007), supply chain events can be classified into recurrent and disruptive events. To specify the focus of research, this study investigates volatility as a recurrent condition that is not caused by one single incident but rather the interaction of multiple recurrently extant sources. In general, from the focal firm point of view, SCV can be originated internally, endogenous to the SC (by SC partners or SC design) or exogenous to the SC. *Article 1* aims at synthesizing the sources of SCV, which includes all three types of origin. Afterwards,

article 2 and *article 3* focus on volatility that is mostly generated internally and endogenously to the SC.

As previously explained, the volatility management process can be subdivided into four process steps (identification, assessment, mitigation and monitoring). *Article 1* of this thesis seeks to contribute to the first step. By synthesizing the sources of volatility, the article aims at developing a framework of SCV that explains the emergence of this SC phenomenon. It has been mentioned above that most of the volatility literature relates to the identification and explanation of sources (step 1) or the mitigation of volatility (step 3). Similarly, the important process steps of assessment (step 2) and monitoring (step 4) have been mostly neglected, leading to a gap in the proposed volatility management cycle. Consequently, *article 2* and *article 3* strive to contribute to the narrowing of this gap: First, *article 2* intends to assess the impact of different sources of SCV. This will provide managers with clear guidelines on which sources to focus on when implementing volatility mitigation measures. Second, *article 3* will provide a measuring instrument that assists SC managers in measuring the impact of different volatility sources on their SC and that assists in monitoring the changes in volatility after implementing new measures.

The management recommendations that can be derived from the thesis and its SCV assessment tool are relevant to the tactical level, but are most significant at the strategic level. First of all, the thesis provides a general understanding of the mechanisms driving volatility, which assists SC managers in the alignment of tactical and strategic decisions when dealing with volatility. The thesis thereby contributes to the general question of what causes volatility – is it the overall length of lead time, unreliability of suppliers, the unpredictability of customer demand, or other sources that induce volatility along the SC? Moreover, the measuring instrument intends to give SC managers indications on which sources to focus on when initiating management initiatives.

2. Article 1

Title:

"Much Discussed, Little Conceptualized: Supply Chain Volatility"

Published in

International Journal of Physical Distribution and Logistics Management; Vol 48, Issue 8,

pp. 866-886

2.1 Introduction

This study seeks to advance our knowledge regarding the sources, dimensions and moderators of supply chain volatility (SCV). SCV is a much discussed phenomenon in supply chain management (SCM), and one that both managers (Handfield *et al.*, 2013) and researchers (Wieland *et al.*, 2016) rank among the discipline's most important phenomena. It has commonly been used to describe episodes of turbulence in the market environment (Christopher and Holweg, 2011, 2017) or to explain unintended changes in material flows along the supply chain (SC), motivating authors to propose various mitigation strategies (Childerhouse *et al.*, 2008; Handfield *et al.*, 2013; Lee *et al.*, 1997).

However, the conceptualization of SCV, its sources and dimensions, remains vague. Wieland *et al.* (2016) state that divergent use of the term SCV inhibits knowledge development in this area and warrants further conceptual research. Practitioners' understandings are likely to vary from those of researchers, who also employ different definitions of what appears to be the same phenomenon, leading to a current gap between research and practice. A coherent theoretical foundation could provide the basis for convergence in the conceptualization of SCV (cf. Suddaby, 2010); without it, analyses of the phenomenon's origin and outcomes, and communication among researchers will remain divergent and disconnected. Practitioners, on the other hand, need a consistent theoretical basis to assess research findings and identify actionable knowledge.

This study seeks to reduce this theoretical void by proposing a conceptualization that contributes to a middle-range theory of SCV. This conceptualization entails the identification of the sources of SCV (understood as variables that induce volatility in a specific dimension, cf. Morris and Feldman, 1996), a classification of its dimensions (mutually exclusive and commonly exhaustive types of SCV, ibid.) and an examination of possible moderating effects.

Additionally, it includes propositions based on different SCV-affecting characteristics to delineate the effect of the SCV dimensions.

Consequently, we strive to provide answers to the fundamental theoretical questions of *what*, *how* and *why* as well as the circumstances that enhance or reduce the impact of sources (cf. Dubin, 1978; Whetten, 1989). In our case, *what* refers to the dimensions of volatility and the sources inducing them; *how* answers the question about the relationships between them; and we seek to answer the question *why* by explicating the underlying mechanisms that explain the proposed relationships. Consequently, our research objective (RO) is to *develop a framework that depicts sources, dimensions and potential moderating variables in the sources–SCV relationship.*

To identify a comprehensive set of SCV sources we apply a systematic literature review (SLR) as well as a group exercise with 23 practitioners. The SLR incorporates two distinct procedures for searching the literature, resulting in the identification of 2,789 relevant articles. The group exercise, based on the nominal group technique (NGT) (Van de Ven and Delbecq, 1971), is conducted to include practical insights on the topic and mitigate the omission of important aspects due to reliance solely on the literature. Subsequently, we use a structured synthesis process that builds on the Q-methodology (cf. Ellingsen et al., 2010) to synthesize 364 sources into a comprehensive set of 20 meta-sources of SCV, and thus identify dimensions of SCV and examine possible moderators for the impact of meta-sources on SCV. Finally, to delineate the effect of these dimensions on SCV according to three SCV-affecting characteristics, an additional group of 17 practitioners was involved to build propositions on the characteristics of SCV dimensions. To reduce bias, different researchers and practitioners are involved in fundamental parts of the research process, especially in the identification of relevant studies, compilation of an appropriate search string, summary and classification of the sources and

dimensions, and building the propositions, as well as the development of the conceptual framework.

We set a number of conceptual constraints for our study. The unit of analysis is the focal firm, along with how it is affected by volatility. The context in which the focal firm is operating (i. e. , the level of analysis) is its supply chain, including all directly linked organizations and people as well as impacted stakeholders. Our research object is manufacturing industry – more specifically, material flows of manufacturing firms, excluding flows of services.

2.2 Theoretical Background

Before developing a framework of supply chain volatility, we need to summarize different understandings of volatility in SCs in order to synthesize a definition of SCV relevant for further investigations. Additionally, we intend to delineate SCV from related concepts and phenomena with thematic overlap (i. e. , risk management and the bullwhip effect (BWE)), thus providing further value for the theoretical construct of SCV.

2.2.1 Development of a definition

Although researchers have often identified SCV as one of the most challenging phenomena in our field (e. g., Christopher and Holweg, 2017; Wieland *et al.*, 2016), few clear definitions exist. An overview of different understandings of volatility in SCs is provided in Table 2.

Table 2 indicates that volatility in SCM is commonly used to describe the movement, in a particular timeframe, of different logistical parameters ranging from customer demand, through process outputs, to economic developments or market conditions. However, independent of the perspective, these definitions convey a common consequence when regarded from the viewpoint of a focal firm: Volatility at the focal firm materializes in variable supply and demand flows of goods, impacting company performance.

Table 2 – Overview of different understandings of volatility in SCM

Authors	Understanding of volatility in SC
Handfield *et al*. (2013, p. 15)	"Volatility refers to major shifts in customer demand volume, product or service mix, government regulations, new competitors, substitute products, short product life cycles, and requirements for rapid network nodal changes and redesign."
Christopher and Holweg (2011, p. 69)	"The variability that hurts performance and is related to supply chain design can emanate from a wide range of factors: from the demand side (e. g. shifts in consumer demand for products), the supply side (e. g. hikes in steel, copper, and gold prices), regulation (e. g. shift in consumer perception towards climate change), political (e. g. opening of markets and growth in East Asia, but also political rows and regional conflict), energy cost (e. g. the price for oil, gas and electricity, and the implications for transportation cost), financial (e. g. exchange rates, currency fluctuations, and availability of credit), and technology (e. g. shifts in dominant designs, disruptive innovations)."
Germain *et al*. (2008, p. 557)	"Supply chain process variability encompasses the (in)consistency in flows into and out of the firm, as well as internal variabilities, such as production lead-times and production output rates."
Kim and Springer (2008, p. 172)	"Supply chains often exhibit persistent volatility. Production and inventories chronically overshoot and undershoot their appropriate levels, and the amplitude of these fluctuations increases as they propagate from the downstream to the upstream elements of a supply chain."

Drawing on financial researchers' understanding of volatility as a measure of uncertainty in stock price movements, involving deterministic and stochastic components (Altman and Schwartz, 1970), we propose that general volatility in SCs consists of two forms of variation, one that can and one that cannot be planned for. Since plannable variations do not pose a threat to companies and are thus seldom perceived as SCV in a practical sense, we focus our SCV investigation on the unplanned aspect of volatility. Synthesizing these insights with the focal-firm perspective on volatility in SCs, we propose a new, SC-specific definition of SCV: SCV is *the unplanned variation of upstream and downstream material flows resulting in a mismatch*

of supply and demand at the focal firm. Below, we will build on this definition of SCV to identify a coherent set of literature for synthesis in our literature review.

2.2.2 Delineation of SCV from risk management and BWE

Risk management: Risk management has emerged as an important area of research in SCM, with many significant contributions occurring in the past 15 years (see Ho *et al.*, 2015 for a recent review). Prior research has mostly focused on the occurrence of upstream SC disruptions that escalate downstream (e. g. Bode *et al*., 2011; Ellis *et al*., 2010; Kleindorfer and Saad, 2005; Klibi *et al*., 2010; Manuj and Mentzer, 2008; Tomlin, 2006; Wagner and Neshat, 2010; Zsidisin, 2003; Zsidisin and Ellram, 2003). Those supply side risks are commonly managed proactively by the focal firm by implementing redundancies and buffers (Sheffi, 2005). Although this stream of literature is important for modern SCM research, it has limitations when it comes to downstream events such as recurrent short-term order changes that cascade upstream in the supply chain.

BWE: Tracing back the literature on fluctuating material flows in SCs inevitably leads to the well-known *Forrester effect* (Forrester, 1958). This phenomenon, later renamed the BWE (cf. Lee *et al.*, 1997), gained intensive research attention for over a decade and remains a relevant research subject today. Nevertheless, the BWE's only function is to describe the effect of increasing order variability on a product level progressing upstream in the SC, which is caused by rational and irrational misbehavior of individuals (Hussain and Drake, 2011; Lee *et al*., 1997); this effect is often masked when data is aggregated on a firm level (Jin *et al*., 2015). However, the BWE's very narrow focus fails to explain the occurrence of volatile material flows along the SC *in toto* (Kim and Springer, 2008).

As a result, both streams of literature investigated different events and misbehaviors on contrasting levels of analysis as well as different directions of a SC that both cause volatility. Indeed, the concept of SCV acknowledges this research and certain overlaps, but extends it to

a more holistic approach that aims to explain the occurrence of volatile material flows along the SC. Figure 5 delineates SCV from risk management and the BWE.

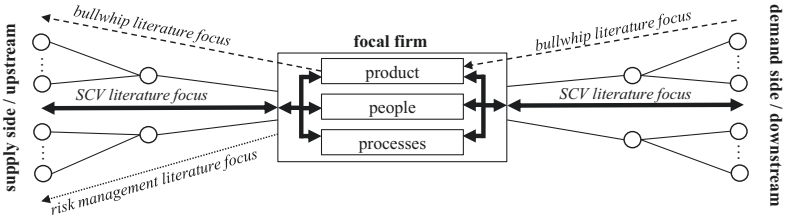

Figure 5 – Delineation of SCV from risk management and the BWE

2.3 Research Design

To identify a comprehensive set of sources of SCV, a data triangulation was performed. We conducted an SLR and a group exercise with 23 SCM practitioners to widen practical insights, increase theoretical understanding and minimize the methodological shortcomings of SLRs. On this basis, we derived dimensions and moderators of SCV through a synthesis process that was based on the Q-methodology involving four researchers and one practitioner. After building the framework, we included an additional group of 17 SCM practitioners with the aim of developing propositions on three SCV-affecting characteristics to delineate the dimension's effect on SCV. Figure 6 provides an overview of the research design of this study.

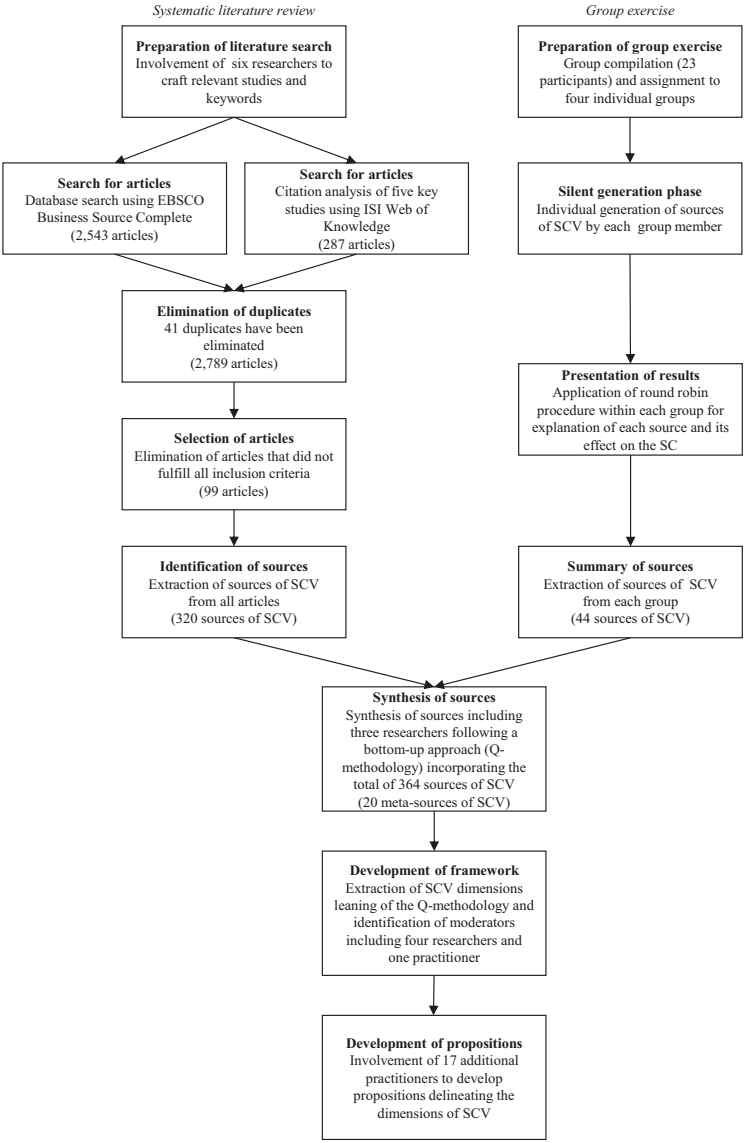

Figure 6 – Research procedure

2.3.1 Systematic literature review

To date, different systematic review methodologies have been proposed that account for the ontological and epistemological idiosyncrasies of specific disciplines (e. g., medicine (Mulrow, 1987); management (Rousseau *et al.*, 2008; Tranfield *et al.*, 2003)). Due to the lack of specific guidelines in SCM, we followed the refined structure of Tranfield *et al.* (2003), as proposed and applied in Durach *et al.* (2015) and discussed in Saenz and Koufteros (2015).[1]

We first determined inclusion criteria to objectively assess the relevance of literature and to ensure that the literature matches the proposed definition of SCV. Table 3 indicates the chosen inclusion criteria. Moreover, we decided to limit the literature search to peer-reviewed publications, in order to ensure high quality of the selected studies (cf. Habib *et al.*, 2015; Hohenstein *et al.*, 2015). Other ex-ante limitations have been avoided.

Table 3 – Inclusion criteria

Inclusion Criterion	**Rationale**
The article mainly deals with volatile demand AND/OR supply affecting the focal firm	This is necessary to ensure that the paper deals with SCV according to the proposed definition
The summary shows an indication that sources of SCV are discussed	The goal of the literature review was to identify the sources of SCV
The article is written in English	English is the prevalent language in SCM research

In the preparation of the literature search we provided six different SCM researchers (from Europe, North America and the Asia Pacific region) with our RO as well as the definition stated above and asked them to: (1) *recommend studies that are helpful to identify sources of SCV*; (2) *name keywords they deem appropriate for the electronic literature search*; and (3) *build a*

[1] The refined guidelines for SLRs in SCM as published in Durach, Kembro, et al. (2017) had not been available at the time this project was initiated. Also, instead of refining existing theory, as proposed in their article, this study aims at unifying and extending our understanding of SCV.

search string using these keywords. By applying the stated inclusion criteria to proposed studies, the following six studies were identified: Chiang and Feng (2007); Christopher and Holweg (2011); Esper *et al.* (2010); Kouvelis and Li (2012); Lee (2002); Mason-Jones and Towill (1998). These studies were prerequisites of the following literature search, especially the citation analysis.

To ensure a comprehensive compilation of literature we applied two different search procedures (cf. Carter and Easton, 2011). First, we conducted an electronic database search using Business Source Complete (by EBSCO). Incorporating the researchers' feedback, a search string was developed (see Table 4). This builds on two blocks that assure that the articles are located in the area of logistics or SCM and deal with synonyms of volatility. Using this search string, in January 2015 a list of 2,543 peer-reviewed studies was compiled. Second, we performed a citation analysis of the key studies mentioned above using the SSCI-Database (by Web of Knowledge). We listed all articles that cited the five key studies listed in the SSCI-database (Mason-Jones and Towill (1998) was not listed) to find thematically similar literature, identifying 287 studies. Combining both sets, we collected a list of 2,789 studies (41 duplicates were eliminated) relevant for further investigation.

Table 4 – Search string for the database search

Business Source Complete (by EBSCO)	(TI=(volatil* OR variability* OR uncertain* OR variation* OR turbulen*) OR (AB=(volatil* OR variability* OR uncertain* OR variation OR turbulen*) OR KW=(volatil* OR variability* OR uncertain* OR variation* OR turbulen*)) AND (TI=(supply chain OR logistic*) OR AB=(supply chain OR logistic*) OR KW=(supply chain OR logistic*))

AB: Abstract Search; TI: Title Search; KW: Keywords

To collect the studies relevant for identifying sources of SCV, both authors individually read the titles and abstracts of all 2,789 articles while applying the inclusion criteria. Only articles

that met all inclusion criteria were selected for further consideration. The authors disagreed on nearly one percent of all studies. As proposed by Durach, Kembro, et al. (2017), the inter-rater reliability was calculated to check the validity of the agreement between both raters. Cohen's κ (Cohen, 1960) was calculated as 0.88, which indicates "almost perfect" agreement (Landis and Koch, 1977, p. 165). In cases of disagreement, the authors further discussed the abstract and title and incorporated the feedback of an additional researcher. Consequently, the set of articles was condensed to 99 studies. These were read and the sources of SCV they mentioned were noted, leading to a list of 320 sources of SCV.

2.3.2 Group exercise

In April 2015 we conducted a group exercise following the NGT process (Van de Ven and Delbecq, 1971). NGT is a structured group discussion process that clearly separates the problem description and problem solution and has proven effective in extracting expert knowledge in SCM (e. g., Schoenherr *et al.*, 2012), outperforming other traditional group exercise methodologies, such as focus group discussions and Delphi studies (Goodman, 1987; Van de Ven and Delbecq, 1971). Delphi studies address the problem that focus group discussions do not embolden less secure members of the group to share their thoughts, by not allowing direct meetings of participants. The NGT seeks to combine both aspects by allowing face-to-face meetings of participants (Green, 1975) but systematically extracting participants' knowledge through a moderated process that encourages less secure participants to express themselves (Lloyd, 2011).

Following the NGT process guidelines proposed by Delbecq and Van de Ven (1971), 23 participants were asked to identify potential sources of SCV (problem description) (see Durach, Glasen, et al., 2017 for an application of this methodology in SCM). The participants were first provided with the definition of SCV, then asked if there was any clarity issue understanding the definition or whether they disagreed with the proposed definition; no objections were raised. Afterwards the group was split into four sub-groups in order to conduct workshops (see Chapple

and Murphy, 1996). First, in a silent generation phase, each group member was asked to individually think of sources of SCV. Thereafter, following a round-robin procedure guided by a neutral external moderator (cf. Delbecq and Van de Ven, 1971), each participant was asked to participate in presenting the sources identified within their sub-group. Each group member presented one source at a time and explained their understanding of this source and how it affected their business until all sources had been collected. The moderators ensured that discussions or judgement by the rest of the sub-group were avoided to ensure a neutral process, then consolidated the results across all sub-groups and presented them to the assembly. Following these steps, a composite list of 44 sources of SCV was compiled.

The firms that participated in this group exercise occupied a variety of positions along the SC and faced, according to their own statements, significant volatility in their businesses. Each firm-representatives had profound knowledge of their firm's SC, and had responsibility for coordinating it. We specifically aimed to organize a heterogeneous group of participants to cover a wide spectrum of possible sources. Although our study focuses on volatility affecting manufacturing firms, we decided to include logistics service providers in the sample to cover the entirety of material flow along the SC. Table 5 depicts an anonymized excerpt of demographic details provided by the participants.

Table 5 – Sample demographics for the group exercise

Industry		**Revenue**		**Total number of employees**	
Automotive	11	Below 10m	3	11–50	3
Electronics	2	10m–100m	4	51–250	4
Consumer Goods	3	100m–1bn	2	251–500	2
Logistics Service Provider	7	1bn–5bn	7	501–2000	2
		above 5bn	7	above 2000	12

2.3.3 Synthesis of sources

To synthesize the results of the SLR and the group exercise and provide a condensed set of meta-sources, we followed the bottom-up approach applied by Durach *et al.* (2015), which is based on the Q-methodology (cf. Ellingsen *et al.*, 2010). The 364 sources were each written on a single card to be sorted into groups by a team of three researchers. The aim was to achieve homogeneity within each group but heterogeneity among groups; therefore, each researcher individually read each card and either placed it into an existing group or created a new group if no appropriate assignment was possible. Afterwards, each researcher presented their group assignments to the others, and the team identified matches and discussed differences. This process resulted in the synthesis of 20 distinct meta-sources of SCV, providing the basis for further investigation.

According to Whetten (1989, p. 490), "comprehensiveness" and "parsimony" are the main criteria in judging whether the authors included the "right" factors for the explanation of an observed phenomenon. To ensure comprehensiveness (the inclusion of all possible factors), we conducted a group exercise in addition to the SLR, leading to 364 possible sources. Parsimony (no further factors can be deleted without losing important information) was assured by applying the Q-methodology when synthesizing these sources to 20 meta-sources.

2.3.4 Development of framework

Based on the meta-sources of SCV, we additionally sought to identify the dimensions of SCV. The three researchers were asked to perform an additional sorting procedure on the 20 meta-sources, also following the Q-methodology, to identify similar traits among them with the aim of categorizing them into mutually exclusive and collectively exhaustive dimensions of SCV. They then presented their results to one another. Similar assignments were identified and differences discussed until a common understanding was found. Consequently, five dimensions of SCV emerged.

The team of researchers then discussed possible amplifying or dampening relationships between the meta-sources and SCV, drawing on the underlying literature. Based on this exercise, a first draft of the conceptual framework emerged that outlines both the dimensions and sources of SCV and also the potential moderating effects in the sources–SCV relationship. The moderating effects were proposed by the group of researchers as a result of their discussion of the literature. In particular, the moderator of erratic behavior of decision makers is a fundamental part of the bullwhip literature that we built upon and expanded to the broader concept of SCV.

Subsequently, the framework was presented to one additional researcher and one practitioner, both of whom had not previously been involved in the research process. They provided feedback on the relationships and moderations of the sources–SCV relationships, which was used to develop the final version of the conceptual framework.

2.3.5 Development of propositions

During the above-mentioned synthesis of sources in the framework building process, it was suggested that the different dimensions, respectively, the different sources of SCV, affect SCV differently. To obtain further insights on this observation, we developed a descriptive classification scheme consisting of three discrete SCV-affecting characteristics. Norrman and Jansson (2004) proposed two characteristics to delineate disruptive supply chain events: (1) their possible *impact* and (2) their *probability* of occurring. Drawing on this well-established categorization, we propose the following as our first two characteristics of SCV: (1) the *relative deviating impact*, which characterizes the effect this dimension has on the magnitude of volatility affecting the focal firm relative to the situation of balanced material flows; and (2) the *repetitiveness* of a dimension, which depicts whether volatility will occur with a high frequency (high *repetitiveness*) or a low frequency (low *repetitiveness*). The third characteristic that we propose for SCV is (3) *influenceability,* which describes the possibility of the focal firm manipulating the effect of a particular SCV-dimension on the volatility of its SC.

Applying the proposed classification scheme, we then strove to posit three propositions for each dimension of SCV to describe the dimension's effect on SCV. To reduce subjectivity in the proposition building process, we invited a group of 17 SCM practitioners – who had not previously been involved in the research process – to an on-site meeting on the topic of SCV. The participants were from a heterogeneous group of manufacturing companies operating in different industries, with an average of eight years' professional working experience in SCM or logistics. The sample demographics are outlined in Table 6.

Table 6 – Sample demographics of practitioner group from the proposition building process

Manufacturing industry		**Revenue**		**Total number of employees**	
Automotive	3	Below 10m	0	11–50	0
Electronics	6	10m–100m	1	51–250	1
Consumer Goods	1	100m–1bn	4	251–500	0
Chemicals	2	1bn–5bn	4	501–2000	2
Machinery/Equipment	5	above 5bn	8	above 2000	14

We first provided the practitioner group with the definition of SCV and an explanation of the framework of SCV (including an explanation of every source and dimension and the descriptive classification scheme); we then answered any questions they had. The participants were asked to rate to a short set of statements with respect to a product that they deem representative of their company. They were presented with the following statements for each of the five dimensions:

(1) For this dimension, the *relative deviating impact* on the magnitude of volatility is: 1 (very low)…4 (medium)…7 (very high).
(2) For this dimension, the *repetitiveness* is: 1 (very low)…4 (medium)…7 (very high).
(3) For this dimension, the degree of *influenceability* is: 1 (very low)…4 (medium)…7 (very high).

Based on their responses, three propositions were developed for each dimension, thus depicting the dimension's effect on SCV in terms of *relative deviating impact, repetitiveness, and influenceability*. As ratings were on an ordinal scale from 1 to 7, we opted for median ratings to obtain indications for each proposition. We found no major signs of skewed or highly dispersed distributions; however, this inference is limited by a small sample (n = 17) that was neither contextualized nor representative of any particular group of companies. Thus, the developed propositions need to be understood as *tentative propositions* requiring further contextualization. Being the first of its kind, this study opted for a rather broad approach to understanding SCV, which does limit its findings in terms of providing, for example, industry specific insights. Its purpose was simply to provide initial indications concerning the characteristics of each dimension of SCV in our framework and to provide some empirical insights beyond the existing literature. Shortcomings arising from this approach will be further discussed in the limitations section.

2.4 Review Results

The goal of this study was to unify and extend the understanding of SCV by conceptualizing its sources, dimensions and moderators. Building on the research steps described above (an SLR combined with a group exercise with 23 practitioners), we developed a conceptual framework of SCV. The additional exercise with 17 SCM practitioners allowed us to refine our understanding of the effect of these five dimensions on SCV, leading us to develop 15 propositions that outline the relationship between dimension and SCV.

The framework depicted in Figure 7 outlines 20 meta-sources of SCV. They directly induce five distinct dimensions of SCV: (1) *organizational volatility*, (2) *vertical volatility*, (3) *behavioral volatility*, (4) *market-related volatility* and (5) *institutional and environmental volatility*. While all meta-sources of all five dimensions have direct impacts on SCV, we

propose two behavioral sources of SCV as moderating variables for the SCV-efficacy of each of the dimensions.

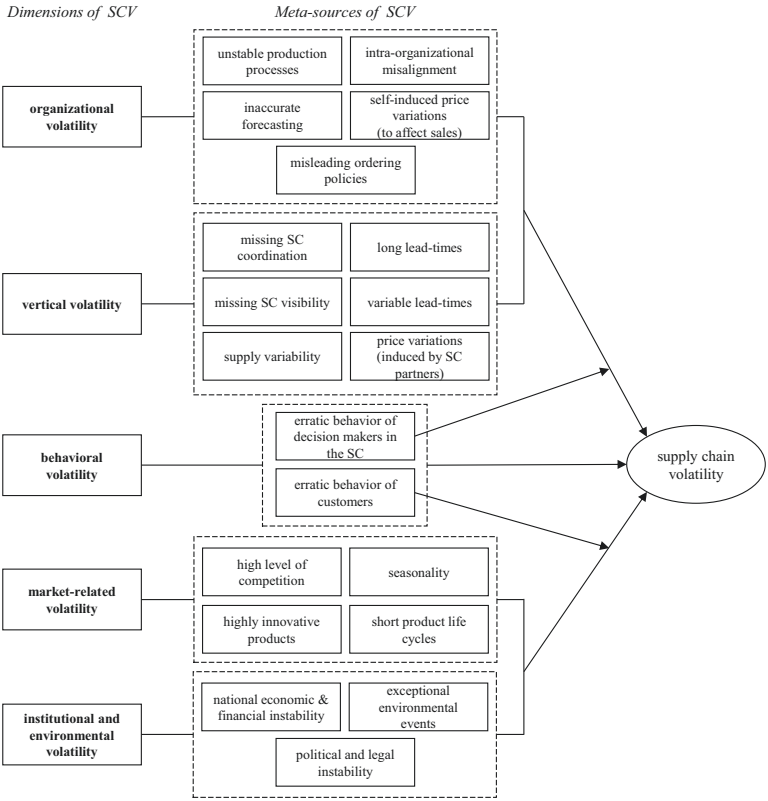

Figure 7 – Conceptual framework of supply chain volatility

To show the different effects these dimensions have on SCV, we developed a descriptive classification scheme (see sub-section 2.3.5 *Development of propositions*). Based on the feedback from the exercise with 17 SCM practitioners, we derived three propositions for each dimension, aiming at delineating the five dimensions by their *relative deviating impact*, *repetitiveness* and *degree of influenceability*. The median of respondent-answers can be found

in Table 7. We used these responses to develop our study propositions. Propositions are formulated as *low* for median values of "1" or "2", as *medium* for values between "3" and "5" (inclusive) and as *high* for values of "6" or "7."

Table 7 – Median values (n = 17) for the three characteristics on each dimension

Dimension of SCV	**Relative deviating impact**	**Repetitiveness**	**Influenceability**
Organizational volatility	5	5	6
Vertical volatility	5	5	4
Behavioral volatility	4	4	2
Market-related volatility	4	2	2
Institutional and environmental volatility	6	2	1

Note: the value show medians of answers between 1…very low; 4…medium; 7…very high

Building on the results in Table 7, we developed the following propositions to describe the relationships between the meta-sources and SCV in our conceptual framework (Figure 3).

2.4.1 Organizational volatility

This o*rganizational volatility* dimension comprises volatility that is self-induced by the focal firm. In particular, we identify five meta-sources contributing to this dimension: *unstable production processes*, *inaccurate forecasting*, *intra-organizational misalignment*, *self-induced price variations* and *misleading ordering policies*.

The results of the study show that a large amount of the perceived supply and demand mismatch is induced by independent variables that are controlled by the focal firm itself. Such variables include, among others, misleading or conflicting goals; internal competition among different value streams or sales channels; misaligned organizational plans; and increasing geographic dispersion of departments. Together, these amplify any intra-organizational misalignment on a regular basis (Childerhouse *et al.*, 2003; Lorentz *et al.*, 2012; Prater, 2005; Wagner *et al.*, 2014). The practitioners in our group exercise agree that firms that are not able to integrate their

departments on all levels will not be able to control the material flow within their SC. Moreover, inaccurate, constantly changing or misaligned forecasts that are transmitted to the supply side are challenging to the supplier and reinforce a mismatch of supply and demand (Adenso-Díaz et al., 2012; Barlas and Gunduz, 2011; Childerhouse et al., 2008; Lee et al., 1997). Insights from the experts show that, in some cases, companies completely renounced long-term forecasts due to their high cost and declining benefits. To influence sales in the short-term, companies often tend to adjust prices in order to uplift sales by a factor of 30 or more (Ramanathan and Muyldermans, 2010). Due to the extensive investigation of the BWE in supply chains, we know that this demand distortion propagates, causing even more volatile orders to move upstream along the SC (e. g., Lee *et al.*, 1997; Warburton, 2004). Consequently, we propose:

P_{1a}: *Organizational volatility* is characterized by a medium *relative deviating impact on* SCV.

P_{1b}: SCV caused by *organizational volatility* is characterized by a medium degree of *repetitiveness*.

P_{1c}: *Organizational volatility* is characterized by a relatively high degree of *influenceability* since it is self-induced by the focal firm.

2.4.2 Vertical volatility

Vertical volatility describes that part of SCV that is induced by sources that appear endogenous to the SC. These sources are affected by partners in the SC or the design of the SC itself. In total we condensed six meta-sources of *vertical volatility*: *missing SC coordination; missing SC visibility; supply variability; long lead-times; variable lead-times;* and *price variations (induced by SC partners)*.

Literature emphasizes that long and variable lead-times dramatically influence the stability of material flows in an SC (Chaharsooghi and Heydari, 2010; Chatfield *et al.*, 2004; Lee, 2002; So and Zheng, 2003). Hence, the design of an SC (including location decisions, number of SC

stages or choice of transport mode) impacts lead-times within the network and is crucial for the successful management of SCV. Directly connected to the design of a SC is the design of the information flow arising from it. Lack of coordination among the actors, deriving from information distortion (Childerhouse et al., 2003; Småros and Holmström, 2005), decentralized decisions (Fiala, 2005), complex feedback loops (Wang *et al.*, 2005), or weak relationships among partners (Childerhouse *et al.*, 2008; Wang *et al.*, 2005), is still present in modern SCs. Missing visibility and consistency of SC data such as actual demand or supply line information can even exacerbate the controllability of material flows (Childerhouse and Towill, 2004; Van der Vorst *et al.*, 1998). *Vertical volatility* stresses the importance of partners in a SC; especially since the volatility observed at the focal firm often emerges from the supply side. In some instances, this supply variability is not controllable, e. g., due to an uncertain raw material supply in the food industry (cf. Hameri and Palsson, 2003; Kekre *et al.*, 1990; Van der Vorst *et al.*, 1998), but in most cases is induced by unreliable supply due to capacity constraints (e. g., Johnson, 2001; Lee, 2002), quality problems (e. g., Hung *et al.*, 2009; Paik and Bagchi, 2006) or unstable processes (e. g., Childerhouse *et al.*, 2008; Germain *et al.*, 2008). In general, it can be determined that companies that intend to control the peculiarity of *vertical volatility* depend on their partners and must invest in the relationship. Consequently, we propose:

P_{2a}: *Vertical volatility* is characterized by a medium *relative deviating impact* on SCV.

P_{2b}: SCV caused by *vertical volatility* is characterized by a medium degree of *repetitiveness*.

P_{2c}: *Vertical volatility* is characterized by a medium degree of *influenceability* since cooperative actions with SC partners or substitution of SC partners are necessary to overcome obstacles induced by this dimension.

2.4.3 Behavioral volatility

The behavior of individuals in the SC plays a vital role for the volatility of material flows. The SLR and group exercises provided evidence that the dimension of *behavioral volatility* directly influences SCV. Two separate meta-sources have been synthesized: *erratic behavior of the customer* and *erratic behavior of decision makers in the SC*.

Erratic behavior of customers describes the unpredictability of customer demand affecting the focal firm. Constantly changing order quantities are hard to predict and challenge companies to adjust the supply accordingly. The higher the demand unpredictability gets, the more probable is a supply and demand mismatch at the focal firm (Childerhouse *et al.*, 2008; Germain *et al.*, 2008). *Erratic behavior of decision makers in the SC* describes the degree to which decision makers react irrationally and unpredictably to certain events. These irrational decisions can be made by individuals in the focal firm or at other SC partners. Typical misbehavior that directly affects volatility in the SC is characterized by over- or underestimation of demand or supply signals (Ancarani *et al.*, 2013; Christopher and Lee, 2004; Warburton, 2004; Wong and Hvolby, 2007); strategic interactions among SC partners (Chatfield *et al.*, 2004; Lee *et al.*, 1997); or a lack of consideration of already placed orders (Adenso-Díaz et al., 2012; Croson and Donohue, 2006; Hoberg et al., 2007; Wu and Katok, 2006). These behavioral aspects often materialize in the form of very high safety stocks or drastically minimized stocks (Nienhaus *et al.*, 2006).

The way individuals react irrationally to events differs and is closely related to certain characteristics, such as the attitude towards benefit, level of risk aversion, speed of decision making or speculative intentions (Wang *et al.*, 2005). To reduce erratic behavior of decision makers and the challenges arising from it, practitioners emphasize the need for teaching and training. Nevertheless, it must be acknowledged that the focal firm has to make strong efforts across the SC. Furthermore, erratic behavior of the customer is even more difficult to control. Consequently, we propose:

P_{3a}: *Behavioral volatility* is characterized by a medium *relative deviating impact* on SCV.

P_{3b}: SCV caused by *behavioral volatility* is characterized by a medium degree of *repetitiveness*.

P_{3c}: *Behavioral volatility* is characterized by a low degree of *influenceability* since considerable efforts are necessary to overcome some of the obstacles induced by this dimension.

2.4.4 Market-related volatility

The market a firm is operating in is mainly described by the product that is offered and the customer, as well as the competitors for the customer. This market also induces volatility that is perceived by the focal firm; thus, *market-related volatility* is influenced in different ways. Altogether, we synthesized four meta-sources that contribute to *market-related volatility*: *high level of competition*, *seasonality*, *highly innovative products* and *short product life cycles*. Specific product attributes, such as innovativeness, short product life cycles and seasonality directly induce volatile customer demand (Childerhouse *et al.*, 2008; Johnson, 2001; Lee, 2002; Taylor and Fearne, 2009; Wong and Hvolby, 2007). Additionally, a large number of competitors in the market offering a variety of substitutes may even amplify demand variability (Croxton *et al.*, 2002; Randall and Ulrich, 2001; Taylor and Fearne, 2009). Practitioners stress that if a company wants to reduce the severity of *market-related volatility*, it has to invest huge effort in strategically adjusting its placement in the market, such as lowering the innovativeness of its products or even moving to a market that is less threatened by the above-mentioned sources.

P_{4a}: *Market-related volatility* is characterized by a medium *relative deviating impact* on SCV.

P_{4b}: SCV caused by *market-related volatility* is characterized by a low degree of *repetitiveness*.

P_{4c}: *Market-related volatility* is characterized by a relatively low degree of *influenceability* since a strategic repositioning of the focal firm is necessary to overcome obstacles induced by this dimension.

2.4.5 Institutional and environmental volatility

Institutional and environmental volatility originates external to the SC. In summary, we synthesized three meta-sources of SCV in this dimension. These are macroeconomic influences, such as *political and legal instability* or *national economic and financial instability*, as well as *exceptional environmental events*, such as meteorological disasters (Christopher and Holweg, 2011; Dooley *et al.*, 2010; Thorbecke, 2008).

Christopher and Holweg (2011) posit the increasing significance of exceptional events and crises for the modern SC, such as oil or world financial crises. The experts of the group exercise agree with that, and extend it to observe that growing globalization of SC instability, especially political and legal instabilities, in specific sourcing or production regions significantly influences material flows. In the case of China, as one of the most important sourcing, production and sales regions, they indicated that short-term legal changes often lead to devastating effects on material flow (e. g., search for new suppliers). Consequently, we propose:

P_{5a}: *Institutional and environmental volatility* is characterized by a high *relative deviating impact* on SCV.

P_{5b}: SCV caused by *institutional and environmental volatility* is characterized by a low degree of *repetitiveness*.

P_{5c}: *Institutional and environmental volatility* is characterized by a relatively low degree of *influenceability* since a relocation of own facilities or SC partners is necessary to overcome some of the obstacles induced by this dimension.

2.4.6 The moderating role of decision makers' and customers' behavior

We further propose that *behavioral volatility* moderates the SCV-efficacy of the four remaining dimensions. More precisely, we propose two effects: First, erratic behavior of the customer moderates the effect of *market-related* as well as *institutional and environmental volatility* on SCV. Second, erratic behavior of decision makers moderates the effect of *organizational* and *vertical volatility* on SCV.

Moderating role of erratic behavior of decision makers: If decision makers in the own organization are prone to erratic behavior, the impact of sources of *organizational volatility* on SCV will be exacerbated (Wang *et al*., 2005). For example, if production processes are unstable, an erratically-acting production scheduler aggravates the seriousness of volatility, e. g., if he over- or underestimates the effects of certain events (Childerhouse *et al.*, 2008). It has been shown that an intra-organizational misalignment fosters *organizational volatility*, leading to supply and demand mismatch at the focal firm. Irrationally-acting individuals in the organization exacerbate this effect (Childerhouse *et al.*, 2003; Nienhaus *et al.*, 2006).

This moderating role holds also true for the sources of *vertical volatility*. We already argued that missing SC coordination and visibility have direct impacts on SCV. If decision makers in the SC tend toward overreaction or underestimation, wrong interpretations of supply and demand signals are exacerbated along the SC. Long and variable lead-times increase the possibility of volatile material flows. The reaction to this circumstance is crucial and differs between different types of decision makers (e. g., risk-averse decision makers tend to over-interpret signals, leading to excessive stock) (Wang *et al.*, 2005).

Moderating role of erratic behavior of the customer: As explained above, the sources of *market-related* as well as *institutional and environmental volatility* directly induce volatility. Erratic behavior of the customer, which describes the unpredictability of customer demand,

exacerbates this effect when the customer irrationally reacts to certain market-related or environmental events. For example, a completely rationally acting *homo oeconomicus* would base a buying decision on the maximization of his own utility function, e. g. getting the most innovative product. In this case the *homo oeconomicus* would always buy the product of the innovation leader. In reality, consumers rarely base their buying decisions on a completely rational analysis of all available information resulting in buying the most innovative product, but are triggered by numerous other factors (e. g., brand loyalty, marketing efforts). This uncertainty of customer demand exacerbates the effect of market-related sources of volatility (cf. Wong et al., 2005, 2006).

2.5 Implications

The present conceptualization of SCV seeks to unify and extend our understanding about this fundamental SCM phenomenon. From a systematic literature review and a workshop with 23 partitions, we identified 20 meta-sources that can be categorized into five distinct dimensions of SCV. To delineate the effect of these five dimensions on SCV we further offered a descriptive classification scheme consisting of three SCV-affecting characteristics; (1) *relative deviating impact*, (2) *repetitiveness* and (3) *influenceability*. This classification scheme was developed from the insights of another set of 17 practitioners. In addition to this, the developed framework of SCV puts the behavior of customers and decision makers in the SC forward as a moderating variable for the relationship between the meta-sources and SCV.

The study results are consistent with our aim of reducing the gap between research and practice that has been intensively discussed in the management literature (e. g., Aguinis *et al.*, 2011; Banks *et al.*, 2016; Hambrick, 1994; Kieser *et al.*, 2015). Research publications often do not transfer to practice, however, because academics' perception of practice varies from the self-perception of practitioners, leaving each on opposite sides of a 'bridge' (Nicolai, 2004). In the case of SCV, our results provide a coherent taxonomy, which is important for researchers and

managers alike, seeking to bring both onto the same page to guide future discussions and knowledge development. The results not only provide a systematically unified basis for research on SCV, they also help practitioners to better understand what researchers discuss in their studies and how to derive implications for their businesses.

To sum up: for researchers, the results of this study provide an important work on volatility in SCs that seeks to help their discussion to converge and provide a common basis for future research efforts. To the best of our knowledge, no systematic approach has yet been undertaken that seeks to explain the emergence of volatility in SCs in a comparatively holistic way. The proposed framework extracts and conceptualizes SCV by combining prior research in this area with practitioners' insights.

For managers, the framework details the complexity and multidimensionality of the phenomenon of SCV, which challenges them on a regular basis. Based on input from 17 SCM practitioners with an average working experience of eight years, we posit propositions on the *relative deviating impact*, *repetitiveness* and *influenceability* of different dimensions of SCV to add practical insights to our conceptual framework and to guide managers on the dimensions on which they can and should focus their efforts. As can be seen in Table 7, the *relative deviating impact* of *organizational volatility* is similar in magnitude to the other dimensions. However, the degree of *influenceability* is comparatively high since *organizational volatility* is induced by the focal firm itself. Therefore companies should focus on this dimension first, since it is subject to influence by them, but has a significant impact on volatility in the whole SC. Practitioners involved in our group exercise agree that the integration of a SC starts with the integration of one's own company (see also Zhao *et al.*, 2011).

Furthermore, we stressed the importance of behavioral aspects in managing volatility. Managers need to understand the crucial impact of the behavior of decision makers in the own organizations and in the SC. To reduce the impact of decision makers' behavior on SCV,

teaching and training across the SC is still necessary. While doing so, managers face the challenge that relationship-specific investments could create spillover effects that are beneficial for competitors using the same source of supply (Dyer et al., 1998; Dyer and Singh, 1998).

2.6 Final Remarks

No study is without limitations. We acknowledge that our results may be biased by the literature chosen for our literature review. To partly overcome this, we performed data triangulation by including a set of 23 practitioners in the identification of the sources of volatility. As described in the research design section, the SLR was solely based upon articles published in peer-reviewed journals. Deficiencies that may arise from this restriction of the literature have been dampened by including the group exercise in the data collection process; however, we must acknowledge that a new bias may have been introduced by the sample of practitioners included in the group exercise. We sought to alleviate this potential issue by selecting a heterogeneous group of company representatives. To further reduce general bias during the development of the conceptual framework, we involved various academics and practitioners in multiple stages of the process.

Finally, the fifteen propositions were created to delineate the effect of the five dimensions on SCV. Such propositions were developed from the responses of 17 SCM practitioners from different manufacturing industries, and potentially influential contextual variables could not be controlled for with this small group of practitioners. This exercise should therefore merely be understood as an effort to further advance theory (cf. Durach, Kembro, et al., 2017). This incorporation of additional practitioners was performed to increase the practical orientation of our proposition, while a more nuanced approach and rigorous testing are still required.

This leads us to our call for further research on SCV. The present study sought to include a heterogeneous group of practitioners from various industry sectors. This approach helped to

decrease the likelihood of bias in the identification of sources and the proposition building process; yet in doing so, we may have erased some contextual factors that can and should form the basis of future research. The proposed conceptual framework and propositions are derived from a rigorous research process, but they require further quantitative testing. In particular, the existence and strength of the proposed relationships between the variables should be examined to guide future research and to better assess volatility mitigating strategies for managers. Moreover, the moderating role of the behavior of supply chain actors and customers requires further investigation. Previous research on the BWE emphasized the importance of human behavior in the variance of material flows, but this has still to be extended to the broader scope of SCV.

3. Article 2

Title:

"Unravelling the Complexity of Supply Chain Volatility Management"

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3.1 Introduction

Managing global supply chains (SC) is becoming ever more challenging, leading to calls for new concepts to deal with the accompanying turbulence (Christopher and Holweg, 2011, 2017). Supply chain volatility (SCV) is one of the most prominent challenges SC managers have to deal with (Handfield et al., 2013). Because of its practical relevance, researchers have acknowledged volatility as an important area of future supply chain management (SCM) research that remains underrepresented in current research (Wieland et al., 2016).

The severity of volatility affecting SCs manifests itself in the emergence of different SCM practices for dealing with it. Broader management concepts such as SC flexibility (Engelhardt-Nowitzki, 2012; Yi et al., 2011) or SC agility (Gligor and Holcomb, 2014; Prater et al., 2001; Qrunfleh and Tarafdar, 2013) aim to respond efficiently to volatile changes in upstream or downstream material flows. Even so, Christopher and Holweg (2017) argue that existing concepts dealing with volatility are not suitable in periods of emerging turbulence, instead proposing different means to achieve structural flexibility in order to deal with volatility more effectively. In addition, recent advances in heuristic optimization of supply chain coordination have made valuable new approaches available to SC managers who need to improve process efficiency in complex scenarios (Bányai et al., 2017; Veres et al., 2017).

In general, volatility in SCM is understood as a multidimensional construct that originates not solely from shifts in customer demand, but also from several other sources, such as the growing number of substitute products on the market, short product life-cycles, increasing lead times, governmental regulations, competition, raw material price variations, and others (Christopher and Holweg, 2011; Handfield et al., 2013).

However, practitioners trying to manage SCV efficiently may reasonably question which sources might be most effectively prioritized. With limited resources at hand, practitioners

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cannot mitigate the impact of them all, and need to know whether to focus on reducing the total lead time in the supply chain, on reducing the number of products offered, or on addressing a completely different source of SCV.

Nitsche and Durach (2018) provided a description of the construct by conceptualizing the sources and dimensions of SCV. More specifically, they proposed 20 meta-sources of SCV that belong to five distinct dimensions of SCV. However, managers still need to know how to handle this number of SCV sources efficiently. Consequently, an assessment of the impact of those sources on SCV is a priority.

Taking this into account, the following study seeks to contribute to the assessment of sources of SCV, as well as to provide specific management approaches to guide SC managers in efficiently dealing with the SCV phenomenon. More specifically, it aims at investigating the following research questions (RQs):

RQ1: Which sources of SCV should SC managers prioritize in order to manage SCV efficiently?

RQ2: What management strategies can be implemented to deal with the most impactful sources of SCV?

In order to provide an answer to these RQs, the study follows a two-stage research approach. First, with the assistance of a group of 17 SC managers working for manufacturing firms, the study applies the Analytical Hierarchy Process (AHP) to assess identified sources of SCV (Saaty, 1980). The study then analyzes the AHP results in terms of the manufacturers' production strategies and the total lead times of their products. Second, a group exercise is conducted with the same group of managers, following the Nominal Group Technique (NGT)

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(Van de Ven and Delbecq, 1971), to synthesize management strategies dealing with the most impactful sources of SCV.

The remainder of the article is structured as follows: Section 2 introduces the framework of SCV sources and dimensions that will form the basis of this research. Section 3 outlines the research design that was deemed appropriate to address the RQs. Section 4 delineates the results, while the Section 5 discusses the results with regard to their implications for practice and research. The paper closes with a summary and a critical assessment of limitations.

3.2 Theoretical Background and Conceptual Framework of SCV

The term volatility originates from the field of finance, where it is defined as a measure of the uncertainty of stock price movement (Altman and Schwartz, 1970). This can be measured historically and in terms of implied volatility. Historical volatility is measured via the standard deviation of historic stock prices over a period of time (Pinches and Kinney, 1971), while, in contrast, *implied volatility* is a calculation that aims to predict the future volatility of stock prices on the market (Black and Scholes, 1973). Since the ground-breaking work by Black and Scholes (1973) and Merton (1973), the assessment of stock volatility has gained increasing attention in economic research.

In the SCM context, volatility is used to describe the movement of different logistical parameters over a period of time, ranging from unpredictable customer demand changes (Childerhouse et al., 2008; Wong and Hvolby, 2007), through variable process outputs (Germain et al., 2008), to uncertain economic developments or market conditions (Bridgman, 2013; Christopher and Lee, 2004). Synthesizing the few existing definitions, this paper defines SCV—from a focal firm point of view—as "the unplanned variation of upstream and downstream material flows resulting in a mismatch of supply and demand at the focal firm" (Nitsche and Durach, 2018).

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To dampen volatility in SCs, multiple studies on sources of SCV have been developed. Tracing back the literature on SCV sources inevitably leads to the discovery of the *Forrester effect* (Forrester, 1958). The *Forrester effect* describes the increasing variability of orders going upstream in the SC. This phenomenon was later reintroduced as the bullwhip effect (BWE) (Lee et al., 1997), that emerged as one of the fundamental phenomena in SCM, and kept researchers busy for decades. In this regard, numerous sources of the BWE have been thoroughly investigated. Miragliotta (2006) separates research on the sources of the BWE into the System Thinking and the Operations Managers schools. While the first explains the BWE as an irrational reaction of decision makers, focusing mainly on behavioral sources (Croson and Donohue, 2006; Nienhaus et al., 2006), the Operations Managers school views it as a rational reaction to single sources, such as order batching, incorrect forecasting, and price fluctuations (Barlas and Gunduz, 2011; Lee et al., 1997).

Although the vast amount of research on sources of the BWE has contributed to an understanding of volatile SCs, it should be noted that the BWE fails to fully explain the occurrence of volatile material flows (Kim and Springer, 2008). A SC regularly faces a number of challenges, such as supply variations (Hameri and Palsson, 2003), variable lead-times (Chaharsooghi and Heydari, 2010; So and Zheng, 2003), increasing volatility of global markets (Christopher and Holweg, 2011, 2017), disruptive events (Chopra et al., 2007; Craighead et al., 2007), and others that cause volatile material flows, leading to a mismatch of supply and demand at the focal firm.

The goal of this study is to assess the relative impact of volatility sources on SCV and to derive suitable management strategies to deal with its most impactful sources. It is therefore necessary to develop a comprehensive framework of volatility sources in order to assess their impact on SCV. Thus, this study is based on the previous research of Nitsche and Durach (2018), who proposed a conceptual framework of SCV that outlines the different sources and dimensions of

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SCV, analyzed from a manufacturer's perspective. Since this framework is derived from a large-scale systematic literature review combined with practitioners' insights on the topic, it is considered appropriate as a tool to assist in solving the above-mentioned RQs.

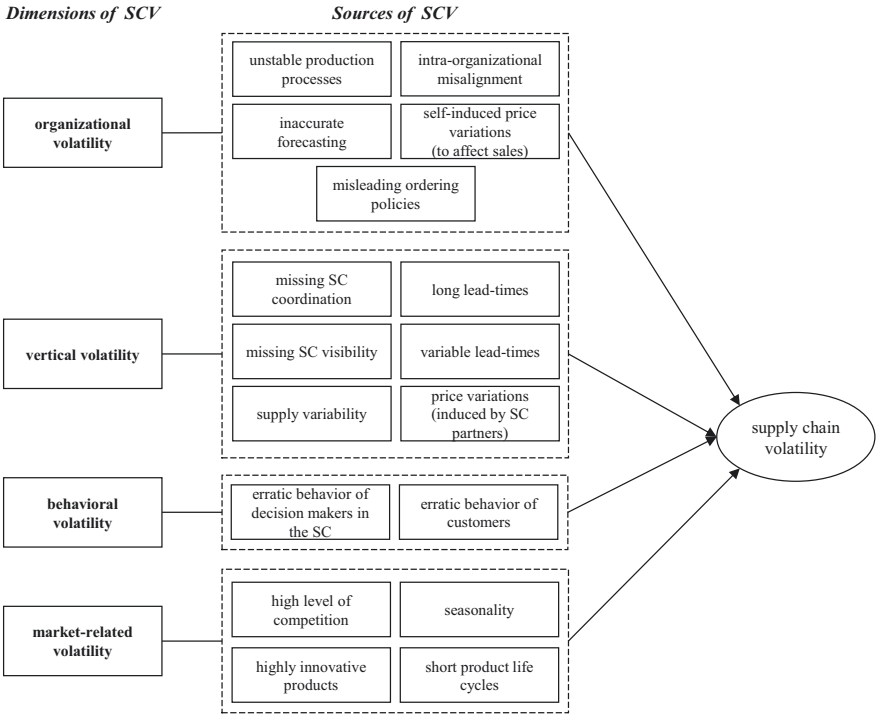

Figure 8 – Adapted framework of dimensions and sources of SCV

Nitsche and Durach (2018) propose 20 meta-sources of SCV that belong to five different dimensions of SCV. These are: (1) *organizational volatility*, (2) *vertical volatility*, (3) *behavioral volatility*, (4) *market-related volatility*, and (5) *institutional and environmental volatility*. While *organizational volatility* is induced by the focal firm itself, *vertical volatility* arises from sources within the SC. Behavioral volatility originates from behavioral patterns of individuals in the SC (decision makers as well as customers), while market-related volatility is

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induced by the market in which the product's SC is located. The fifth dimension includes volatility that is induced by sources that appear exogenous to the SC, such as national economic, financial, political, or legal instability. However, due to the high context-dependency of the fifth dimension, this study uses an adapted version of the framework that focuses only on the first four dimensions.

Figure 8 illustrates this adapted SCV framework, while Table 8 provides overview descriptions of all four dimensions of SCV, as well as the 17 sources of SCV. This framework and the descriptions of the variables form the basis for the research procedure, which involved 17 SC practitioners in a moderated workshop setting.

Table 8 – Description of dimensions and sources of SCV

Tier	Variable	Description
1st tier-dimensions of SCV	Organizational volatility	Describes that part of SCV that is self-induced by the focal firm.
1st tier-dimensions of SCV	Vertical volatility	Describes that part of SCV that is induced by sources appearing endogenous to the SC.
1st tier-dimensions of SCV	Behavioral volatility	Describes that part of SCV that is induced by behavioral patterns of individuals in the SC.
1st tier-dimensions of SCV	Market-related volatility	Describes that part of SCV that is induced by the market in which the offered product is placed.
2nd tier-sources of SCV	Unstable production processes	Refers to the instability of a production process (e. g., machine breakdowns, inappropriate or volatile production schedules, unstable throughput, capacity constraints).
2nd tier-sources of SCV	Misleading ordering policies	Described as ordering policies that distort actual demand (e. g., order more than you need due to very high MOQs or cost saving targets).
2nd tier-sources of SCV	Intra-organizational misalignment	Plans and actions of different departments within the own organization are not well coordinated (e. g., conflicting goals, competition among different value streams, misaligned organizational plans such as forecasts).

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Tier	Variable	Description
2nd tier-sources of SCV	Inaccurate forecasting	Customer demand forecast does not meet the actual demand and has to be changed constantly.
2nd tier-sources of SCV	Self-induced price variations	Prices are changed by the focal firm itself to influence the customer demand (e. g., promotions).
2nd tier-sources of SCV	Supply variability	Refers to deviations from planned supply (incorrect amount or quality) caused by suppliers (e. g., quality problems, capacity problems, or others caused by suppliers).
2nd tier-sources of SCV	Missing SC coordination	Decisions along the SC are not taken jointly between SC partners (e. g., due to lack of synchronization and weak relationships among SC partners).
2nd tier-sources of SCV	Long lead times	The total amount of days between ordering a component from a supplier and delivering a final product to a customer is very high.
2nd tier-sources of SCV	Price variations induced by SC partners	Prices are changed constantly by SC partners to influence supply and demand on their side.
2nd tier-sources of SCV	Missing SC visibility	Refers to poor availability of data along the SC (e. g., no sharing of actual point of sale demand data).
2nd tier-sources of SCV	Variable lead times	There is an expected lead time that is used to plan supply and demand, but the lead time actually realized varies considerably.
2nd tier-sources of SCV	Erratic behavior of decision makers in the SC	Refers to the degree to which decision makers react irrationally and unpredictably to certain events (e. g., over- or underestimation of demand or supply signals, strategic interactions among SC partners, or a lack of consideration of already placed orders).
2nd tier-sources of SCV	Erratic behavior of customers	Customer demand behavior is very uncertain and hard to predict (e. g., due to short-term order changes).
2nd tier-sources of SCV	Short product life cycles	The period between the beginning and end of life of a product is comparatively short.

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Tier	Variable	Description
2nd tier-sources of SCV	High level of competition	Characterized by a very high number of product variants offered on the market and/or a very high number of competitors.
2nd tier-sources of SCV	Seasonality	The customer demand varies during the year, but this variation is relatively predictable.
2nd tier-sources of SCV	Highly innovative products	Characterized by a poor availability of data along the SC (e. g., no sharing of actual point of sale demand data)

3.3 Research Design

To address the aforementioned RQs, the researchers conducted a moderated on-site workshop with 17 SC managers, who were invited to discuss the topic of SCV. The workshop followed a two-stage research procedure applying two distinct research methods. In the first stage, designed to investigate which sources of SCV need to be prioritized when trying to manage SCV efficiently (RQ1), the practitioner group was requested to execute an AHP based on the two-tier framework shown in Figure 8 in order to assess the relative impact of SCV sources on SCV. In the second stage, a moderated group exercise was conducted, applying the NGT (Van de Ven and Delbecq, 1971) in order to identify volatility management strategies for dealing with the six most impactful sources of SCV (RQ2). Figure 9 outlines the overall research procedure applied in this paper.

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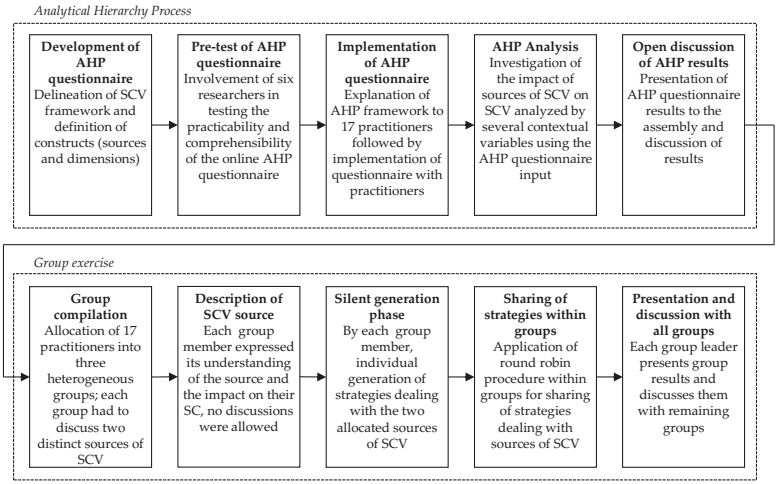

Figure 9 – Research procedure

Since the SCV framework (see Figure 8) outlines sources and dimensions of SCV from a manufacturer's point of view, the researchers decided to restrict participation in the on-site workshop to SC managers working in manufacturing firms (this particular case is limited to those with a manufacturing site located in Germany). They were employed in logistics, purchasing, or SCM departments, and their average work experience in this field was eight years. Although neither AHP nor NGT prescribes a set minimum sample size, a group size of 15 to 20 people was selected to ensure the feasibility of the moderated workshop setting. The intention was to compile a heterogeneous group of practitioners covering different types of manufacturers, especially covering different production strategies. Table 9 outlines the sample demographics of the workshop participants. The following two subsections will describe the two-stage research approach in detail.

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Table 9 – Sample demographics of participants in on-site workshop

Industry Type	Annual Turnover	Total Number of Employees	Production Strategy	Participants' Management Level	Participants' Department	Years of Experience
Automotive	>5 bn €	>5000	MTO	Department manager	SCM	5
Automotive	>5 bn €	>5000	MTO	General manager	SCM	9
Automotive	>5 bn €	>5000	MTO	Department manager	SCM	4
Chemicals	>5 bn €	>5000	MTS	Team member	Purchasing	3
Chemicals	>5 bn €	>5000	MTS	Department manager	Logistics	3
Consumer Goods	1 bn €–5 bn €	>5000	MTS	Team member	Logistics	2
Electronics	500 m €–1 bn €	>5000	MTS	Team leader	Logistics	5
Electronics	1 bn €–5 bn €	>5000	ETO	General manager	Logistics & SCM	20
Electronics	1 bn €–5 bn €	>5000	ETO	Team member	SCM	2
Electronics	1 bn €–5 bn €	>5000	MTO	Department manager	Logistics	25
Electronics	>5 bn €	>5000	MTS	Team member	SCM	7
Electronics	10–50 m €	51–250	MTO	Department manager	SCM	15
Equipment/ Machinery	500 m €–1 bn €	501–2000	MTO	Team member	SCM	9
Equipment/ Machinery	100–250 m €	501–2000	ETO	General manager	Purchasing	19
Equipment/ Machinery	250–500 m €	>5000	ETO	Team leader	Purchasing	5
Equipment/ Machinery	>5 bn €	>5000	MTO	Team member	Logistics	3
Equipment/ Machinery	>5 bn €	>5000	MTO	Team leader	SCM	5

3.3.1 Analytical Hierarchy Process

The AHP, originally developed by Thomas L. Saaty, is a structured approach to support complex decision-making processes (Saaty, 1980). It assists in deriving weights of factors from a pairwise comparison among them in a hierarchic model. It thereby creates a ranking of factors that are relevant in prioritizing certain factors over others for a decision-making problem. Due to its straightforward nature and formalized applicability to many business processes, making use of techniques such as balanced scorecards, resource allocation problems, benchmarking,

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and others, the methodology has found wide acceptance in a business context (Bhushan and Rai, 2004).

SCM researchers have applied AHP to solve supplier selection problems (Ramanathan, 2007; Shaw et al., 2012), or to measure performance (Chan, 2003; Sharma and Bhagwat, 2007). Other studies have applied AHP to assist in extracting practitioners' knowledge and perceptions on complex cause and effect relations in SCM problems. Even though, to the best of the author's knowledge, AHP has not been applied in the context of SCV, researchers have applied it in the area of risk management, a stream of literature with a thematic overlap with the SCV literature (Nitsche and Durach, 2018). Gaudenzi and Borghesi (2006) used an AHP approach to synthesize practitioners' perceptions of certain risk factors and their effect on various SC goals. Due to AHP's strengths in extracting experts' knowledge on a certain topic and the possibility of quantifying and prioritizing the importance of certain factors in a framework, it is considered an appropriate technique to provide answers to RQ1.

This study applied AHP to draw out practitioners' perceptions of the relative impact of sources of SCV on SCV using the hierarchic framework presented in Figure 8 (1st level of hierarchy: dimensions of SCV; 2nd level of hierarchy: sources of SCV). Although the researcher acknowledges the limitations of this methodology in assessing cause and effect relations (as will be discussed further in the '3.6 Conclusions and Limitations' section), this is understood as the primary approach to investigate the impacts of sources of SCV and their implications for SCM.

Before performing the AHP with the group of practitioners, an online AHP survey was developed to enable pairwise comparisons between the dimensions of SCV, as well as pairwise comparisons between the sources of SCV within a dimension. This survey also included the description of dimensions and sources of SCV, as outlined in Table 8.

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The questionnaire enabled the pairwise comparison of the dimensions of SCV, as well as pairwise comparisons of sources of SCV within their respective dimensions. For pairwise comparisons, each questionnaire participant was required to think of the SC of a product they knew very well, and assess which of the respective sources of the dimensions of SCV had a greater impact on SCV for the SC of that product (e. g., '*Please state, which of both factors has a bigger impact on supply chain volatility: unstable production processes or intra-organizational misalignment*'). This assessment was done on a scale of 1 to 9 in each direction, where 1 indicates equal importance of each source on their respective dimensions, whereas 9 in the direction of one source means that this source has the highest possible directional impact on SCV compared to the other paired source, from the participant's point of view (Saaty, 2008). After developing the questionnaire, a pre-test of the survey was conducted with six SCM researchers who had not been involved in the research process so far. This group of researchers met at a dedicated on-site meeting, where they were provided with an explanation of the SCV framework and its sources and dimensions, as well as an introduction to the AHP. Subsequently, they were guided step-by-step through the survey, explaining, once again, each source of SCV in its respective dimension.

For the pre-test of the AHP questionnaire, the group result was calculated using the geometric mean, as proposed by Saaty (2008). The consistency ratio (CR) of the AHP group result was calculated at 0.0022, which indicates very good consistency among the answers of individual participants (Saaty, 1990). This also indicates that the description of sources and dimensions of SCV was well understood by the participants in the group exercise. In addition, the pre-test group of researchers was asked for feedback on the accessibility of the questionnaire, as well as the understandability of sources and dimensions. The final questionnaire was compiled incorporating minor amendments based on the feedback received.

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For the final study session, the group of 17 SC managers met in a moderated on-site meeting dedicated to the specific topic of managing SCV. They were provided with a definition of SCV, as well as a detailed explanation of the SCV framework, including all dimensions and sources of SCV. Questions were solicited and discussed to generate a common understanding of the SCV framework. Subsequently, the group was asked to fill in the AHP online questionnaire. The moderators of the meeting compiled all answers and analyzed them using a previously prepared template. The analyses were presented to the group, and an open discussion on the results followed. Based on the results, researchers applied the NGT to determine the six most impactful sources of SCV for further investigation in a subsequent group exercise that aimed to identify management strategies for dealing with these sources.

3.3.2 Nominal Group Technique

After identifying the most impactful sources of SCV, the same group of SC managers participated in a moderated group exercise based on NGT principles (Van de Ven and Delbecq, 1971) in order to derive management strategies for dealing with these sources of SCV. While Delphi group techniques completely eliminate interaction and forbid face-to-face meetings among group members, focus group discussions can induce bias due to strong-willed group members who tend to lead the discussion (Goodman, 1987). The NGT is intermediate between these techniques, allowing on-site meetings of group members, as well as encouraging all group members equally in the idea generation process (Green, 1975). The NGT assists in extracting practitioners' knowledge through a moderated process (Lloyd, 2011) that has previously demonstrated its advantages in SCM research (Durach, Glasen, et al., 2017; Schoenherr et al., 2012).

At the beginning of the group exercise, participants were assigned to three heterogeneous groups of five or six members. Each group had to discuss two out of the six most impactful sources of SCV (*intra-organizational misalignment*, *inaccurate forecasting*, *long lead times*, *erratic behavior of customers*, *erratic behavior of decision makers in the SC,* and *high level of*

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competition), according to the average AHP result. Before starting the NGT procedure, within the group each group member had to express his/her understanding of the sources the group had to discuss, especially with regard to the impact of these sources on their business.

Initiating the NGT, each group member had time, during a silent generation phase, to individually think of possible management strategies for dealing with one of the sources of SCV. Subsequent to this phase, a process was conducted for sharing strategies within the group, applying a round-robin procedure (Chapple and Murphy, 1996). Thus, each member of the group had to explain one strategy and its implementation, followed by the explanation of another strategy by the next member, and so on until all strategies had been addressed. The moderators ensured that only questions concerned with comprehension were allowed in this stage, preventing any judgement or discussion. Subsequently, the group synthesized the list of strategies.

The whole process was applied separately for each of the two sources that had to be discussed in each group. After each group completed the generation of strategies, they presented the results to the remaining groups, which also added their ideas on possible strategies, leading to a finalized list of strategies for dealing with six sources of SCV.

3.4 Results and Discussion

This section outlines the results gathered from the two-stage research approach. First, the relative impact of sources of SCV will be assessed by utilizing the AHP results gathered from the expertise of 17 SC managers. Subsequently, insights into SCV management approaches are given that are derived from a moderated group exercise among the same group of managers.

3.4.1 Assessing the impact of sources of SCV

Before initiating SCV management strategies, SC managers need insights into the effects of SCV sources on SCV. Since the mitigation of all sources of SCV is considered to be

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challenging, and with heavy cost pressure a reality, management approaches need to tackle the most impactful sources to manage SCV efficiently. To shed light on this area, the AHP aimed to assess the relative impacts of SCV sources to provide managers with a set of guiding principles when they attempt to manage SCV. The overall AHP results are outlined in Table 10. The depicted weights describe the relative impact of the specific source or dimension of SCV on SCV as determined by the workshop participants. For example, it can be seen that, in terms of the group average, 34.1 percent of SCV is generated by the dimension *organizational volatility*.

The calculation of weights was done by using the geometric mean to combine all participants' final outcomes with equal weighting, as proposed by Saaty (2008). In the following discussion, this data will be further analyzed in terms of the total group result, as well as the production strategy and total lead time of the product.

Table 10 – Overview of AHP results

Source/Dimension of SCV	**Group average** (n = 17)	**by production strategy**			**by total lead time (in days)**		
		ETO	MTO	MTS	0–28	29–90	91–800
		n = 4	n = 7	n = 6	n = 5	n = 6	n = 6
Unstable production process	5.2 %	4.1 %	8.4 %	2.6 %	6.5 %	2.2 %	8.3 %
Misleading ordering policies	4.0 %	1.8 %	6.3 %	2.8 %	5.9 %	2.8 %	3.2 %
Intra-organizational misalignment	10.0 %	5.9 %	19.2 %	4.5 %	11.5 %	8.4 %	7.9 %
Inaccurate forecasting	11.5 %	6.7 %	8.8 %	15.1 %	13.6 %	11.6 %	7.8 %
Self-induced price variations	3.4 %	4.6 %	2.4 %	2.8 %	7.2 %	2.0 %	2.4 %
Organizational Volatility*	**34.1 %**	**23.1 %**	**45.1 %**	**27.7 %**	**44.7 %**	**27.1 %**	**29.6 %**
Supply Variability	3.0 %	3.6 %	4.0 %	1.4 %	0.8 %	2.6 %	7.5 %
Missing SC coordination	5.0 %	5.2 %	5.0 %	3.8 %	3.0 %	2.9 %	9.4 %
Long lead times	7.3 %	6.2 %	5.4 %	9.0 %	2.6 %	10.9 %	8.6 %
Price variations (by SC partners)	1.5 %	2.7 %	1.1 %	1.2 %	1.2 %	1.1 %	1.8 %
Missing SC visibility	5.9 %	3.7 %	9.7 %	3.7 %	3.2 %	4.4 %	9.8 %
Variable lead times	4.9 %	4.8 %	4.5 %	4.3 %	4.0 %	4.8 %	4.4 %
Vertical Volatility*	**27.6 %**	**26.1 %**	**29.6 %**	**23.4 %**	**14.9 %**	**26.7 %**	**41.4 %**
Erratic behavior of decision makers	8.7 %	3.4 %	12.9 %	5.2 %	6.0 %	14.1 %	5.9 %
erratic behavior of customers	11.6 %	22.4 %	3.9 %	13.6 %	16.3 %	17.0 %	4,8 %
Behavioral Volatility*	**20.3 %**	**25.9 %**	**16.8 %**	**18.7 %**	**22.2 %**	**31.1 %**	**10,6 %**
Short product life cycles	2.1 %	2.7 %	1.1 %	3.3 %	2.6 %	1.5 %	1.9 %
High level of competition	7.9 %	10.2 %	3.6 %	13.9 %	6.7 %	9.1 %	6.4 %
Seasonality	3.1 %	3.1 %	1.7 %	6.0 %	3.9 %	1.6 %	4.0 %
Highly innovative products	4.8 %	8.9 %	2.2 %	6.9 %	5.0 %	3.0 %	6.0 %
Market-related Volatility*	**17.9 %**	**24.9 %**	**8.5 %**	**30.1 %**	**18.2 %**	**15.1 %**	**18.3 %**

* Bold lines represent the impact of the respective SCV dimension on SCV, meaning that they represent the sum of the sources above.

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Table 11 provides an overview of the CRs of the AHP analysis. All CRs of the respective dimensions of volatility, as well as the CR among those dimensions, are below 0.1, indicating very high consistency of AHP results (Saaty, 1990).

Table 11 – Overview CRs of AHP

Consistency Ratio (CR)	**Group average** (n = 17)	**by production strategy**			**by total lead time (in days)**		
		ETO n = 4	MTO n = 7	MTS n = 6	0–28 n = 5	29–90 n = 6	91–800 n = 6
CR Organizational Volatility	0.008	0.010	0.028	0.044	0.065	0.030	0.038
CR Vertical Volatility	0.004	0.044	0.009	0.013	0.048	0.021	0.019
CR Market-related Volatility	0.003	0.060	0.016	0.021	0.010	0.002	0.010
CR Dimensional Level	0.003	0.008	0.036	0.025	0.012	0.001	0.017

3.4.1.1 Impact of SCV sources analyzed by group average

The overall group results (see Table 10) indicate that there are impactful sources of volatility in every dimension of SCV. The dimension of *organizational volatility* has the largest relative impact on SCV. This is mostly caused by *intra-organizational misalignment* and *inaccurate forecasting.* According to the practitioners' perceptions, within the dimension of *vertical volatility*, *long lead times* seem to have the largest relative impact on SCV, while other sources of that dimension such as *supply variability* do not impact volatility as significantly. Both sources of the *behavioral volatility* dimension rank among the six most impactful sources of SCV. The dimension of *market-related volatility* has the lowest impact on SCV compared to the other dimensions. Nevertheless, *high level of competition* ranks among the six most impactful sources of SCV.

The six most impactful sources of SCV (according to the AHP group result) were discussed further in the group exercise that aimed to develop strategies to deal with them. Before initiating the NGT, participants explained their understanding of these sources, as well as their influence

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on participants' businesses (see Figure 9, step *Description of SCV source*), to create a common understanding. A brief summary of the results of these discussions is given below.

Intra-organizational misalignment: In the group exercise, practitioners expressed that their internal departments do not work closely together, which leads to misalignment. Logistics is not in regular touch with the customer, but is nevertheless responsible for facilitating flexibilities that were discussed between the sales department and the customer. Thus, flexibilities agreed upon between sales and the customer get lost within the organization, or logistics does not have access to information on these (e. g., they were agreed upon via email years ago). Practitioners agreed with the statement of one participant:

> *Our sales department agrees upon flexibilities with our customers before sealing the contract and without first agreeing with us whether we can handle these flexibilities regarding our capacity. During the contract period, those customers often count on the promises made by the sales department, but we have never known about it until that point, when confronted with the customer.*

Additionally, research and development departments plan product changes but do not communicate those changes in a timely fashion; as a consequence, the purchasing department orders too many components that will not be needed in the near future. Previous SCM research also acknowledged the importance of intra-organizational alignment. For example, Wagner et al. (2014) state that the adjustment of supply and demand starts with an alignment of all functional departments through a comprehensive sales and operations planning process. This is also supported by others, who propose that companies have to integrate their own company activities before starting to integrate the whole SC (Zhao et al., 2011).

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Inaccurate forecasting: Practitioners state that, in general, deviations are acceptable and must be covered by logistics to a certain extent. However, forecasts are considered to be inaccurate whenever deviations exceed certain thresholds that are often are not clearly defined, depending on the individual case. Practitioners also stressed that the main objective of forecasts is to ensure a stable production process, rather than predicting customer demand; this is often misunderstood within the organization. From their point of view, decisions that are made based on forecasts do not necessarily have to be extremely accurate, but after they are made people have to stick with them instead of changing decisions constantly.

Long lead times: The practitioner group responsible for discussing this source mutually agreed that long lead times are challenging in all phases (supply lead time, manufacturing lead time, warehouse lead time, transport lead time, and others) because they decrease plannability, and consequently, induce SCV in an uncertain environment. They also argued that companies try to decrease manufacturing and warehousing lead times, but in a world that is becoming more and more diversified and globalized, supply and transport lead times in particular become longer, with less sign of abatement.

Erratic behavior of decision makers: From the practitioners' point of view, this was understood as decisions that are perceived as irrational by the recipient of the decision, such as negligent and spontaneous behavior, as well as "gut decisions" that are not comprehensible to others. The decision maker who acts erratically is not necessarily aware of the fact that he/she is seen as acting irrationally from an objective point of view. One practitioner stated an example of erratic behavior of decision makers in his company:

> *Although we do get forecasts regarding sales and purchasing from our system, there are employees who do not trust these forecasts. As they think they know better, they adjust order quantities or other things on their own authority.*

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Another example that was expressed indicated that the type of erratic behavior is linked with the personality of the decision maker:

> *The behavior when ordering is definitely strongly linked to the personality of the buyer. There are people who consistently order less to reduce their stock, which also carries risks. Others order more than necessary, as they are planning with a buffer. This main reason for this is that proposals from the system are often seen just as proposals instead of something you have to stick to.*

Such erratic behavior is only visible if it causes problems in the SC. Practitioners explained that, if erratic behavior causes a problem, such erratic behavior is mostly treated as a mistake, instead of being seen as a chance to mitigate a source of process uncertainties in the long run.

Erratic behavior of customers: Practitioners described that the unpredictability of their customers' demand behavior challenges them on a regular basis, leading to volatility along the SC. In a B2B environment in particular, they argued that their customers regularly change order specifications, mostly quantities, at short notice, leading to unexpected and unplannable expenses at the manufacturing firm. This is underlined by one practitioner who stressed that, according to firm policy, customer wishes have to be realized:

> *Although we have our customers place their orders three months in advance, this does not prevent them from changing order quantities or even other specifications right before the start of production. We all know that the customer is king, so these wishes are then also realized in most of the cases. The worst thing is that in those cases the customers do not even know what this change request means for our logistics, they do not know that we, for example, have to organize cost-intense short-term air freight. But unfortunately, no one communicates that either.*

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High level of competition: Group members argued that fierce competition in their respective markets forces them to offer a high number of product variants. This product variety consequently decreases availability at the single part level. Moreover, they also fight for resources such as transport capacity, which is exacerbated during peak seasons (e. g., Chinese New Year). In situations where only one or few competitors exist, the level of competition is even higher, because those competitors fight for production capacity at the same suppliers.

3.4.1.2 Impact of SCV Sources Analyzed by Length of Lead Time

To analyze the AHP results according to the length of lead time, the practitioner group was split into evenly distributed tertiles. The lead time shown indicates the total lead time of an individual product the questionnaire participant had to think of when filling in the questionnaire. More specifically, the total lead time was described as the total number of days between ordering necessary components at suppliers and delivering the final product to the customer.

To analyze the relative impact of SCV sources on SCV by the length of lead time, two figures are given to provide a more detailed view on the AHP results. Figure 10 visualizes the assessment on a dimensional level, indicating the relative impact of each dimension of SCV on SCV perceived by the focal firm for each of the three lead time groups shown in three different columns. The percentages shown indicate the relative impact of this dimension of SCV on the volatility perceived at the focal firm (e. g., for total lead times below 28 days, 44.7 % of volatility perceived by the focal firm is induced by *organizational volatility* according to the AHP assessment of the five practitioners in this group). Since AHP assesses the relative importance of a factor, the percentages shown Figure 10 in one column add up to 100 % (except for minor rounding errors). Additionally, Figure 11 outlines a more detailed breakdown view of the impact of the individual sources of SCV. Thereby, the relative contribution of each source on the impact of their respective dimension is shown (e. g., in the group of total lead times up to 28 days, 13.7 % of SCV perceived by the focal firm is induced by *inaccurate forecasting,*

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which thereby is the most impactful source of *organizational volatility*). To ensure readability, values below 2.5 % are not shown in Figure 11, but those values can be found in Table 10.

The analysis of AHP data on the dimensional level (see Figure 10) indicates that the relative impact of vertical volatility on SCV, compared to the other dimensions, increases with an increasing lead time. This is supported by previous research that argued that the reduction of lead times supports the management of variability at the supply and/or demand side (here, *vertical volatility*) and improves SC performance (de Treville et al., 2004). For products with a relatively short lead time, the vertical dimension seems to have the lowest relative impact on SCV, while the dimension of *organizational volatility* causes the largest share of SCV, and should receive more attention when managing SCV.

Figure 10 – Impact of SCV dimensions on SCV analyzed by length of lead time (in days)

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Figure 11 outlines a more detailed view of the relative impact of SCV sources on SCV. As explained previously, the relative impact of *vertical volatility* increases with increasing lead time. It can be observed that, in particular, the SCV sources *supply variability*, *missing SC coordination*, *missing SC visibility* increase in their relative impact on SCV with an increasing lead time. Especially in light of globalization, where relatively long lead times and complex SCs are often considered as givens, *SC coordination* and *SC visibility* become more and more important, but are even harder to achieve (Arshinder et al., 2008; Caridi et al., 2010a; Jonsson and Mattsson, 2013; Wang and Wei, 2007; Williams et al., 2013).

The comparatively high ratio of *organizational volatility* for products with a comparatively short total lead time is, according to the AHP results, mainly caused by a high level of *intra-organizational misalignment*, as well as *inaccurate forecasting*. Practitioners involved in the group exercise underlined that, in a situation where the total lead time is comparatively short, customer proximity rises, and the integration of all departments and functions within the company is key to managing SCV efficiently.

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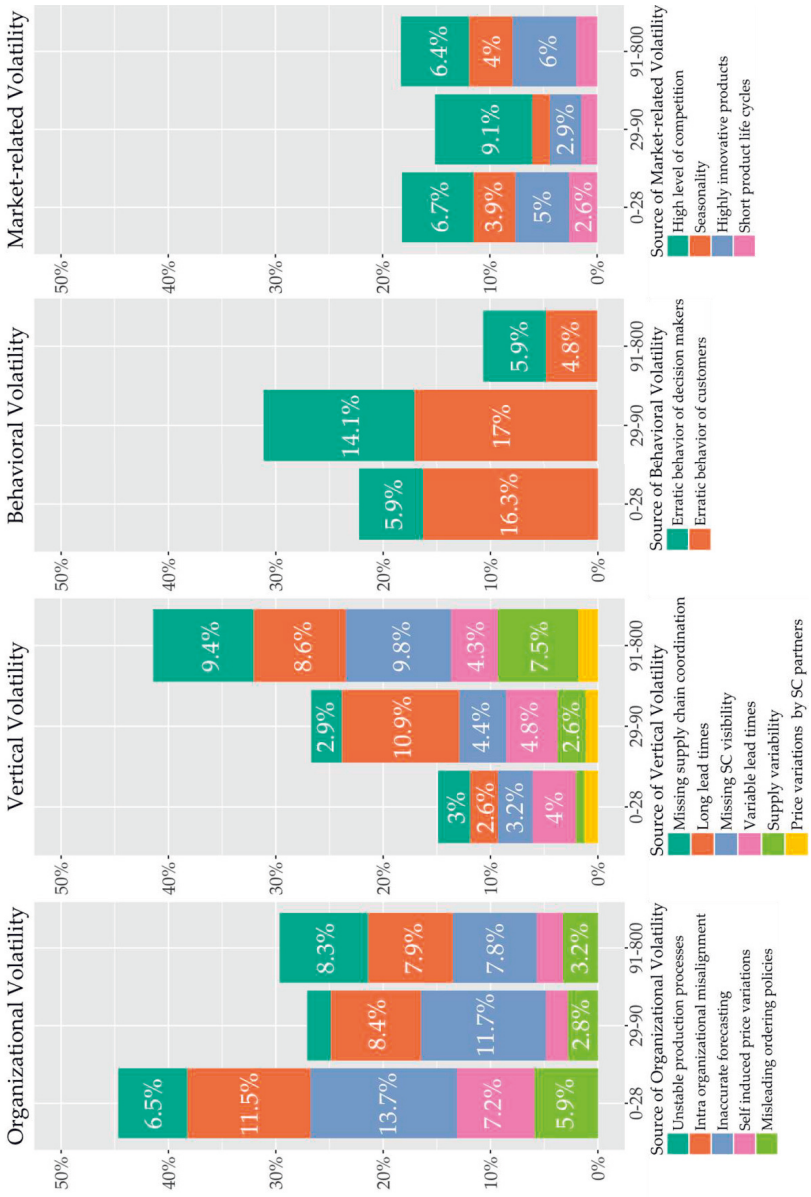

Figure 11 – Impact of SCV sources on SCV analyzed by length of lead time (in days)

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3.4.1.3 Impact of SCV sources analyzed by production strategy

The group of practitioners involved in the analysis came from different types of manufacturing firms. When filling in the AHP questionnaire, the practitioners were asked to think of one particular product they knew very well that is manufactured by their firm. Dividing the group according to their corresponding production strategies regarding the selected products leads to a reasonably even distribution among the groups: engineer to order (ETO, $n = 4$); make to order (MTO, $n = 7$); and make to stock (MTS, $n = 6$). Analyzing the AHP results for each group led to different results that were discussed with the group.

As in the previous sub-section, two figures will be provided to give a more detailed view on the AHP results. Figure 12 outlines the relative impact of SCV dimensions, while Figure 13 shows the relative impact of the SCV sources in their respective dimensions analyzed by their production strategy. Analyzing the ETO group on a dimensional level (see Figure 12) indicates a comparatively even spread for the relative impact of different dimensions of SCV. However, breaking it down into sources (see Figure 13, in which it can be observed that *erratic behavior of customers* seems to be by far the most impactful source of SCV for ETO products. At first, this seems counterintuitive, given that companies offering classic ETO products (e. g., cruise liners, gas turbines, or airplanes) experience customer demand mostly years in advance, which does not change drastically. However, the practitioners in this group argued that they receive the customers' demands very far in advance on a product level, but, during the engineering and manufacturing processes, product specifications often change drastically, leading to high volatility on a component level. This is underlined by the statement of one practitioner, who commented:

> *We know our customer demand very early in advance since in the business of individualized large-scale machinery lead times can be very long, up to 2 years. Those lead times are roughly the same throughout the industry, including our competitors. The whole thing becomes difficult when certain technical specifications on a single*

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part level change shortly before or in the worst case even after the start of production because the customer's situation changed. These changes at short notice are the ones that increase our networks volatility. Unfortunately, this is more the norm than the exception.

The second most impactful source for the ETO group is *high level of competition*. One practitioner of the ETO group stated:

We only have one real competitor. While this might sound great it becomes a problem when it comes to the supplier base, since there are only a few suitable suppliers for castings of this size. Therefore, we compete not only on the demand but also the supply side. Situations arise again and again in which one of us cannot be supplied in time because both of us ordered components at the same supplier at the same time.

Practitioners from the ETO group agreed with this statement, and added that, even in the situation of few competitors, competition is high because they also have the same customers, leading them to intense price competition, which makes the level of competition even fiercer.

For the MTO group, on a dimensional level it can be observed that *organizational volatility* contributes most to SCV experienced in MTO SCs, while *market-related volatility* seems to have a much lower relative impact on SCV compared to other production strategies (see Figure 12). Breaking this down on a source level (see Figure 13), it can be observed that *intra-organizational misalignment* seems to have the largest relative impact on SCV for MTO SCs. Practitioners argued that, especially in MTO scenarios, efficiency of internal coordination is key to success. Compared to ETO products, where the total lead time is relatively long, and MTS products, where internal processes are often clearly defined and highly efficient, MTO products often are partially individual, and according to the practitioner group, internal processes are not as clearly defined.

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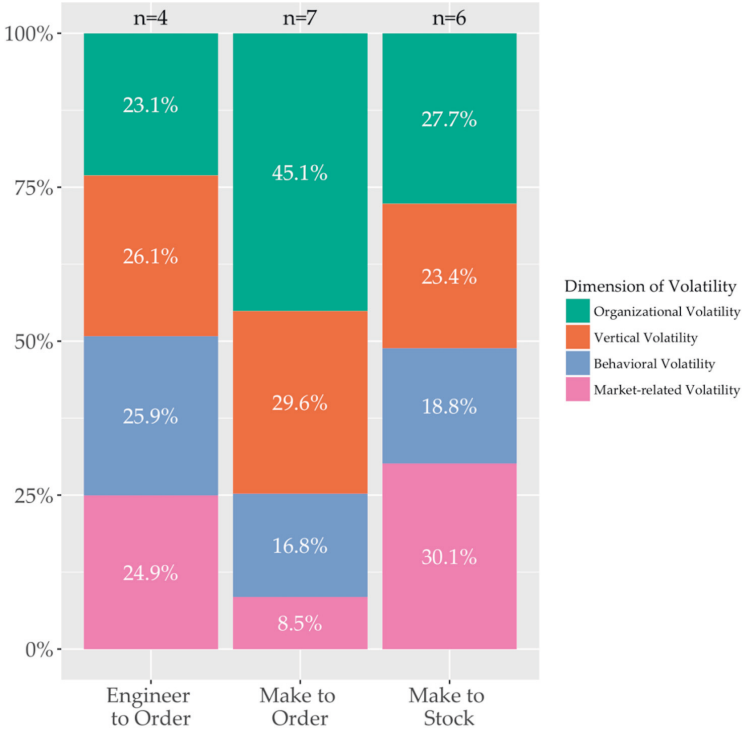

Figure 12 – Impact of SCV dimensions on SCV analyzed by production strategy

As stated by a supplier for the automotive industry:

> *Our basic products are clearly defined but still somewhat customizable as technical specifications, such as coatings and materials, often have to be adapted to the customers' applications. Unfortunately, we do not have standardized processes [for] how to handle every possible product variant that could be individualized by our customers. So, frankly speaking, we are quite slow when it comes to coordinating between all the involved departments – R&D, production, sales and logistics. As a result, our production processes are not as stable as we would like them to be.*

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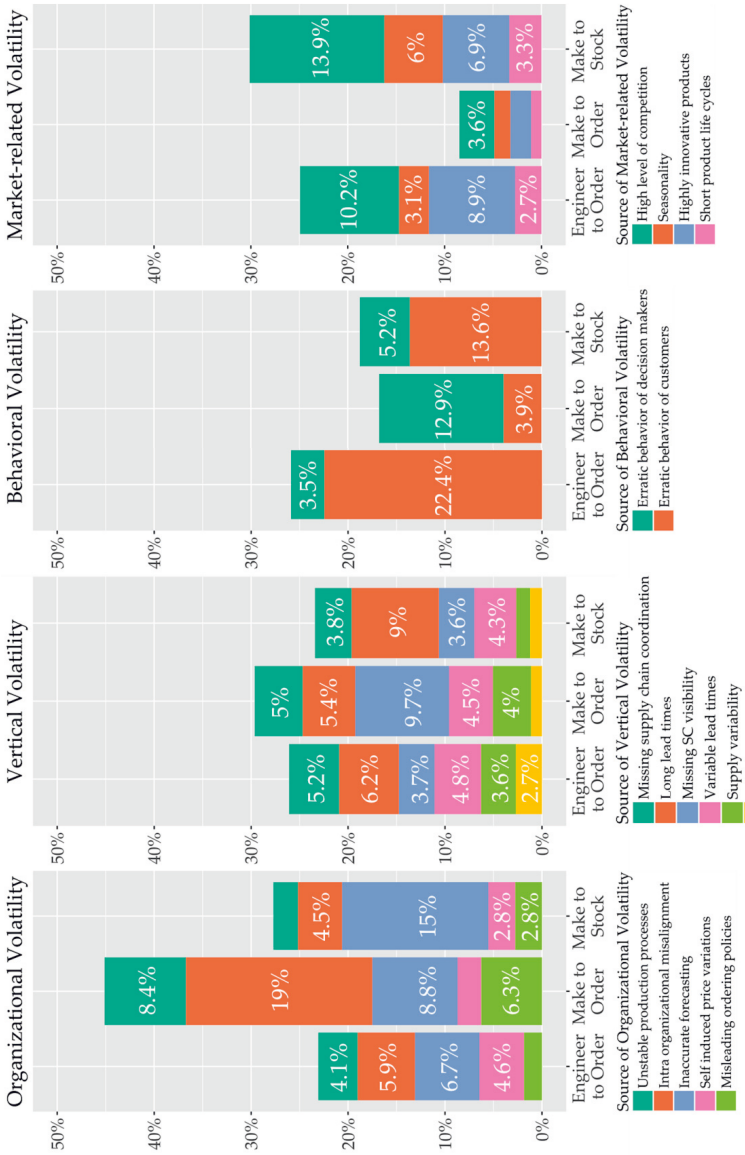

Figure 13 – Impact of SCV sources on SCV analyzed by production strategy

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This is underlined by the result that the relative impact of *unstable production processes* for MTO products is much higher than for ETO and MTS products (see Figure 13). The second most impactful source of SCV is *erratic behavior of decision makers*. Practitioners stressed that this is mostly because of the argument stated previously: In situations where efficiency and speed are key but product specifications are more vague, decision makers often tend to over- or underestimate signals, leading to SCV.

MTS products are usually characterized by a plan-based 'push' production strategy, holding stock of finished goods at the end of the supply chain (Kaminsky and Kaya, 2009), while manufacturing operations are intended to be highly optimized, applying lean approaches (Naylor et al., 1999). The results of the analysis of the MTS group support these characteristics; *inaccurate forecasting* and *erratic behavior of customers* are the most impactful sources of SCV for MTS products, while unstable production processes, for example, do not seem to impact SCV significantly (see Figure 13). Additionally, a *high level of competition* is among the most impactful sources of SCV. As described before, a *high level of competition* is characterized by a very high number of offered product variants at the market, and/or a very high number of competitors. Practitioners particularly stressed that this high number of product variants on the market, combined with a high number of competitors, challenges them in forecasting demand on a product level, leading to high volatility along their SCs. This is underlined by the statement of a SC manager from the confectionary industry:

> *Taking, for example, the product family chocolate: we offer several hundred variants worldwide, as do our competitors. This huge variety makes forecasting on variant-level nearly impossible. Why? Because we can only take past sales into consideration, but the real customer demand changes much more quickly than we can react to.*

3.4.2 Strategies for dealing with SCV

After jointly discussing the AHP results, the practitioners split up into three groups. Each group was asked to apply the NGT to identify strategies for dealing with SCV caused by two out of the six most impactful sources. Following the NGT process described in Section 3.3, the results were presented to the assembly, followed by an open discussion. During this discussion it was

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proposed to classify the strategies into short-, mid-, and long-term solutions to better guide managers when starting to implement SCV management strategies. Consequently, a total of 44 strategies for dealing with SCV caused by one or more of these sources was compiled (see Table 12 to Table 17).

To deal with *intra-organizational-misalignment* (see Table 12), internal transparency is one key to success, starting with transparency of departure and arrival dates of shipments within the organization, instead of leaving these to purchasing alone, followed by a company-wide database on contractual agreements to close the gap between sales and logistics. Additionally, the group argued that internal alignment is only achievable if company and departmental goals are aligned. Instead of creating silo-thinking due to non-aligned departmental goals, shared company goals must be set up.

To decrease volatility created by *inaccurate forecasting* (see Table 13), companies can expand their databases by implementing data-sharing incentives for customers, in the long-term, to build forecasts that are more sound. The forecast itself should be aligned through the whole organization, avoiding individual departments creating their own forecasts based on their own data. Following this, there should be constant evaluation and adjustment, allowing the process to continually improve by constantly challenging current assumptions made in the forecasting model.

In the short term, the effect of *long lead times* on SCV (see Table 14) can be mitigated by initiating incentives to the supplier to communicate lead time deviations as early as possible, rather than hiding them until the planned departure date expires. Following this early detection of lead time deviations, clear emergency plans with clear rights and responsibilities have to be defined (e. g., cut-off values for special shipments) to initiate follow-up actions. Moreover, the whole value stream from suppliers through the organization to the customer has to be analyzed and optimized. Practitioners agreed that that processes are often too long and time consuming, because they evolved historically but have not been challenged. Nevertheless, to achieve large lead time reductions, SC redesign actions such as localization, dual sourcing, or increased postponement are necessary.

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To mitigate *erratic behavior of decision makers in the SC* (see Table 15), companies can initiate process reengineering initiatives aiming to implement uninterruptable processes within the company. These must be expanded to include their SC partners, leading to clear, end-to-end processes. To achieve this, a different culture with regard to errors, coupled with organizational learning, can be implemented. Errors are allowed once, but they must be traced back to their roots and eliminated to prevent them from recurring. Therefore, the cultural mindset of an organization often has to be changed to allow open communication of problems and dissemination of the lessons learned.

Erratic behavior of customers (e. g., constantly changing order quantities of already placed orders) can be tackled by introducing customer incentives for not changing orders in the short term (see Table 16). However, the group unanimously agreed that, in a business-to-business context, *erratic behavior of customers* can often be mitigated by joint communication and discussion of the customer's demand behavior with the customer. The group stressed that customers are often unaware of their behavior, and change it after understanding its consequences for their supplier.

Practitioners were of the opinion that coping with a *high level of competition* is challenging, and cannot be addressed by short-term solutions (see Table 17). In general, it is all about achieving and maintaining a competitive advantage, either by a clear focus on cost reduction, or a focus on innovation, to differentiate the manufacturer from its competitors. Therefore, strategic partnerships with competitors can be an option to lower competition and jointly target increased profitability.

Table 12 – SCV management strategies dealing with intra-organizational misalignment

Time Horizon	SCV Management Strategies
Short-term	**Proactive communication of problems** • Instead of hiding problems that can have devastating effects on business performance, people have to communicate them proactively without getting blamed

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Time Horizon	SCV Management Strategies
	Weekly S&OP meetings • Regular meeting to synchronize all activities along corresponding departments/functions within the company **ETD/ETA transparency** • Create transparency on ETDs/ETAs within the company instead of leaving it to purchasing **Concentration of responsibilities** • Concentration of all responsibilities in one person or department instead of spreading them among different departments
Mid-term	**Internal risk assessment** • Among all relevant stakeholders, identify possible sources of intra-organizational misalignment on a regular basis **Goal alignment** • Departmental goals have to be aligned with company goal **Flexible materials planning** • Agreed contractual flexibilities have to integrated into the materials planning process
Long-term	**Company-wide database on contractual agreements** • To close the gap between sales and logistics, a database is needed that includes important contractual agreements that have been agreed with the customer (e. g., volumes, flexibilities, prices, etc.) • An SC-wide cloud database could be expanded to customers and suppliers as well • Database rights and responsibilities must be chosen wisely, clarified at an early stage, and put into practice accordingly **Internal value stream visualization and optimization** • Cross-functional visualization of internal value stream → identification of problems → mitigation → definition of clear organizational procedures/workflows about internal information flows that cover all company actions end-to-end

Table 13 – SCV management strategies dealing with inaccurate forecasting

Time Horizon	SCV Management Strategies
Short-term	**Forecasting transparency** • Increase transparency of forecasting models used • Calculations and assumptions have to be transparent, comprehensive and well-documented **Exception management** • Concentrate on outliners (situations where forecast and actual demand strongly differ from another), and identify what went wrong in order to mitigate outliers in the long-term **Data-sharing incentives** • Create incentives for customers (e. g., price promotions) to share their stock levels and other relevant data to increase forecasting accuracy **Determination of clear forecasting responsibilities** • Reduce/eliminate influence of stakeholders on the forecasting process through clear delineation of responsibilities
Mid-term	**Forecasting-process-alignment** • Forecasting models used have to be aligned with the product-related production and distribution processes; criticism by process owners has to be considered **Constant forecasting adjustment** • Controlling and adjusting forecasts on a regular basis throughout the company and the SC • Assumptions made must also be challenged and updated on a regular basis
Long-term	**Statistically sound forecasts** • Build forecasts on the basis of statistics instead of financial goals by incorporating other aspects as well (if applicable, weather, social media data, etc.) • Establish product life-cycle-dependent customer demand profiles building on comparisons with different product types **Better understanding of product and its customers' needs** • Build up an understanding of the product in all departments instead of leaving this to sales

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Time Horizon	SCV Management Strategies
	• Intra-organizational communication of relevant customer data from sales through all departments • Better analyses of the causes of consumption to better forecast customer demand

Table 14 – SCV management strategies dealing with long lead times

Time Horizon	SCV Management Strategies
Short-term	**Emergency plans** • Define clear emergency concepts in case lead time deviations are experienced at an early stage • Allow for higher spending on transportation in emergency cases; clear cut-off values have to be defined **Incentives of suppliers** • Encourage supplier to proactively communicate lead-time changes
Mid-term	**Value stream optimization** • Bring relief to the critical path by intensively analyzing networks and processes that have been built up over years without lead-time optimization in mind **Contractual volume flexibilities** • Delays in supply often arise from order quantities that have not been contractually agreed upon • Include volume flexibility into the contract combined with a flexible pricing system **LSP flexibility** • Arrange for flexible agreements with a broad LSP base instead of relying on just one **Lead time transparency** • Current planning processes often do not incorporate this appropriately • Incorporate lead-times of sub-components in logistics planning (and ERP system) to ensure simultaneous arrival
Long-term	**Localization/Regionalization** • Move production closer to the customer, as well as using local suppliers

Time Horizon	SCV Management Strategies
	• Some back-shoring/localization trends can be observed, evolving 3D printing can potentially accelerate progress
	SC Flexibilization through dual/multi sourcing
	• For the most important/strategic parts, search for an alternative supply strategy to reduce dependency and risk of stock outs • Cross-regional and/or cross-product line backup sources of supply have been proven to work well • Successful companies tell their suppliers if there is a backup source, and communicate to both of the quantities the other gets in order to create awareness and increase competition among them
	3D printing
	• Currently economically unfeasible for mass production in most cases, workshop participants are of the opinion that it is just a matter of time until 3D printing becomes more feasible, and lead times will be drastically reduced
	Rolling manufacturing site
	• In some cases, manufacturing steps such as curing or outgassing can be realized during transportation to reduce unnecessary waiting times
	Postponement
	• Movement of order-decoupling-point closer to the customer in order to ensure late individualization

Table 15 – SCV management strategies dealing with erratic behavior of decision makers in the SC

Time Horizon	SCV Management Strategies
Short-term	**Workload-reduction** • Reduction of exhaustion and stress of employees
Mid-term	**Robust processes/process reengineering** • Uninterruptible/gapless end-to-end processes with clear responsibilities that are resistant to failure • People act irrationally because they are given freedom/room to maneuver • Evaluate intra- and inter-organizational processes on a regular basis for early detection of errors

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Time Horizon	SCV Management Strategies
	Goal alignment • Intra-organizational alignment of goals and incentives through all departments and management levels
Long-term	**Organizational learning as a continuous improvement process** • Problems that occur have to be traced back to their roots to identify causes of interruptions in process chains • No blaming of individuals allowed • Incorporation of 'lessons learned' and follow-up to improve communication processes; specific effects of misbehavior have to be shown to the people within the organization to create awareness • Resources and capacities for organization learning have to be ensured and responsibilities need to be clarified • Concentrate on often-repeated problems first **Culture of errors** • It's okay to talk about errors in order to mitigate them proactively in the long-term • Implement culture in all departments and on all hierarchy levels • Intra- and inter-organization communication code necessary

Table 16 – SCV management strategies dealing with erratic behavior of customers

Time Horizon	SCV Management Strategies
Short-term	**Incentive system** • Implement an incentive system that leads the customer to proactively communicate demand changes that it observes in its customer demand **Buffer stock contracts** • Integrate buffer stocks in contractual agreements to increase delivery reliability for the customer and to secure profitability for the manufacturer
Mid-term	**Support of customer in its forecasting** • Data analysis of combined customer demand patterns to support customers in their forecasting based on a larger amount of data

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Time Horizon	SCV Management Strategies
	Joint communication and discussion of customer demand behavior with the customer • If customer regularly changes its demand to a certain extent (numerical boundaries must be defined), the manufacturer has to show the customer the consequences of its demand behavior • To better understand the customer's demand behavior and to adjust its own forecasts accordingly, insights into the sales of the customer as well as its planning processes are helpful • Joint analysis and discussion of gathered data **Frozen-zones** • Limit customer demand changes by implementing time windows where demand changes are not allowed
Long-term	**Dual sourcing** • Two suppliers for important components to increase flexibility in meeting customer demand changes

Table 17 – SCV management strategies dealing with high level of competition

Time Horizon	SCV Management Strategies
Mid-term	**Low cost as USP** • Differentiation from competitors by focusing on cost reduction **Innovation focus** • Stabilize market share by clear focus on innovative ideas **Product configurator** • Offering a product configurator to the customer that pretends to offer a high number of product variants, but that in fact involves a low number of components at the manufacturing site due to a sophisticated level of modularization • If not currently implemented in any form, rethinking of product development is necessary and requires know-how

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Time Horizon	SCV Management Strategies
Long-term	**Big Data market research approaches** • In cooperation with research institutes/universities • In-depth Big Data analysis of social media channels (Facebook, forums, blogs, etc.) to derive customer requirements • Obtaining a comprehensive picture of customer requirements assists in reducing the number of product variants → just produce what the customer needs, instead of hoping the customer will buy what you are offering **Strategic partnerships with competitors** • Partnership on large scale projects that are beneficial for all parties • Has been done in the past, but depends strongly on individuals **Increase innovation capabilities** • Focus on innovation assists in setting a company apart from its competitors

3.5 Implications

This study has sought to advance understanding on the mechanisms that cause SCV by assessing the sources of SCV according to their relative impact, building on an AHP among 17 SCM practitioners. In this way, the study aims to provide SC managers with insights on those SCV sources that should be prioritized when trying to manage SCV efficiently. In addition, building on an NGT group exercise with the same group, strategies are proposed for dealing with the sources of SCV which are identified as most impactful.

For managers, the study provides clear indications of the sources on which they should focus when trying to mitigate SCV. It can be observed that a considerable amount of SCV is generated by the manufacturer itself (*organizational volatility*). This is noteworthy, taking into account that self-induced volatility seems to be more manageable compared to volatility that is induced by SC partners, or the market in which the manufacturer is operating. Additionally, it appears that, for products with relatively short total lead-times, managers should focus more on mitigating *organizational volatility*, while managers handling products with comparatively long lead-times should focus on managing the dimension of *vertical volatility*.
In addition, the study investigated the relative impact of SCV sources according to a product's production strategy. The results indicate considerable differences between ETO, MTO, and

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MTS products. While manufacturers operating in an ETO environment should focus more on managing the *erratic behavior of customers* (e. g., short-term order changes on a regular basis) and a *high level of competition*, for MTO products, managers should implement strategies aimed at internally aligning the company first, before tackling sources appearing outside the focal firm. In contrast, for MTS products, *inaccurate forecasting* appears to be the most impactful source of SCV.

To assist managers in coping with SCV, we provide a set of 44 strategies for dealing with the six most impactful sources of SCV (*intra-organizational misalignment*, *inaccurate forecasting*, *long lead times*, *erratic behavior of decision makers in the supply chain*, *erratic behavior of customers*, and *high level of competition*), ranging from short-term solutions that require a comparatively short amount of time to implement, to time- and resource-intensive long-term strategic projects.

Among the identified strategies, a few core concepts and their respective strategies that were repeated by different sources throughout the group exercise stood out. First, transparency in several areas (internal and external) is necessary to initiate efficient actions for dealing with SCV, e. g., transparency about lead-time deviations caused by the supplier; departmental and company goals; contractual agreements with customers; forecasting models used and assumptions made; erratic customer demand behavior; and mistakes that have been made and the lessons that can be learned from them. Second, smart incentive systems can be set up, not only within the company, but also for suppliers and customers, to facilitate transparency. More specifically, certain incentives can trigger suppliers to communicate lead-time deviations well in advance, or for customers to change placed order less frequently; however, the configuration of such incentives remains unclear, and should be investigated further. Third, a continual improvement process should be implemented on a regular basis in several areas to challenge existing structures, such as processes, forecasting models, SC designs, and others. Fourth, to facilitate this improvement process, companies should change their mindset from blaming people for mistakes to a culture of errors, where mistakes are allowed once, but will be discussed openly to mitigate them in the long term.

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3.6 Conclusions and Limitations

By applying an AHP with a group of 17 practitioners of manufacturing firms with an average working experience of eight years, this study has sought to assess the relative impact of sources of SCV on SCV itself. This is further contextualized by analyzing this relative impact of SCV sources according to the total lead time of a product, while at the same time taking into account its production strategy, to guide managers more efficiently. Moreover, by applying the NGT with the same group of practitioners, a total of 44 strategies to deal with the six most impactful sources of SCV have been compiled to provide a set of guiding principles for managers who are aiming to manage SCV.

This is the first study that has sought to assess the relative impact of sources of SCV on SCV. While other studies have mostly stressed the multidimensionality and complexity of volatility in modern SCs (Christopher and Holweg, 2011, 2017), an assessment of the sources to provide assistance for managers has not previously been provided. However, due to its novelty, the study contains some limitations that need to be pointed out.

First, although it is suitable for an AHP application from a methodological point of view, the sample size of 17 practitioners is comparatively small, especially when it is further contextualized. This is why the results have to be understood as a first attempt at assessing the impact of sources of SCV in order to provide a guiding hand for SC managers. Nevertheless, further large-scale quantitative research is necessary to derive more reliable conclusions, additional insights, and to extend or refine the contextualization that has been made.

Second, AHP results are based on the participants' perceptions of the SCV sources and their relative impact on their businesses. Relationships that are not directly observable are not easy to detect with this type of approach. In order to investigate underlying mechanisms causing SCV that are not directly observable or completely understood by practitioners, further research is necessary.

Third, the assessment of sources and dimensions of SCV is based on the framework provided by Nitsche and Durach (2018). However, the dimension of *institutional and environmental*

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volatility was excluded from the analysis. Further research in this area should take this factor into account, and expand the assessment to all five dimensions to obtain a more holistic picture. Finally, this study constitutes a call for further research on SCV. Companies are challenged by volatility on a regular basis, but SCM research mostly focuses on managing catastrophic disruption risks, instead of providing guidance for managing the steady state of mismatching demand and supply variations. This study contributes to critical research on SCV, but it only scratches the surface, and SCV assessment requires further quantitative research.

Additionally, the implementation of the proposed SCV management strategies in a specific business environment remains a task for practice that can surely be assisted by further research on particular strategies.

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4. Article 3

Title:

"Development of a Benchmarking Instrument to Assess Supply Chain Volatility"

4.1 Introduction

Managing supply chain volatility (SCV) is one of the core challenges of modern supply chains (SCs) (Christopher and Holweg, 2011, 2017; Handfield et al., 2013; Wieland et al., 2016). Since volatility has been a challenge across several decades, researchers have, on the one hand, focused on describing the multidimensional sources of SCV and, on the other, developed management strategies for dealing with it. However, to efficiently manage volatility, SC managers need to assess the impact of those SCV sources on their particular SC first, before initiating management strategies (Nitsche, 2018).

In general, to continually manage unintended changes in material flows in a SC, managers need to regularly identify and understand the root cause, assess the impact on the SC, implement mitigation strategies, monitor changes, and learn from experience (Zsidisin et al., 2005). This supply chain business continuity planning process, originally proposed by Zsidisin et al. (2005), is widely accepted in the SC risk management literature, motivating researchers not only to identify strategies for dealing with risks, but also to develop different instruments to assess the specificity of risks to a SC (Aven, 2016).

Nevertheless, research on the assessment of SCV is sparse. Christopher and Holweg (2011, 2017) were the first to develop a SCV index that assesses the state of SCV from a macroeconomic point of view. However, a case-based evaluation of the current state of volatility of a product's supply chain, taking a microeconomic, focal firm point of view, is still lacking. If implemented, it could assist managers in implementing more target-oriented SCV management.

Based on this, the present study aims to develop an assessment instrument that enables SC managers to critically evaluate the current state of volatility of their products' SCs and identify concrete needs for action. The assessment is performed in such a way as to incorporate a means of benchmarking, not only to provide managers with an assessment of their SCV management performance, but also to show them how they perform against their competitors. Consequently, this study aims to satisfy the following research objectives (RO):

RO1: Identify appropriate measures to assess the state of SCV of a product's SC;

RO2: Propose a benchmarking instrument that assesses the state of SCV of a product's SC and benchmarks it against competitors;
RO3: Analyze the current state of SCV management.

To achieve this, the following section will provide theoretical background on benchmarking/performance measurement of SCs in general and on the concept of SCV. Next, the SCV assessment model is developed and presented. Based on that, the current state of SCV in the manufacturing industry will be analyzed and further contextualized based on a large-scale survey among 87 manufacturing firms aiming to propose industry benchmarks for the assessment model.

4.2 Theoretical Background

4.2.1 Benchmarking as a tool to assess performance of supply chains

In general, benchmarking is understood as an approach that involves comparing the performance of own activities in a certain field to those of others, with the aim of achieving superior performance (Camp, 1989). The process of benchmarking has to be repeated on a regular basis with the aim of continuously improving performance in order to stay competitive (Dattakumar and Jagadeesh, 2003). Benchmarking is also a commonly used tool in SCM because SC managers first need to measure performance in order to identify problems (Peng Wong and Yew Wong, 2008; Shafiee et al., 2014).

Because of the practical relevance of this approach, SCM researchers have developed numerous benchmarking tools. Some of them aim at assessing the performance of SCM in general (e. g., (Shafiee et al., 2014; Stewart, 1995; Supply Chain Council, 2008)), but there are also benchmarking models that specifically aim at measuring the performance in dedicated areas such as SC visibility (Caridi et al., 2010b), SC collaboration (Simatupang and Sridharan, 2004), green initiatives (Sangwan and Choudhary, 2018), carbon emissions (Acquaye et al., 2014), and others. An SC is understood as a complex system of interacting organizations, thus, although benchmarking started on an intra-organizational level, it has been expanded to an inter-organizational level incorporating other stakeholders (e. g., customers; suppliers) in the benchmarking process (Peng Wong and Yew Wong, 2008).

Due to the variety of SC performance evaluation models, Estampe et al. (2013) developed a taxonomy to characterize SC performance evaluation models based on the decision level affected (strategic, tactical, operational); type of flows analyzed (physical, informational, financial); level of supply chain maturity (intra-organizational, inter-organizational, extended inter-organizational, societal); type of benchmarking (internal, external); contextualization; quality factors; human capital; and sustainability. This taxonomy will be used to characterize the SCV assessment tool developed here.

However, in order to establish a benchmark, appropriate qualitative and/or quantitative performance measures have to be defined that characterize the focus of the benchmark (Beamon, 1999; Chan, 2003). Therefore, the next section provides an introduction to and conceptualization of SCV to better derive suitable measures for assessing SCV.

4.2.2 Conceptualization of supply chain volatility

Although research on volatility in SCs has been described as one of the most important tasks of SCM research today (Wieland et al., 2016), SCV is not a novel phenomenon. Indeed, research on SCV started with the discovery of the *Forrester Effect* (Forrester, 1958), later known as the *Bullwhip Effect* (BWE) (Lee et al., 1997), which initiated a wide-ranging discussion on how to handle volatile material flows in a SC. However, the *Bullwhip Effect* does not explain the origin of SCV in full (Kim and Springer, 2008; Nitsche and Durach, 2018). Numerous researchers have investigated different sources of volatility, such as unpredictable changes in demand, variable lead times, insufficient quality of supplied materials, highly innovative markets, and others.

Nitsche and Durach (2018) were the first researchers to attempt to synthesize this research on sources of volatility in a study that combined a large-scale literature review with practitioner insights to propose a novel conceptualization of SCV that forms the basis of this research. According to the authors, SCV is caused by 20 different sources that contribute to five distinct dimensions of SCV: *organizational*, *vertical*, *behavioral*, *market-related* and *institutional and environmental volatility*.

First, *organizational volatility* includes that part of SCV that is induced by the focal firm itself (e. g., due to intra-organizational misalignment, inaccurate forecasting, or self-induced price variations). Second, *vertical volatility* is induced by sources appearing endogenous, including

SC partners (e. g., long lead times, supply variability, missing SC visibility). Third, *behavioral volatility* is understood as the part of SCV that is induced by certain behavioral patterns of individuals in the SC that cause unintended volatile material flows along the SC. More precisely, *behavioral volatility* is caused by two sources: erratic behavior of decision makers in the SC (e. g., order batching or readjustment of plans) and erratic behavior of customers (e. g., short-term demand changes). Fourth, *market-related volatility* is induced by the market the focal firm is positioned in (e. g., highly innovative products, high level of competition, seasonality). Fifth, *institutional and environmental volatility* is induced by sources appearing exogenous to the SC (e. g., national economic and financial instability, political and legal instability) that are most likely very hard for the focal firm itself to control (Nitsche and Durach, 2018).

Based on this conceptualization, Nitsche (2018) subsequently assessed the impact of those sources and dimensions on SCV, although excluding the fifth dimension due to its high context dependency. Consequently, it was proposed that *intra-organizational misalignment*, *inaccurate forecasting*, *long lead times*, *erratic behavior of decision makers in the SC*, *erratic behavior of customers* and *high level of competition* are the six most impactful sources of SCV.

4.3 Development of a Benchmarking Instrument to Assess Supply Chain Volatility

4.3.1 Introduction to the benchmarking instrument

In order to set the conceptual constraints of this study and the developed instrument, we first apply the taxonomy of Estampe et al. (2013), developed to guide SC managers who require an instrument to assess the state of SCV in their products' SCs. The decision level affected is strategic as well as tactical, since the benchmarking instrument seeks to assist managers in critically assessing their SC structures and adjusting them in the medium and long term. The types of flow investigated are mainly physical, because SCV results in a mismatch of supply and demand side material flows at the focal firm (Nitsche and Durach, 2018), but informational flows are also affected and investigated. Although the developed instrument assesses SCV of a product's SC at the focal firm, the level of SC maturity has to be understood as inter-organizational since it includes data directly connected to suppliers and also customers. The type of benchmarking is external because the user of the benchmarking instrument will benchmark the volatility of its product's SC against the performance of other manufacturers according to different dimensions of SCV. With regard to the contextualization of the developed

instrument, it should be noted that it has been developed specifically for use in manufacturing companies. Quality management aspects and human resource management, as well as sustainability initiatives, are outside the scope of the benchmarking instrument (Estampe et al., 2013).

4.3.2 Measures to assess supply chain volatility

In order to assess the level of volatility of a product's SC, it was first necessary to define appropriate measures. Therefore, the study builds upon the conceptualization of Nitsche and Durach (2018) with the aim of assessing the state of volatility for the first four dimensions of SCV. The fifth dimension of SCV – *institutional and environmental volatility* – was excluded from the benchmarking instrument due to its high context dependency, as argued by Nitsche (2018). Moreover, to make the practical application of the instrument more feasible, we decided to limit the number of variables for each dimension. Therefore, the measurement of each dimension focuses on the most pressing sources of volatility in the respective dimension, as proposed by Nitsche (2018). Development of the model followed an iterative process. Variables that had been identified as suitable for measuring certain sources of SCV were subsequently refined incorporating feedback from two additional researchers and one practitioner. All variables for the benchmarking instrument will be further described in the following sub-sections.

4.3.2.1 Organizational volatility

Organizational volatility is mainly caused by *intra-organizational misalignment* and *inaccurate forecasting* (Nitsche, 2018). Based on a survey among 88 manufacturing companies, Wagner et al. (2014) investigated how companies can align their organization by means of sales and operations planning (S&OP). Building on this, they proposed an S&OP maturity model that outlines the different areas of intra-organizational alignment as well as the embodiment of each maturity level. Based on that, in the proposed benchmarking instrument, *intra-organizational misalignment* will be measured qualitatively via six distinct characteristics of organizational alignment (formality of the planning process, promotions planning integration, information availability and exchange, planning efficiency, assignment of roles and responsibilities, and integration of planning systems) using the proposed maturity level descriptions of Wagner et al. (2014), as shown in Table 18. The rating of those maturity levels is performed, via a self-assessment by the user of the benchmarking instrument, on a scale from 1 (low maturity level) to 7 (high maturity level). Descriptions for maturity levels 1, 4 and 7 are given (see Table 18),

but the user is also free to choose intermediate maturity levels. It has to be stated that, for all qualitative variables of the benchmarking instrument, it is recommended that different perspectives from different relevant departments of the manufacturer are included in this self-assessment process.

In general, there are multiple measures to assess the accuracy of a forecast in SCM (Hyndman and Koehler, 2006; Kerkkänen et al., 2009). One of the more commonly proposed measures is the mean absolute percentage error (MAPE) (Bowerman et al., 2005; Mentzer and Moon, 2005). This is also often used by practitioners and, in addition, was considered appropriate by other benchmarking studies (Weller and Crone, 2012). To assess the level of inaccuracy in forecasting, the benchmarking instrument includes the MAPE one, three and six month ahead on product variant and product family levels, as shown in Table 18.

Table 18 – Variables to assess organizational volatility

	variable name	type of variable	description
intra-organizational misalignment	OA_1	$\mathbb{Z}$ [1;7]	*level of planning process formality* 1: no formalized planning process 4: moderately formalized planning process 7: internally completely formalized planning process
	OA_2	$\mathbb{Z}$ [1;7]	*level of promotions planning integration* 1: no promotions and price changes planned 4: issues like promotions and price changes are planned and considered but insufficiently performed 7: issues like promotions and price changes are planned and considered sufficiently throughout the whole organization
	OA_3	$\mathbb{Z}$ [1;7]	*efficiency of information availability and exchange* 1: Information is only partially available including many redundancies 4: partially centralized information storage; moderate friction losses in information flows 7: people receive only information they actually need; no friction losses in cross-departmental information flows
	OA_4	$\mathbb{Z}$ [1;7]	*level of planning efficiency* 1: no alignment of plans throughout the company 4: due to rudimentary alignment of plans, frequent re-planning is required 7: due to sufficient alignment of plans, re-planning becomes very rare

	variable name	type of variable	description
	OA_5	$\mathbb{Z}$ [1;7]	*level of assignment of roles and responsibilities* 1: no concrete assignment of roles and responsibilities with regard to planning tasks and activities 4: roles and responsibilities are clearly defined but not yet successfully implemented; no dedicated planning process owner; people partially held accountable for their plans and performance 7: dedicated planning organization responsible for planning process owner and role descriptions; planning organization entirely aligned with the business
	OA_6	$\mathbb{Z}$ [1;7]	*level of integration of planning systems of different business functions* 1: heterogeneous spreadsheets existent and in use 4: information from other systems need to be manually entered or uploaded (no interfaces) 7: one integrated system with one single version of truth
inaccurate forecasting	MAPE1f	$\mathbb{R}$ [0;1]	1-month-ahead MAPE (family level)
	MAPE3f	$\mathbb{R}$ [0;1]	3-month-ahead MAPE (family level)
	MAPE6f	$\mathbb{R}$ [0;1]	6-month-ahead MAPE (family level)
	MAPE1v	$\mathbb{R}$ [0;1]	1-month-ahead MAPE (product variant level)
	MAPE3v	$\mathbb{R}$ [0;1]	3-month-ahead MAPE (product variant level)
	$MAPE6_V$	$\mathbb{R}$ [0;1]	6-month-ahead MAPE (product variant level)

4.3.2.2 Vertical volatility

Although *long lead times* have been identified as the most impactful source of *vertical volatility*, it was decided to incorporate the source of *variable lead times* into the benchmarking instrument since the length of lead time has to be assessed in combination with its variability in the context of SCV (Nitsche, 2018; Nitsche and Durach, 2018).

To benchmark the SCV source of *long lead times* from a manufacturer's point of view, the user will be asked to state the supplier lead time (period of time between ordering a component at the supplier and the supplier having it ready for shipment) for suppliers of A-level components (based on a traditional ABC analysis) belonging to the product as well as their transportation lead time (period of time between having the component picked at the supplier and having it transported to the designated production site). Additionally, the average production lead time of the final product as well as the delivery lead time (period of time between shipping a

customer order and having it received by the customer) to the manufacturer's A-level customers has to be defined.

Although long lead times induce SCV, they could be manageable if lead times are always accurate and therefore plannable. In reality, real-world SC lead times vary, making the planning process inaccurate, which consequently causes SCV. To include this aspect in the SCV benchmarking instrument, the source of *variable lead times* will also be assessed. Therefore, the on-time delivery rate (OTDR, percentage of goods delivered on time (Chan, 2003)) of suppliers of A-level components of the product as well as the OTDR to the A-level customers has to be stated as an indicator of *variable lead times*. Additionally, the spread of lead times at the supply side is benchmarked by asking the user to indicate, for the majority of deliveries (set at 95 %), the minimum and maximum times required to order them from the supplier and have them shipped to and received at the production site. The necessary variables to assess the level of *vertical volatility* are outlined in Table 19.

Table 19 – Variables to assess vertical volatility

	variable name	type of variable	description
long lead times	LTS_i	$\mathbb{R}$ [0;∞[	supplier lead time of supplier *i* in days
	LTT_i	$\mathbb{R}$ [0;∞[	transportation lead time from supplier *i* in days
	LTP	$\mathbb{R}$ [0;∞[	production lead time in days
	LTC_j	$\mathbb{R}$ [0;∞[	delivery lead time to customer *j* in days
variable lead times	$OTDS_i$	$\mathbb{R}$ [0;1]	on-time delivery rare of supplier *i*
	$OTDC_j$	$\mathbb{R}$ [0;1]	on-time delivery rate to customer *j*
	SP_i	$\mathbb{R}$ [0;∞[	time window of arrival of majority of goods (95 %) of supplier *i* (*longest time span − shortest time span between ordering and receiving a good*)

4.3.2.3 Behavioral volatility

Behavioral volatility is induced by *erratic behavior of customers* as well as *erratic behavior of decision makers in the SC* (Nitsche and Durach, 2018). Both sources have been ranked among the most pressing sources of SCV by SC managers (Nitsche, 2018). To assess both sources, qualitative measures have been defined for the user of the benchmarking instrument to rate via a self-assessment exercise.

Table 20 – Variables to assess behavioral volatility

	variable name	type of variable	description (self-assessment, indicate to what extend you agree to the following statement, 1(totally disagree) to 7 (totally agree)
erratic behavior of customers	EBC_1	$\mathbb{Z}$ [1;7]	In general, our customer demand is very hard to predict.
	EBC_2	$\mathbb{Z}$ [1;7]	Market trends are difficult to monitor because customer preferences change constantly.
	EBC_3	$\mathbb{Z}$ [1;7]	Our customers often adjust already placed orders.
	EBC_4	$\mathbb{Z}$ [1;7]	Customer loyalty to our brand is relatively low and the customer changes its preferences constantly.
	EBC_5	$\mathbb{Z}$ [1;7]	Our customers often adjust orders (quantities or other specifications) in a short time window before planned delivery.
erratic behavior of decision makers in the SC	EBD_1	$\mathbb{Z}$ [1;7]	At the end of the year we order more than we actually need to get a cash-back from our supplier.
	EBD_2	$\mathbb{Z}$ [1;7]	Sometimes we order more than actually needed in order "to be safe".
	EBD_3	$\mathbb{Z}$ [1;7]	Sometimes we order less than actually needed in order to reduce our safety stock level.
	EBD_4	$\mathbb{Z}$ [1;7]	Due to lack of confidence in our IT system we adjust order quantities that are generated by the system based on personal experience.
	EBD_5	$\mathbb{Z}$ [1;7]	Due to lack of confidence in our IT system we adjust forecasts that are generated by the system based on personal feelings.
	EBD_6	$\mathbb{Z}$ [1;7]	When we expect a shortage of a component (not clear yet), we order more than actually needed.
	EBD_7	$\mathbb{Z}$ [1;7]	Sales people place customer orders early in advance before an actual customer order exists.
	EBD_8	$\mathbb{Z}$ [1;7]	If the actual demand in one month is higher or lower than planned demand, we immediately adjust our future plans.
	EBD_9	$\mathbb{Z}$ [1;7]	If we expect a price increase in the near future, we order more than we actually need to benefit from the current price.

Erratic behavior of customers is characterized by unpredictable customer demand that causes a supply and demand mismatch at the focal firm (Childerhouse et al., 2008; Germain et al., 2008). This can be caused by changing customer preferences, fads, short-term order changes or cancellations, and others (Childerhouse et al., 2008; Germain et al., 2008; Johnson, 2001; So and Zheng, 2003; Van der Vorst et al., 1998). *Erratic behavior of decision makers in the supply*

chain involves decisions that are perceived as irrational from the recipient's point of view (Nitsche, 2018) because they induce volatility along the supply chain. This can be caused by overreactions to certain demand signals (e. g., higher orders than usual, expected shortages), forward buying, ordering more than needed, drastically reducing safety stocks, and others (Lee, 2002; Lee et al., 1997; Nienhaus et al., 2006; Nyoman Pujawan, 2004; Wong and Hvolby, 2007). The variables chosen to measure SCV caused by both sources are depicted in Table 20.

4.3.2.4 Market-related volatility

Prior research evaluated *high level of competition* as the most important source of *market-related volatility* (Nitsche, 2018). Fierce competition is, inter alia, characterized by a high number of product variants offered by the focal firm itself and/or a high number of substitutes offered at the market (Randall and Ulrich, 2001; Taylor and Fearne, 2009), leading to greater demand volatility at the single part level. Additionally, if competitors are fighting for the same source of supply, a consequence can be volatile material flows originating on the supply side (Nitsche, 2018).

Table 21 outlines the qualitative variables chose for assessing the dimension of *market-related volatility*.

Table 21 – Variables to assess market-related volatility

	variable name	**type of variable**	**description** (self-assessment, indicate to what extend you agree to the following statement, 1(totally disagree) to 7 (totally agree)
high level of competition	HC_1	$\mathbb{Z}$ [1;7]	We often lose customers to our direct competitors.
	HC_2	$\mathbb{Z}$ [1;7]	We are forced to an intense price competition with our competitors.
	HC_3	$\mathbb{Z}$ [1;7]	We often have to rely on the same suppliers as our direct competitors.
	HC_4	$\mathbb{Z}$ [1;7]	In our market, it is difficult for us to differentiate ourselves from our competitors.
	HC_5	$\mathbb{Z}$ [1;7]	We offer a high number of product variants of our representative product.
	HC_6	$\mathbb{Z}$ [1;7]	There is a high number of substitutes for our representative product at the market.

4.3.3 Benchmarking instrument

The basic idea of the benchmarking instrument is that a user who would like to assess SCV affecting a product's SC will benchmark his volatility management performance against others. Therefore, he inserts data that have previously been collected and this is subsequently

benchmarked against data from other manufacturers with the objective of identifying areas on which to focus when trying to manage volatility. SCV is a reality in all supply chains and cannot be completely eradicated. However, in order to stay competitive, managers need to know in what areas their volatility management performance is worse than the performance of others in order to initiate purposeful management measures. The benchmark that builds the basis for this instrument was developed through an online survey with 87 participating manufacturing firms from different industries. Based on their feedback, a user of the benchmarking instrument can assess the SCV of their product's SC.

The assessment itself is done through a weighted scoring model that calculates volatility scores from 1 (low volatility) to 10 (high volatility) for four dimensions of SCV as well as an overall SCV score for the product's SC. In this way, the user will be enabled to dig deeper into the assessment, seeking to identify certain areas on which to focus when managing SCV. Figure 14 provides a schematic representation of the general structure of the benchmarking instrument. Every input variable has to be benchmarked using the benchmarking tables (see Table 24 and Table 25). Therefore, the user has to check which group the input variable has to be assigned to and choose the corresponding score. The calculation of the output scores of the volatility dimensions as well as the overall SCV score will be further described in the following sub-sections.

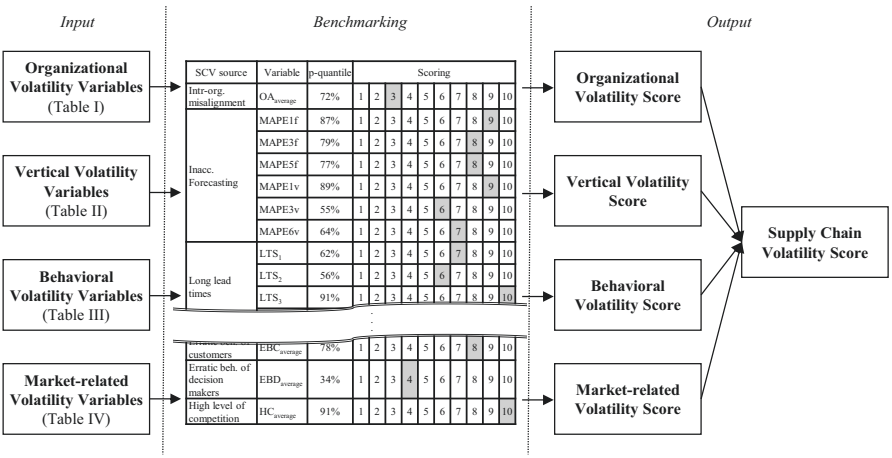

Figure 14 – Exemplary schematic representation of the structure of the benchmarking instrument

4.3.3.1 Organizational Volatility Score

The *Organizational Volatility Score* (SC_{OV}) is calculated as the mean of the sub-scores for *intra-organizational misalignment* (SC_{OA}) and *inaccurate forecasting* (SC_{MAPE}):

$$SC_{OV} = 0.5 \cdot SC_{OA} + 0.5 \cdot SC_{MAPE} \quad (1)$$

The SC_{OA} is derived from the benchmarking of the mean of the input variables OA_1 to OA_6. The SC_{MAPE} results from the benchmarking of MAPE variables described in Table 18. In general, a lower MAPE one month ahead is of higher importance in the context of SCV than a low six month ahead MAPE, since more expensive measures have to be undertaken to match supply and demand in the short term (e. g., special freight, higher stock expenses). Hence, to calculate the SC_{MAPE} a weighting is applied to incorporate the higher importance of a short-term MAPE over a mid-term MAPE into the SC_{MAPE} calculation:

$$SC_{MAPE} = 0.3 \cdot SC_{MAPE1f} + 0.3 \cdot SC_{MAPE1v} + 0.15 \cdot SC_{MAPE3f} + 0.15 \cdot SC_{MAPE3v} + 0.05 \cdot SC_{MAPE6f} + 0.05 \cdot SC_{MAPE6v} \quad (1.1)$$

Without a doubt, the weighting itself can be questioned, since it is not based on prior research, but the higher impact of a poor short-term MAPE over a poor mid-term MAPE has been stated by multiple practitioners who were involved throughout the process. Nevertheless, in certain circumstances where a six month ahead MAPE is of high importance, this weighting can be adjusted by the user of the benchmarking instrument.

4.3.3.2 Vertical Volatility Score

Not only will the user of the benchmarking instrument be enabled to assess the level of volatility that is induced by the company itself, as in the case of the SC_{OV}, but the instrument will also enable the assessment of the effect of certain members in the supply chain (e. g., suppliers, customers) on SCV. The *Vertical Volatility Score* (SC_{VV}) is calculated as the mean of the two sub-scores of the assessment of *long lead times* (SC_{LLT}) and *variable lead times* (SC_{VLT}):

$$SC_{VV} = 0.5 \cdot SC_{LLT} + 0.5 \cdot SC_{VLT} \quad (2)$$

To assess SCV induced by *long lead times* (SC_{LLT}), different input variables have been defined, as shown in Table 19. SC_{LLT} itself incorporates four sub-scores for the impact of supplier lead

time (SC_{LTS}), transportation lead time (SC_{LTT}), production lead time (SC_{LTP}), and delivery lead time (SC_{LTC}).

In general, those four lead times sum up to the supply chain lead time (t_{total}), the time span between ordering components at a supplier and having the final product shipped to the customer. The longer the lead time gets, the more devastating the effects on SCV become. This being said, it is proposed to weight the sub-scores by the share of their respective lead time on the total supply chain lead time. It is therefore proposed to use the median values of all supplier lead times (t_{LTS}), transportation lead times (t_{LTT}), production lead times (t_{LTP}), and delivery lead times (t_{LTC}) and relate them to the median total supply chain lead time of the products SC (t_{total}):

$$SC_{LLT} = \frac{t_{LTS}}{t_{total}} \cdot SC_{LTS} + \frac{t_{LTT}}{t_{total}} \cdot SC_{LTT} + \frac{t_{LTP}}{t_{total}} \cdot SC_{LTP} + \frac{t_{LTC}}{t_{total}} \cdot SC_{LTC} \quad (2.1)$$

To calculate the sub-scores SC_{LTS} and SC_{LTT} it is proposed to weight the scores for each supplier by the share of purchasing volume of supplier *i* (ps_i) in the total purchasing volume for the assessed product (ps_{total}). The same will be applied for SC_{LTC}, where the score of each customer will be weighted by the share of the sales volume of the customer (pc_j) in the total sales volume of the investigated product (pc_{total}). The sub-score for the production lead time (SC_{LTP}) results from the benchmarking of the product's production lead time (LTP) using the benchmarking tables (see Table 24 and Table 25) independently from suppliers or customers.

$$SC_{LTS} = \sum_i \left(\frac{ps_i}{ps_{total}} \cdot SC_{LTS_i} \right) \quad (2.1.1)$$

$$SC_{LTT} = \sum_i \left(\frac{ps_i}{ps_{total}} \cdot SC_{LTT_i} \right) \quad (2.1.2)$$

$$SC_{LTC} = \sum_j \left(\frac{pc_j}{pc_{total}} \cdot SC_{LTC_j} \right) \quad (2.1.3)$$

The assessment of volatility induced by *variable lead times* (SC_{VLT}) includes three sub-scores, in particular for the on-time delivery rate of suppliers (SC_{OTDS}), the on-time delivery rate to customers (SC_{OTDC}), and for time window of incoming deliveries (SC_{SP}). SC_{VLT} will be calculated as the mean of those three sub-scores.

$$SC_{VLT} = \frac{1}{3} \cdot SC_{OTDS} + \frac{1}{3} \cdot SC_{OTDC} + \frac{1}{3} \cdot SC_{SP} \quad (2.2)$$

As previously explained, the scores of each supplier for SC_{OTDS} and SC_{SP} will be weighted by the share of the purchasing volume of the supplier in the total purchasing volume. Consequently, the SC_{OTDC} for each customer will be weighted by the share of sales volume of the customer in the total sales volume of the investigated product:

$$SC_{OTDS} = \sum_i \left(\frac{ps_i}{ps_{total}} \cdot SC_{OTDS_i} \right) \quad (2.2.1)$$

$$SC_{OTDC} = \sum_j \left(\frac{pc_j}{pc_{total}} \cdot SC_{OTDC_j} \right) \quad (2.2.2)$$

$$SC_{SP} = \sum_i \left(\frac{ps_i}{ps_{total}} \cdot SC_{SP_i} \right) \quad (2.2.3)$$

In providing all the inputs described, the user of the tool will be enabled not only to assess vertical volatility in their product's SC, but also to assess which supplier or customer contributes most to the volatility that affects their product's SC.

4.3.3.3 Behavioral Volatility Score

The *Behavioral Volatility Score* (SC_{BV}) is calculated as the mean of the two sub-scores for *erratic behavior of customers* (SC_{EBC}) and *erratic behavior of decision makers* (SC_{EBD}). Those sub-scores themselves result from the benchmarking of the mean of the input variables EBC and EBD, as described in Table 20.

$$SC_{BV} = 0.5 \cdot SC_{EBC} + 0.5 \cdot SC_{EBD} \quad (3)$$

4.3.3.4 Market-related Volatility Score

To assess market-related volatility, the source of *high level of competition* is measured via a qualitative self-assessment of six variables as described in

Table *21*. Thus, the *Market-related Volatility Score* (SC_{MV}) results from the benchmarking of the mean of those input variables.

4.3.3.5 Supply Chain Volatility Score

To calculate the total SCV score (SC_{SCV}) of a product, SC, SC_{OV}, SC_{VV}, SC_{BV}, and SC_{MV} are necessary. As proposed by Nitsche (2018), the corresponding four volatility dimensions do not impact SCV equally. Based on an AHP among SC practitioners, Nitsche (2018) assessed the impact of those four dimensions on SCV. In addition, he contextualized this impact by the production strategy of the manufacturing firm and proposed that the impacts of those four dimensions differ significantly between make to order and make to stock supply chains.

Building on these findings, it is prosed to apply Nitsche's (2018) proposed weightings to calculate SC_{SCV}, and the weighing factor α is therefore introduced. The user of the benchmarking instrument has to decide whether he wants to apply the overall weighting factors including all production strategies (including engineer to order), or the weighting factors for either make to order or make to stock production strategies, as proposed by Nitsche (2018). The corresponding weightings are outlined in Table 22.

Table 22 – Weighting factors for the calculation of the overall SCV score

weighting factor	independent from production strategy	make to order production strategy	make to stock production strategy
α_{OV}	0.341	0.451	0.277
α_{VV}	0.276	0.296	0.234
α_{BV}	0.203	0.168	0.187
α_{MV}	0.179	0.085	0.301

Consequently, SC_{SCV} is calculated as the sum of dimensional volatility scores multiplied by their corresponding weighting factor:

$$SC_{SCV} = \alpha_{OV} \cdot SC_{OV} + \alpha_{VV} \cdot SC_{VV} + \alpha_{BV} \cdot SC_{BV} + \alpha_{MV} \cdot SC_{MV} \quad (4)$$

4.4 Current State of Supply Chain Volatility Management Performance

4.4.1 Sample description

To gather required benchmarking data, a survey among manufacturing firms operating in different industries was conducted from June to July 2018. This was intended to cover a heterogeneous group drawn from different types of manufacturing firms. To complete the survey, participants first had to fill in general company-related data and afterwards had to think of a representative product that is manufactured by their company and that they know very well. Subsequently, all questions were asked with reference to the representative product. In total, 87 responses were collected from different manufacturing industries, mainly from the machinery/equipment, automotive, consumer goods, and chemicals/pharmaceuticals sectors. The surveyed products mostly had make to order/assemble to order and make to stock production strategies, and their production sites were mostly located in western Europe. The sample demographics are outlined in Table 23.

Table 23 – Sample demographics of SCV benchmarking

Company-related								Product-related					
Manufacturing industry		**SC position ***		**Total annual turnover**		**number of employees**		**Production strategy ****		**Turnover with the product *****		**Location of main production site**	
Consumer goods	15	OEM	54	up to 50m €	6	up to 50	0	Make to order/ assemble to order	44	1–10 m €	9	Western Europe	65
Chemicals/ pharmaceuticals	13	Module/ system supplier (1st tier)	29	51–250m €	11	51–250	6	Make to stock	33	11–100 m €	24	Eastern Europe	4
Automotive	20	Component supplier (2nd tier)	12	251–500m €	11	251–500	7	Engineer to order	9	101–250 m €	14	China	10
Electronics	8	Standardized parts supplier (3rd tier)	2	501–1000m €	12	501–1000	7			251–500 m €	10	South East Asia	3
Machinery/ equipment	23	Raw material supplier (n-th tier)	6	1–2.5bn €	11	1001–2500	10			501–1000 m €	7	USA/Canada	1
Others	8			2.5–5bn €	6	2501–5000	11			>1 bn €	20	Others	4
				5–10bn €	10	5001–10000	10						
				more than 10bn €	20	more than 10000	36						

(* multiple answers possible; ** one participant refused to answer; ***three participants refused to answer)

4.4.2 Benchmarking results

Table 24 outlines the benchmarking results of all questionnaire participants. The average, median, and distribution of variables are detailed. The categories for the corresponding volatility scores are ranked in ten quantiles (deciles), meaning that the best values are assigned to the best decile and given the lowest volatility score of 1, going up to a volatility score of 10 for the worst values assigned to the worst decile. Values that are very frequently represented sometimes form two or even three deciles. This means that the user must use the average of the respective scores for benchmarking.

It can be observed that best-in-class companies in the area of organizational alignment assess themselves with average scores of above 5.5 (on a 7-point Likert scale), while the worst companies scored mean values below 3.27 for the six categories of organizational alignment.
For the SCV source of *long lead times*, the biggest share in the total lead time is associated with the supplier lead time (LTS), meaning that this area should be prioritized when trying to mitigate SCV originating from long lead times in the SC. Companies with an average of above

110 days of LTS for their main components form the worst decile of the companies investigated. Best-in-class companies achieve very low LTS for their main components of below five days. Although the median of on time delivery rates on the supply and demand sides (OTDS and OTDC) are 90 percent and 92 percent, respectively, the best companies demonstrate delivery reliabilities above 99 percent.

Table 24 – Benchmarking table including all production strategies

					Volatility Score									
					Best in class		Advanced		Typical		Catch up		Latecomer	
SCV dimension	**SCV source**	**Input Variable**	**Average**	**Median**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Organizational Volatility	intra-org. misalignment	OAavrg	4.64	4.67	>=6.17	>5.5	>5.2	>5	>4.67	>4.5	>4	>3.83	>3.27	<=3.27
	inaccurate forecasting	MAPE1f	9.27	6.00	<=2	<4.8	<5		<6	<10		<11.8	<20	>=20
		MAPE3f	15.67	15.00	<=5	<6.6	<10		<15	<18	<20	<22	<30	>=30
		MAPE6f	22.58	20.00	<=5	<10	<11.2	<15	<20	<25	<30	<33	<40	>=40
		MAPE1v	10.86	10.00	<=2.3	<3.6	<5	<6.4	<10		<10.1	<15	<20	>=20
		MAPE3v	17.98	15.00	<=5	<8	<10		<15	<20	<21.2	<30	<34.2	>=34.2
		MAPE6v	24.92	23.00	<=8	<10	<12.9	<15.4	<23	<28	<34.1	<40	<50	>=50
Vertical Volatility	Long lead times	LTS	50.48	30.00	<=5	<12.8	<20	<28.8	<30	<46.8	<60	<78.4	<110.8	>=110.8
		LTT	11.04	5.00	<=1	<2	<3	<4	<5		<7.2	<13.4	<32.4	>=32.4
		LTP	25.06	7.00	<=0.6	<1	<3	<5	<7	<10	<17	<30	<73.6	>=73.6
		LTC	8.72	4.00	<=1	<2		<3	<4	<5	<7.3	<10	<20.7	>=20.7
	variable lead times	OTDS	81.18	90.00	>=97	>95	>90.8	>90		>84.86	>80	>75	>52	<=52
		OTDC	87.28	92.00	>98.9	>98	>95	>94.6	>92	>90		>81	>70.5	<=70.5
		SP	39.04	25.00	<=4	<6.8	<11	<16.2	<25	<30	<40	<48.4	<94	<=94
Behavioral Volatility	erratic behavior of customers	EBCavrg	3.62	3.60	<=2	<2.6	<3	<3.28	<3.6	<3.8	<4.2	<4.6	<5.2	>=5.2
	erratic behavior of DM	EBDavrg	3.73	3.89	<=2.44	<2.78	<3.31	<3.6	<3.89	<4.07	<4.33	<4.44	<4.93	>=4.93
Market-related Volatility	high level of competition	HCavrg	4.22	4.17	<=2.87	<3.33	<3.83	<4	<4.17	<4.5	<4.67	<5	<5.5	>=5.5

For sources of *behavioral volatility*, the majority of participants rank themselves with scores below 4 (7-point Likert scale), meaning that a high level of erratic behavior of decision makers as well as erratic behavior of customers is not a given in all supply chains. However, companies with erratic behavior scores of above 5 rank among the worst in class, resulting in a high level of SCV originating from the behavioral dimension.

A more detailed assessment of the benchmarking values, analyzed according to the production strategies for the products of the participating manufacturing firms, is outlined in Table 25. Although values do not differ immensely, it can be observed that MTO companies seem to have better intra-organizational alignment that MTS companies. This result stands in contrast to

previous findings of Nitsche (2018), who proposed that companies with make to order production strategies are exposed to a high degree of intra-organizational misalignment since intra-organizational processes for MTO products are not as well defined as for MTS products. With regard to forecasting, it is interesting to see that, based on the median values, MTS companies seem to perform better than or as well as MTO companies one month in advance on a product family and variant level. However, three and six months in advance, MTO companies achieve better MAPE values, in some cases significantly so, than MTS companies.

Table 25 – Benchmarking table for make to order und make to stock production strategies

						Volatility Score									
						Best in class		Advanced		Typical		Catch up		Latecomer	
SCV dimension	**SCV source**	**Input Variable**	**Production Strategy**	**Average**	**Median**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Organizational Volatility	intra-org. misalignment	OAavrg	MTO	4.77	5.00	>=6.33	>5.67	>5.35	>5	>5	>4.5	>4.33	>4	>3.55	<=3.55
			MTS	4.45	4.67	>=5.67	>5.33	>5	>4.83	>4.67	>4.33	>4	>3.47	>3.03	<=3.03
	inaccurate forecasting	MAPE1f	MTO	9.71	8.00	<=2		<5		<8		<10		<22	>=22
			MTS	9.32	5.00	<=3.4	<4	<5			<10		<17.6	<20	>=20
		MAPE3f	MTO	15.81	15.00	<=6.2	<10		<12	<15	<16.8	<20		<30	>=30
			MTS	16.38	16.50	<=5	<6	<7.8	<10	<16.5	<20	<22	<25	<28.5	>=28.5
		MAPE6f	MTO	23.65	20.00	<=6	<10	<12.5	<18	<20	<25	<30	<40	<45	>=45
			MTS	22.63	23.00	<=5	<7.2	<11.8	<15	<23	<26.6	<30	<30	<38.5	>=38.5
		MAPE1v	MTO	10.57	10.00	<=2.5	<5		<8	<10			<14.7	<15	>=15
			MTS	11.88	10.00	<=3	<3	<5	<6	<10	<10.4	<14.8	<20	<23	>=23
		MAPE3v	MTO	17.04	15.00	<=7	<10		<15			<20		<30	>=30
			MTS	20.29	19.00	<=5	<7.2	<9.8	<10.4	<19	<24.6	<30	<30.4	<38.5	>=38.5
		MAPE6v	MTO	24.96	20.00	<=7	<10	<15	<18	<20	<25	<37	<40	<50	>=50
			MTS	26.38	30.00	<=8	<10	<12	<21.8	<30	<30	<35.5	<40	<48.5	>=48.5
Vertical Volatility	Long lead times	LTS	MTO	49.05	40.00	<=4.65	<14	<20	<26	<40	<49.6	<60	<79.2	<104	>=104
			MTS	45.17	30.00	<=10	<13.5	<20	<27.4	<30	<31	<47	<60	<100	>=100
		LTT	MTO	7.43	5.00	<=1	<2	<2.9	<3		<5		<7.4	<13.1	>=13.1
			MTS	14.36	5.00	<=1.2	<2	<3	<4	<5	<7.6	<12	<26	<44	>=44
		LTP	MTO	22.71	5.00	<=0.29	<1	<1.9	<5		<7.12	<14	<20.4	<60	>=60
			MTS	18.66	5.00	<=1	<2	<3	<5		<7	<16	<28.8	<64	>=64
		LTC	MTO	7.39	3.00	<=1	<1.64	<2	<2.8	<3	<5	<5.72	<10	<18.8	>=18.8
			MTS	8.18	4.00	<=2	<2		<3	<4	<5	<10		<25	>=25
	variable lead times	OTDS	MTO	81.84	85.00	>=95	>92.6	>90	>90	>85	>84.04	>80	>75	>60	<=60
			MTS	84.15	90.00	>=98	>97	>95	>90.8	>90	>88	>80	>79	>63.5	<=63.5
		OTDC	MTO	89.30	90.00	>=99	>98	>95	>92.2		>90		>85	>76	<=76
			MTS	88.58	94.00	>=98	>98	>97	>95	>94	>93	>90	>85	>75	<=75
		SP	MTO	38.33	25.50	<=3	<6	<9.5	<15	<25.5	<30	<42.5	<50	<80.5	<=80.5
			MTS	34.29	25.00	<=7	<10.6	<15	<17.6		<25	<31.2	<40	<67	<=67
Behavioral Volatility	erratic behavior of	EBCavrg	MTO	3.73	3.40	<=2.4	<2.72	<2.8	<3.2	<3.4	<3.8	<4.22	<4.88	<5.6	>=5.6
			MTS	3.37	3.40	<=1.8	<2.36	<2.92	<3.4	<3.4	<3.6	<3.88	<4.12	<4.72	>=4.72
	erratic behavior of	EBDavrg	MTO	3.78	3.89	<=2.56	<2.78	<3.21	<3.6	<3.89	<4	<4.33	<4.56	<4.97	>=4.97
			MTS	3.93	4.00	<=2.93	<3.38	<3.62	<3.67	<4	<4.13	<4.33	<4.51	<4.98	>=4.98
Market-related Volatility	high level of competition	HCavrg	MTO	4.21	4.17	<=2.5	<3.33	<4	<4.03	<4.17	<4.47	<4.68	<5.17	<5.5	>=5.5
			MTS	4.19	4.17	<=3	<3.33	<3.5	<3.97	<4.17	<4.53	<4.67	<4.93	<5.5	>=5.5

According to the length of SC lead times, the best 10 percent of MTO companies achieve shorter lead times for all four lead time categories than MTS companies. However, comparing the median values of both groups, MTS companies manage to achieve shorter lead times on the

supply side. For transportation lead times, although median values are the same, it can be observed that MTS companies in the catch up and latecomers groups score significantly higher lead times than MTO companies. The worst 10 percent of MTS companies score above 44 days of transportation lead time for their A-level components, while the worst MTO companies manage to achieve at least 13.1 days of transportation lead time. Based on this result, it seems that MTS companies rely more on global sourcing than MTO companies. This could indicate that MTO companies, in order to reduce waiting times for their customers, rely more on suppliers from their region. Also, for the variability of lead times, differences between MTO and MTS companies can be observed. Both on the supply side as well as on the customer side, MTS companies manage to achieve significantly better on-time delivery rates than MTO companies.

According to the dimension of behavioral volatility as well as for the dimension of market-related volatility, slight differences between both production strategies can be observed, but they are not significant.

4.5 Implications

The aim of this study has been to propose a benchmarking instrument that enables SC managers to critically assess the current state of SCV for their products' SCs. Building on prior research in the field of SCV management, the benchmarking instrument assesses SCV according to four distinct dimensions of SCV. The assessment was done via a benchmarking exercise conducted among 87 manufacturing firms that are ranked according to their SCV management performance within those four dimensions.

For managers, the benchmarking instrument enables them to investigate the volatility of a product's SC and monitor it in the long-run, seeking to identify areas on which to focus when trying to manage SCV efficiently. With the help of the instrument, they are able to assess whether the volatility of their product's SC is induced by themselves, by certain actors within their supply chain, by a high level of competition in the market, or by irrational behavioral patterns of customers or decision makers in the SC. Thus, the study is the first of its kind that facilitates a holistic assessment of SCV, one of the core phenomena in SCM. Consequently, the user of the tool will be able to track down the most pressing sources of SCV for their specific case.

In addition, this study provides valuable information for practitioners about the current state of volatility management performance in the manufacturing sector. Based on the feedback from 87 manufacturing firms, a benchmark has been condensed and incorporated into the SCV assessment tool that facilitates managers to compare their SCV management performance against others. This is of high importance since performance data generated by the focal firm itself are more valuable if they can be put into context with the performance data of competitors. To add more value to this, the benchmark has been further contextualized according to the production strategy of the participating manufacturing firm. It can be observed that for some variables there are essential differences between make to order and make to stock production strategies, which adds further depth to the analysis of SCV performance.

For researchers, the study provides a holistic approach to measure the volatility of a product's SC which can be the basis for further research. Prior research in the assessment of SCV evaluated volatility in SCs from a macroeconomic perspective via measuring the volatility of exchange rates, raw material prices, and other factors (Christopher and Holweg, 2011, 2017). Although it is of importance to measure and monitor the volatility of SCM-related market prices, from a practitioner point of view, a case-based evaluation of their specific state of SCV is necessary to derive SC-specific information and initiate more purposeful actions from it.

4.6 Conclusion and Final Remarks

By incorporating volatility management performance data from 87 manufacturing firms, this paper proposes a benchmarking instrument that enables a case-based assessment of the SCV management performance of a manufacturer. For practitioners especially, it is important to identify areas on which to focus when seeking to manage SCV observed in their products' SCs. However, like every study, this one also has limitations that must be pointed out.

First, the benchmarking data gathered from 87 manufacturing firms provides a solid basis, but has to be extended to a larger scale in order to be more reliable. The current sample size is, on the one hand, large enough to enable the intended benchmarking, but, on the other, is too small to extract more fine-grained analyses.

Second, the contextualization of benchmarking data according to make to order and make to stock production strategies adds depth to the analysis of benchmarking but can only be

understood as a starting point for further contextualization that is still necessary. Since it is the first study of its kind, it was intended to cover a heterogeneous group of manufacturing companies, but for future analyses the sample size needs to be increased and should be focused only on certain industries. In particular, a more in-depth analysis of benchmarking data according to different manufacturing industries (automotive, consumer goods, and others) would be necessary and of particular relevance for practitioners, since this would enable them to benchmark themselves against their competitors. Unfortunately, due to the sample demographics described in Table 23, such an analysis could not reliably be undertaken.

Third, the proposed benchmarking instrument assesses the impact of certain SCV sources on volatility of a product's SC via a benchmarking of volatility management performance data. It thereby assesses the performance of a product's SC in a certain category according to the benchmark, but it does not relate this to the impact on overall company performance. This being said, this study has to be understood as a call for further quantitative research on the impact of SCV sources on company performance.

Nevertheless, the study extends prior research on the assessment of SCV that has so far taken a macroeconomic perspective by adding a microeconomic view that is of particular importance for SC managers who are managing SCV on a daily basis. To the best of the authors' knowledge, the study is the first of its kind that seeks to assess SCV management performance in a holistic way.

5. Development of an Assessment Tool to Control Supply Chain Volatility

The following will describe the structure of the SCV assessment tool that aims to assist managers in controlling SCV. This assessment tool is the synthesis of this dissertation, based on the research findings of the three consecutive articles followed by a summarizing conceptualization of an SCV management framework.

5.1 Structure of the Assessment Tool

The aim of this thesis is to assist SC managers in managing SCV. Therefore, an assessment tool will be developed that (1) measures the volatility of a product's supply chain, (2) identifies the most pressing sources of SCV for that product and (3) provides managers with strategies that assist in managing SCV. The structure of the SCV assessment tool is shown in Figure 15. The assessment tool is subdivided into three distinct areas that build on each other. First, the *input layer* describes the necessary input variables that need to be inserted by the user in order to assess the volatility of their supply chain. Second, the *computation layer* is located in the back-end of the SCV assessment tool, not necessarily visible to the user. It includes a measuring instrument that calculates the volatility of a product's supply chain based on the input data combined with the weighting of the target system as well as an industry benchmark. Third, the *output layer* describes the main front-end functionalities that can be accessed by the user of the tool. It includes several analysis and monitoring functionalities to dive deep into the origin of volatility of a product's SC, as well as an SCV management framework that provides managers with strategies and concepts for dealing with SCV.

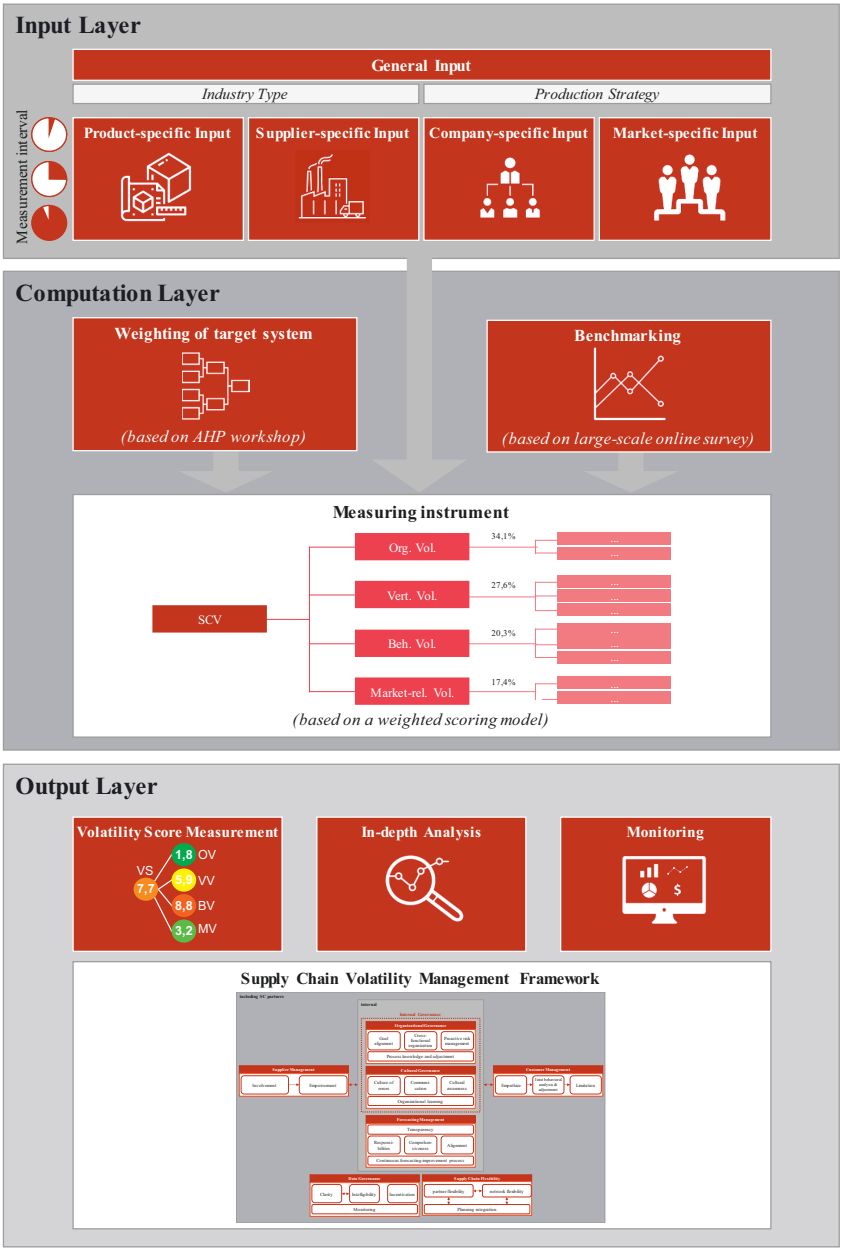

Figure 15 – Concept of the SCV assessment tool (for copyright declaration see p. 161)

5.1.1 Input layer

Before measuring the volatility of a SC, the definition of input variables that a user of the tool has to provide is of crucial importance. Based on the previous research results of article 1, SCV was conceptualized in order to structure the dimensions and sources of SCV. This conceptualization builds the basis for the assessment tool. Subsequently, in article 2, an AHP workshop was conducted with SCM practitioners to identify the most important sources of SCV (*inaccurate forecasting*, *intra-organizational misalignment*, *long/variable lead times*, *erratic behavior of decision makers in the SC*, *unpredictability of customer demand* and *high level of competition*). Based on those most important sources of SCV that have been identified in article 2, variables have been defined that seek to measure the impact of the particular source on SCV. Those measures have been described in article 3 (see section 4.3, p. 85 ff.).

Due to the nature of these variables, they have different measurement intervals. Supplier-specific (e. g., lead time variability, delivery reliability) and product-specific (e. g., customer demand forecasting accuracy) input variables will be measures frequently (e. g., weekly). Other variables, such as the level of external competition in the market, will be measured less frequently because they most likely do not change as frequently as others.

5.1.2 Computation layer

The core of the *computation layer* is an SCV measuring instrument. Building on the results of *article 1* and *article 2*, a measuring instrument that seeks to measure the volatility of a product's supply chain for four dimensions of SCV was developed in article 3. The measuring instrument is based on a weighted scoring model that processes the input variables of the *input layer*, combines them with a weighted target system and compares them with an industrial benchmarking that has been conducted among 87 manufacturing firms. This benchmarking of input variables, combined with the weighting of the target system, will provide the basis for the measuring instrument that calculates a SCV score that can be broken down into four sub-scores corresponding with the four dimensions of SCV.

5.1.3 Output layer

The *output layer* consists of four distinct functionalities that assist the user of the tool in managing SCV: (1) *volatility score measurement*, (2) *in-depth analysis*, (3) *monitoring* and (4) a *volatility management framework*. The *volatility score measurement* is the core result of the measuring instrument that has been described in article 3. A score from "1" (nearly no volatility)

to “10” (extremely volatile) will indicate the volatility of a product’s supply chain. Moreover, this score will be broken down into four sub-scores (organizational volatility, vertical volatility, behavioral volatility and market-related volatility) that provide a first indication of the origin of volatility in that specific case. *In-depth analysis* refers to the possibility of tracking down the source of volatility in detail. After measuring the different dimensions of SCV, the user of the tool will be able to identify the impact of certain suppliers or customers on the volatility score. By applying the tool in a real-world scenario, the user can perform an intra-organizational benchmarking between multiple SCs. After measuring the volatility of an SC and identifying the causes, a *volatility management framework* will provide several strategies and concepts, dealing with the most pressing sources of SCV. Since the measuring instrument itself has been developed and described in article 3, the following sub-section will propose a SCV management framework that synthesizes findings of the three dissertation articles as well as volatility management measures that have been conducted through multiple workshops and case studies over the course of the research project “*Navigator for German–Chinese Logistics Networks,*” funded by the Kuehne Foundation.

5.2 Supply Chain Volatility Management Framework

Over the course of this thesis project, multiple workshops and case studies have been conducted in cooperation with practitioners aiming at identifying measures dealing the most important sources of SCV. Those measures are outlined in a SCV management tool box that is shown in the Appendix section of this document (see chapter 9, p. 147 ff.) delineating management measures for the most important sources by their time horizon of implementation. However, this section seeks to condense those measures to a SCV management framework that synthesizes the core characteristics of successful SCV management.

In order synthesize those measures, the Q-methodology was applied, seeking to identify management clusters among those measures. To reduce bias in the framework building process, two additional SCM researchers participated in the sorting procedure. A set of 90 measures (see Appendix section, chapter 9, p. 147 ff.) was written on single cards and was sorted via the Q-methodology. Therefore, every researcher individually read every card, one after another, and assigned them into one management cluster if they identified similarities among measures, or placed the card in a new management cluster if no assignment to existing groups was possible. After identifying the core management clusters, all three researchers performed a second Q-

methodology within the management clusters that they identified in order to propose antecedents within those management clusters. Following this process, the researchers presented their results to each other, identified similarities and discussed contrasting assignments and relationships between management clusters and their antecedents. Subsequent to this discussion, a SCV management framework has been developed that is outlined in Figure 16 (see p. 112). The framework is subdivided into seven management clusters that comprise distinct antecedents within those clusters.

Throughout the discussion with multiple practitioners over the course of the thesis project, as well as in the discussion for the framework building process, it became obvious that managing volatility along the whole supply chain starts within the company. Practitioners often stressed that a significant share of SCV is generated by the focal firm itself. Consequently, managing SCV starts within the company. The framework outlined in Figure 16 (see p. 112) incorporates this by delineating the management clusters as internal management clusters, whose management can be established by the company itself; and management clusters that need direct involvement of supply chain partners (suppliers, customers, logistics service providers). Nevertheless, it has to be noted that the establishment of internal management clusters starts within the company – but can, and should, be expanded to supply chain partners as well.

5.2.1 Organizational Governance

As described before, instead of fighting volatility on the supply or demand side, companies need to align themselves first in order to manage SCV efficiently. Aligning the own organization has to be initiated by a clearly structured and executed internal governance. Internal governance is divided into *Organizational Governance* and *Cultural Governance*. While *Organizational Governance* describes structures within the company that need to be established on the organizational and process levels, *Cultural Governance* comprises strategies that seek to change the corporate culture at the employee level.

Organizational Governance contains four key antecedents that outline how to manage volatility on the organizational and process levels. More precisely, these are: *goal alignment*, *cross-functional organization*, *proactive risk management* and *process knowledge and adjustment*. Practitioners often stated that departmental goals within their companies are not well aligned, leading to opportunistic behavior and self-optimization rather that working on the same goal. To achieve aligned goals throughout the company, a clear top-down alignment strategy has to

be formulated that cascades through the organization including clear company-wide shared goals to break departmental "silo thinking." This alignment strategy should focus on mitigating conflicting goals of different departments that inevitably lead to SCV (e. g., logistics needs to reduce stock levels but the sales department needs to increase customer satisfaction through higher product availability). Matching goals for multiple departments decrease the chance of erratic behavior and increase team spirit. After a clearly structured goal system has been established, goal achievement has to be controlled and monitored by an equally aligned and harmonized system of key performance indicators (KPI). Therefore, practitioners stressed the importance of KPI reduction when monitoring firm performance. Instead of monitoring every possible performance KPI, a clear focus on few KPIs should be maintained. Those KPIs should be purpose-driven, company-wide KPIs (total profit, customer satisfaction etc.) with the purpose of keeping the idea of shared goals across departments.

From an organizational perspective it became obvious that most companies struggle to align activities among different departments, mostly due of a lack of mutual understanding of the activities of different departments. The bigger the company gets, the more this effect becomes reality due do multiple departments, hierarchy and decision-making levels. To manage this issue, a *cross-functional organization* is proposed as one key antecedent to achieve intra-organizational alignment. This *cross-functional organization* comprises a lean organization with cross-functional S&OP teams and clearly set responsibilities. Those cross-functional S&OP teams, including quality, purchasing, logistics, sales and other departments, should track sources of lead-time variability on a regular basis and mitigate them. By creating a more structured cross-functional communication, a better understanding of the activities of all departments can be achieved. This can additionally be accelerated by increasing inter-personal contacts via team events across multiple departments. Moreover, successful companies start to initiate a structured job rotation for employees of different departments to spread expertise and experiences within the company and increase cross-departmental awareness. However, a cross-functional organization should be the target for more than just regular S&OP activities. In addition, a more agile and cross-departmental project management has to be established for long-term projects. Early involvement of logistics and others in the product development process and following stages should include rolling test-assess-change cycles among all relevant departments to ensure feasibility at all stages and minimize changes to underestimated topics such as contract flexibilities, customs, packaging and others. However, although cross-

functionality has to be targeted, responsibilities within those teams have to set clearly. Therefore, companies often concentrate responsibilities in one person or department instead of spreading responsibilities among different departments. Logistics departments are very well suited for this, as they can act as cross-functional integrators thanks to various interfaces to various departments.

When companies perceive lead time or volume changes which deviate from the norm, increased volatility often arises from the circumstance that companies often lack concrete plans, processes and responsibilities for those cases, leading to a time-consuming case-based evaluation and decision-making process. The establishment of a *proactive risk management* assists companies in proactively dealing with unanticipated situations of volatility. Therefore, processes have to be analyzed proactively to identify sources of process deviations, intra-organizational misalignment and erratic behavior among all relevant stakeholders on a regular basis. Those intra-organizational risk management teams should also analyze outliers from the past where high volatility occurred and track down its sources. As a consequence of those internal risk management activities, clear emergency concepts have to be defined for how to deal with volume or lead time deviations when they are perceived. Those emergency plans should also include clear and undisputable cut-off values for cases in which higher spending on special freight (e. g., air freight) is allowed.

Moreover, *process knowledge and adjustment* is proposed as the fourth antecedent of *Organizational Governance*. In addition to internal risk management teams that concentrate on outliers and situations of extreme volatility, profound process knowledge should be built by internal, cross-functional value stream optimization teams. Such teams should closely follow the process of (1) visualizing value streams including all stakeholders, (2) in-depth analysis of sources of lead time deviation, erratic behavior and organizational barriers, (3) re-engineering the value stream and corresponding processes to bring relief to the critical path and (4) standardizing processes throughout the company. Re-engineered processes should seek to be gapless from an end-to-end perspective with clear responsibilities that are resistant to erratic behavior, since erratic behavior only occurs if people are provided with freedom to act irrationally. Although this seems very intuitive, practitioners in multiple workshops and case studies stressed that the level of process standardization in most companies is relatively low. This mostly arises from two aspects. First, supply chain networks and corresponding processes

often evolve over a long period of time, often without a dedicated mindset for lead time optimization. In order to challenge those historically evolved processes, dedicated teams have to be formed. Second, it has been noted by practitioners that, especially in make to order/assemble to order environments, processes often have not been standardized in the past because their products are individualized for the customer to a certain extent, making standardization more challenging. However, this mindset is changing and companies are trying to offer product variety to the customer, but also trying to establish standardized processes alongside, which will also be discussed in the *Customer Management* section.

5.2.2 Cultural Governance

When talking about governance, the first things likely to come to mind are management concepts and strategies at organizational and process levels, as described in the previous section. But, in order to initiate successful SCV management, changes in the corporate culture have to be initiated at the employee level as well. Those strategies belong to the management cluster *Cultural Governance* that includes four antecedents: *culture of errors*, *communication*, *cultural awareness* and *organizational learning*.

The underlying concept of effective *Cultural Governance* is the initiation and manifestation of a *culture of errors*. This concept basically describes the idea of allowing mistakes, but only once – meaning that it's okay to make mistakes but, when they occur, people should discuss those mistakes instead of hiding problems that can have devastating effects on the volatility of an SC. Whenever problems occur that have negative effects on the volatility of the SC, the root causes have to be identified and mitigated. However, a discussion of problems in order to mitigate the chance of making the same mistake a second time is only possible if employees are sure that they can communicate mistakes without being blamed. This culture of encouraging employees to talk about problems has to cascade throughout the organization to all departments and hierarchy levels, initiated from the management team. Additionally, some companies initiate improvement-process-marketplaces where problems and mistakes can be discussed and improvement concepts can be proposed in order to facilitate a proactive discussion of problems in the organization.

The antecedent of *communication* is closely linked to the *culture of errors* and describes the way of communicating problems, process variations and knowledge throughout the organization. Practitioners agreed that intra-organizational misalignment can be mitigated by a

clearly structured communication language that is known and practiced in all departments. Such a code of communication aims at increasing the speed of communication and mitigating the chance of costly misunderstandings between departments. Additionally, companies should target a leaner way of communication, meaning that communications chains through different hierarchy levels should be shortened to increase agility and speed of reaction. Indeed, this is only possible if responsibilities in the organization are clearly defined, as described in the management cluster *Organizational Governance*. Subsequent to achieving a lean and clear code of communication through the organization this can be extended to suppliers and customers as well to close the communication loop along the SC. However, this seems to be even more difficult to achieve, acknowledging the circumstance of different organizational mindsets and that customers as well as suppliers are not always willing to adapt their way of communication. However, if a clear communication language is set in the company, communication with customers and suppliers becomes more standardized, leaving less room for misunderstandings.

Since volatility management often means to detect a supply and demand mismatch and initiate changes in a short period of time along a complex supply chain, *cultural awareness* can assist in understanding and mitigating costly misunderstandings. To increase a more diverse cultural understanding on the way certain cultures react to certain events, cultural competencies have to be built by cultural trainings. Companies also strive to establish a multi-cultural employee base to increase cultural awareness.

The three antecedents *culture of errors*, *communication* and *cultural awareness* have to be embedded into a culture of *organizational learning* to continuously improve internal alignment. Lessons that have been learned from mistakes and misunderstandings have to be processed and spread through the organization to ensure that same mistakes do not repeat. Although this sounds intuitive, companies often lack a clearly-structured system of spreading lessons learned, nor do they provide the necessary resources for organizational learning. To show the specific effect of misbehavior on SCV it is not enough to share those lessons learned via e-mail or hide them in a knowledge-sharing platform. Organizational learning has to be initiated proactively by actively involving relevant employees in the continuous improvement process.

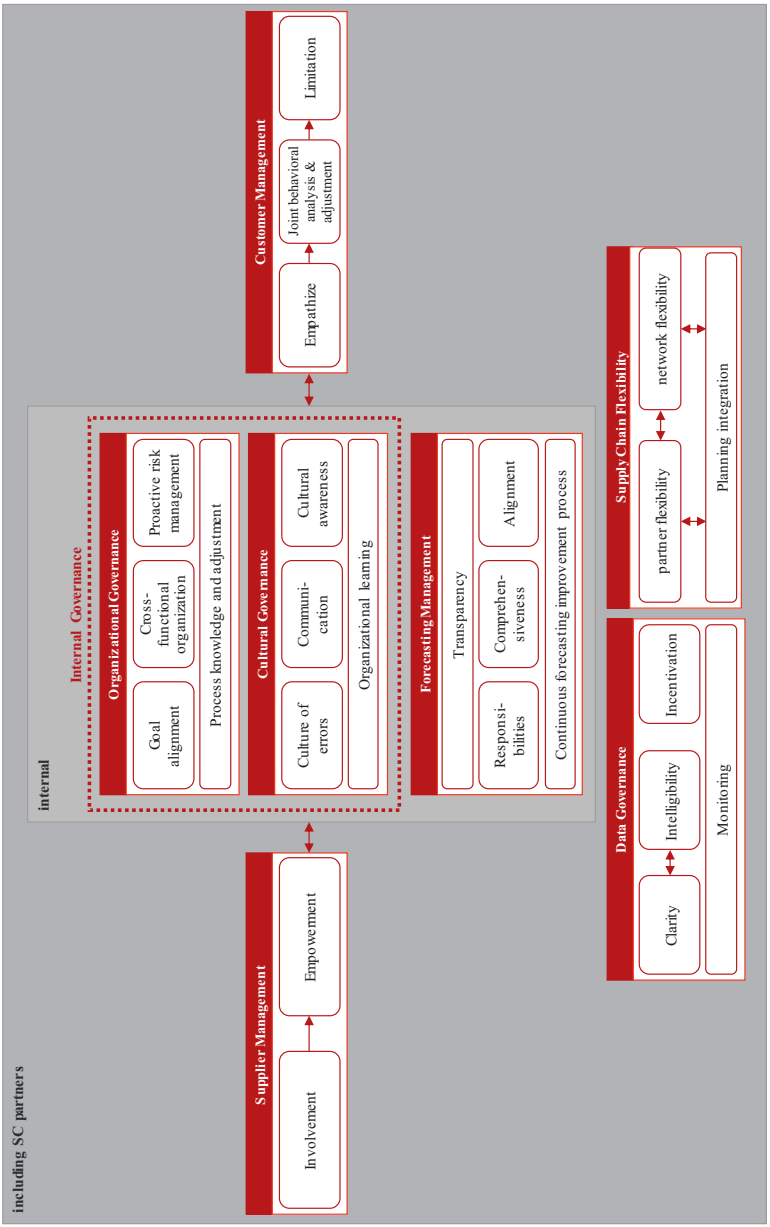

Figure 16 – SCV management framework

5.2.3 Forecasting Management

In general, forecasting is one of the core business functions of a company related to managing volatility. Nevertheless, for most companies, forecasting is more likely be seen as a task an organization has to fulfill rather than a complex management discipline. More often sales or marketing departments initiate customer sales forecasts and pass them on to following stages, such as purchasing or production planning, without letting those functions know under what assumptions the forecast has been made. Because of that, departments start do develop their own forecasts that build on their models and assumptions. To reduce volatility caused by inaccurate forecasting, forecasting has to be understood as an interdisciplinary management discipline that requires input from several business functions and includes five antecedents whose configuration is crucial in managing SCV.

First of all, clear *responsibilities* within the *Forecasting Management* have to be set and spread through the organization. Thereby the influence of several stakeholders on the forecasting process should be eliminated. The person or department in charge of the forecast has to ensure that there is "one single version of truth" throughout the organization, rather that multiple self-developed forecasts of different departments.

Second, the *comprehensiveness* of forecasts created is of utmost importance. Companies tend to build forecasts top-down starting with the financial goals of the company that are cascaded through the product portfolio. To get an indication of sales of different products, they tend to base their forecasts of past sales instead of, from practitioners' point of view, including numerous other factors in the forecasting process. To ensure *comprehensiveness*, forecasts should be built on statistically sound data instead of financial goals. Different market-research initiatives based on Big Data assist in getting a sounder picture of customer demand behavior. These initiatives are often performed with the involvement of external partners such as research institutes. Also, product-life-cycle-dependent customer demand profiles for different product types assist companies in better forecasting customer demand.

Third, as previously described, forecasting activities of different departments are often not well harmonized. The *alignment* of those activities can be seen as an additional core antecedent of successful *Forecasting Management*. To achieve this, standards for forecasting have to be defined globally (for all regions) and for all departments. Without using the same source of data

that will passed on through different stages of forecasting, all forecasting alignment activities will fail. During this process, the forecasting models used have to be aligned with the product-related production and distribution processes including their requirements. One-size-fits-all forecasting solutions will no longer exist. In addition to including production and distribution process requirements, criticism by process owners of forecasting results has to be considered carefully. Moreover, there is no perfect forecast. Hence, companies have to define expectations on the accuracy of forecasts by evaluating how much variability they can cover without further expenses.

Fourth, *transparency* on the embodiment of the first three antecedents has to be targeted. Not only the forecasting process and corresponding responsibilities should be transparent and easily accessible, in particular the forecasting models used have to be transparent. All calculations and related assumptions have to be well-documented and openly available.

Fifth, the aforementioned steps have to be embedded into a *continuous forecasting improvement process*. In case of inaccurate forecasts, the root causes of variations have to be traced and current models and assumptions have to be challenged without blaming responsible people. This has to be understood as an iterative process of small improvements rather than re-engineering all forecasting models at once. Therefore, companies should concentrate on outliers first (situations where forecast and actual demand strongly differed from another) and mitigate small deviations afterwards. In conjunction with the previously described *culture of errors* including *organizational learning* throughout the company, lessons-learned also have to be documented and disseminated for changes in forecasting models.

5.2.4 Supplier Management

While risk management evolved from the supply side, stating supply disruptions as the main source of devastating material flow deviations, SCV is not mainly caused by supply variations. This was also underlined by practitioners involved in the thesis process who stated that predominantly customers, as well as the focal firm itself, are responsible for volatile material flows. This was also underlined by the second article of this thesis where the SCV source of *supply variability* was ranked as a less important source of SCV by practitioners. However, *Supplier Management* remains a management cluster of successful SCV management which mainly comprises two antecedents. These are *involvement* and *empowerment*.

Involvement, on the one hand, expresses the idea of including suppliers early into supply chain-relevant processes to mitigate volatility caused by them because they have no time to react to changes adequately. On a strategic level, this includes an early involvement in the product development process to allow long-term planning and adjustment instead of passing requirements to the supplier and requiring steady supply from the start without ever discussing those requirements. This also means communicating flexibilities that have been ensured to the customer with suppliers of relevant product components to check whether suppliers are able to meet those flexibilities on their side. Instead of just defining documentation duties of the supplier with regard to lead time changes, the benefits of an early communication of those changes for both sides have to be explained. Of course, this requires long-term strategic partnerships with main suppliers instead of initiating competitive tendering every year. Involvement also includes the provision of rolling forecasts to the supplier to help him to better prepare for upcoming orders and consequently reduce lead times. However, practitioners agree that rolling forecasts that are provided to the supplier have to be to a certain extent binding in order to initiate activities at the supplier

Empowerment, on the other hand, contains all activities that ensure the enhancement of volatility management capabilities at the supplier. Instead of passing requirements to the supplier while hoping that he will meet them, proactive coaching and training is necessary to enhance suppliers' quality. Thereby, issues can be jointly discussed and awareness will be raised. Companies can also actively provide relevant lessons learned from their company to the customer. Instead of just providing rolling forecasts to the supplier, which is part of the *involvement* section, companies start to actively provide forecasting competencies that have been built by them to their suppliers to ensure better availability on the supply side.

5.2.5 Customer Management

Although it has been stated that volatility is often initiated by the focal firm itself rather than always caused by the customer, *Customer Management* is a management cluster of high importance that comprises three subsequent antecedents: *empathize*, *joint behavioral analysis and adjustment* and *limitation*. Since the thesis takes a manufacturer's point of view, the direct customer of a manufacturer is generally another business (retailer, OEM and others) instead of the real end-customer. This being said, the following approaches deal with managing direct customers in a business to business (B2B) context but do not limit themselves to this because the analysis of the end-customer itself is also crucial.

Empathize includes all activities that increase the awareness of customer needs and requirements at the focal firm. The term *empathize* itself is currently been used very often in the context of Design Thinking initiatives. However, it basically seeks to develop a more profound understanding of customer needs, which is not only important when thinking of innovation activities – it is of equal importance when managing volatile customer demand. In the context of SCV, it is important to spread the knowledge of customer demand behavior through the whole company, and this is mostly built up in marketing and sales departments. Therefore, an understanding of the products themselves is of importance in all stages. To increase this knowledge, market research initiatives to identify trends and risks far in advance have to be performed on a regular basis to obtain more insights into market segments, customer types, competitors etc. It is also of equal importance to categorize customers in different groups and define customized strategies for dealing with them instead of a one-size-fits-all approach.

After building up a profound knowledge about the customer and its needs, companies should seek to initiate a *joint behavioral analysis and adjustment* together with the customer. This is of importance especially in the B2B context since a direct communication and adjustment of customer behavior is more likely in this scenario than in a direct business to consumer (B2C) situation. This being said, *joint behavioral analysis and adjustment* includes all activities that actively seek to change customer demand behavior in cooperation with the customer. If a customer regularly changes its demand to a certain extent (numerical boundaries have to be defined), the manufacturer has to show the customer the consequence of its demand behavior. Practitioners mentioned that most of their customers do not know about the consequences at the manufacturer's side if the customer changes an already placed order shortly before the planned start of production. After a joint communication of this issue that created customer awareness of the consequences of his behavior, practitioners reported many situations where behavior was changed and short-term changes of already placed orders as well as order batching decreased significantly.

Moreover, successful companies send their best demand planners to their customers in order to transfer strategies and competencies for demand forecasting to the customer to reduce unpredictable demand changes that are often caused because the customer is performing inaccurate forecasts himself. Indeed, this can also be accelerated if the customer shares with the manufacturer data that have been the basis for his assumptions of realized end-customer

demand. However, strategies described in this section are more likely to be implemented if there is a long-term relationship with the customer, including longer contractual periods.

Although empathizing with the customer and jointly adjusting his behavior should be targeted, companies should, in addition, seek ways to limit volatile customer demand. Hence, *limitation* includes all activities that are performed to directly or indirectly reduce volatile customer demand or the effects of it. In general, this can be done directly or indirectly. The most common direct way to limit short-term order changes that cause volatility is to set up frozen zones. By implementing these, customer demand changes will be limited due to concrete time windows where quantity changes are only allowed to a certain extent.

However, most companies try to limit demand volatility indirectly without requesting the customer to stabilize their demand behavior. One very effective way is to set up a capacity insurance program. This means that customers have to buy production capacity for a certain total quantity well in advance (e. g., for one year) before a concrete demand is realized. In the case that the bought capacity is used, customers get back the money they used to secure that capacity; in the case that their actual demand is lower, part of this money remains with the manufacturer for unutilized production capacity. However, this strategy is only possible in a situation where total market demand exceeds total supply (e. g., in oligopoly or monopoly scenarios), otherwise customers will not be willing to secure production capacity that they can get somewhere else without paying for it. Another way of indirect limitation of volatile customer demand is standardization – for example, by offering a product configurator to the customer that appears to offer a high number of product variants but in fact involves a lower number of standardized components at the manufacturing site due to a sophisticated level of modularization. This often requires product reconfigurations on a strategic level, however, not having a multitude of individual components increases the chance of significantly lowering the level of forecasting inaccuracy. Moreover, companies can think about buffer stock contracts to reduce the effect of volatile customer demand on their side. This means integrating buffer stocks into the contractual agreements so that they are also paid for by the customer to increase delivery reliability for the customer, but also to secure profitability for the manufacturer, who does not have to obtain supplies at short notice because of demand changes at the customer.

5.2.6 Data Governance

In order to ensure appropriate planning and timely reaction to changes along the SC, efficient *Data Governance* is necessary. Therefore, practitioners agreed, *clarity* and *intelligibility* of data should be targeted, combined with constant *monitoring*. *Clarity* means that there should be just one source of data that will be used for planning throughout the whole organization, including all regions and departments, instead of self-created databases within the own organization. *Intelligibility* is achieved when the data is easily accessible and understandable by all relevant stakeholders.

Although different types of data are required to manage volatility (customer demand, capacity lead time data etc.), two types of data were perceived as particularly important by practitioners; data on contractual agreements as well as absolute transparency on lead times; and, especially, lead time changes along the supply chain. According to them, current planning processes often do not incorporate lead times and changes in lead times appropriately. Instead of leaving ETD/ETA (estimated time of departure/estimated time of arrival) data to purchasing departments, it should be spread to relevant departments (e. g., production planning, marketing) to let them also react to those changes (adjustment of production plans, postponement of promotions etc.). With regard to contractual agreements, it was stated that sales departments often agree upon volume flexibilities with customers without informing logistics and purchasing about it. Over the course of the business relationship, logistics has to meet agreed flexibilities without ever checking the feasibility. To close this gap between those departments a company-wide database on contractual agreements was proposed that includes important contractual agreements (volumes, flexibilities, prices etc.) and communicates that information to relevant stakeholders well in advance. Nevertheless, database rights and responsibilities must be chosen wisely, clarified at an early stage and put into practice accordingly to mitigate the chance of creating a database that nobody uses.

Although the importance of appropriate and timely data to manage volatility has been widely acknowledged, in reality customers as well as suppliers are mostly not willing to share important information in a timely fashion. But, to manage volatility, lead time data along the whole supply chain is necessary. Hence, efficient *incentivation* of customers as well suppliers to share relevant data is proposed as a key antecedent of *Data Governance*. On the customer side, in a B2B scenario, incentives have to be developed (e. g., price discounts) to lead the

customer to share data that is relevant for the manufacturer's forecasting activities, such as stock levels, point-of-sales data, promotional activities and others. On the supply side, manufacturers should implement an incentive system that leads suppliers to proactively communicate lead time changes far in advance instead of communicating them when countermeasures are even more expensive.

Even though the *incentivation* of customers and suppliers to share important volatility management data seems to be a promising approach to overcome data-sharing barriers, concrete measures and concepts are sparse and even research on the monetary value of data is missing, but necessary to set up those incentive systems.

5.2.7 Supply Chain Flexibility

Modern supply chains have become complex systems involving a multitude of actors that have to be managed. Those supply chain networks often evolved historically under the light of globalization and heavy cost pressures. Due to those two mega trends, manufacturers often have to rely on single sources of supply, sometimes far away from their manufacturing sites. Those historically evolved networks tend not to be flexible enough to deal with SCV. The management cluster *Supply Chain Flexibility* includes the two main antecedents *partner flexibility* and *network flexibility*, which have to be designed in conjunction with the antecedent of *planning integration*. Thereby, the designs of *partner flexibility* and *network flexibility* are mutually dependent because flexibilizing partners also includes the flexibilization of the network itself.

Partner flexibility includes all activities that seek to reduce dependency on partners as well as increase the manufacturer's chance to adjust quickly to volatility caused by partners. Partners in this case can be suppliers, logistics service providers as well as customers. The most common way to reduce partner dependency on the supply side is dual or multi-sourcing. Although the concept of dual sourcing is not novel, even today many companies rely on one supplier for strategic parts. Successful companies (especially in the automotive industry) implement alternative suppliers into their network and spread quantities among them. Cross-regional backup sources of supply have been proven to work well. Successful companies also tell their suppliers if there is a backup source and openly communicate the quantities both suppliers receive to create awareness and increase competition among them. The same holds true for the selection of logistics service providers. Manufacturers also move away from relying on just one or few service providers, take a price increase and arrange flexible agreements with multiple

service providers to reduce the chance of not getting the required capacities in situations of high volatility. Another important aspect of *partner flexibility* is the flexibilization of contracts. Practitioners agreed that delays in networks often arise from order quantities that have not been contractually agreed upon, since contacts tend to be relatively inflexible. Therefore, volume flexibilities have to be integrated into contractual agreements combined with a flexible pricing scheme. This pricing scheme should be very explicit about the logistics costs that arise due to short-term demand fluctuations and cover them accordingly.

The longer lead times in a complex SC network get, the less the network can react to volatility. Therefore, the basic idea of the management cluster *Network Flexibility* is to reduce lead times along the whole SC. This being said, trends of localization or regionalization can be observed in serval industries that have tended to have very long lead times in the past. However, although few companies start to localize suppliers instead of buying in low cost countries or even moving their production sites from low cost countries closer to the customer, recent signs of a potential de-globalization are sparse. Nevertheless, reducing total SC lead times by local sourcing, regional distribution centers or even regional production in micro-factories would lower volatility that is caused by the supply chain significantly because, with lower lead times, the network is more capable of quickly reacting to volatile customer demand changes. Although comparatively new technologies such as 3D printing are currently economically unfeasible for mass production, practitioners are of the opinion that it is just a matter of time until this technology will change SC lead times drastically. But the reconfiguration of SC nodes can not only bring relief to the lead times problem; managers should also think about the flexibilization of transport routes and modes in times of extreme volatility. Alternatives such as the New Silk Road remain an alternative to avoid capacity limitations on shipping routes in peak seasons. However, it has to be stated that transportation by train is still four times more expensive and transportation via airplane ten times more expensive than the traditional ship transportation route between China and Europe. The third antecedent in this management cluster is *planning integration*. Practitioners reported that they try to create supply chain flexibility but fail to integrate the achieved flexibility into their materials planning process. This means that, for example, flexibilities that have been agreed upon with the customer have to be consequently integrated into materials planning. This seems intuitive, but companies often struggle to make flexible plans that depict multiple volatility scenarios and rather stick to relatively rigid plans, although they ensure flexibility to the customer.

6. Case-based Evaluation of Supply Chain Volatility Assessment Tool

In the following, a case study in the automotive industry will be conducted to perform a case-based evaluation of the SCV measurement instrument as well as the SCV management framework. Therefore, the case study company provided necessary benchmarking data to perform the SCV measurement. Subsequent to this, an on-site group discussion at the case company was conducted, including two case company employees responsible for logistics and supply chain management. At this on-site meeting both practitioners were provided with an explanation of the SCV framework, and a discussion was held about how they are affected by SCV in the respective dimensions of SCV and how they are dealing with it. After that discussion they were confronted with their results from the SCV measurement instrument. Subsequently, their perception of the validity of the results was recorded and critically discussed. To reduce biased perceptions in the discussion process, an additional researcher was present at the on-site meeting. In the following, I will refer to the case study company as "Motion Tech," which is not the real name of the case study company and was chosen for demonstrative purposes only.

6.1 Motion Tech: A Case Study in the Automotive Industry

Motion Tech is a globally operating manufacturer of a variety of components and modules for the automotive industry, ranging from clutch bearings to complex customized modules. More than 50,000 employees work for the company and the annual turnover is more than 10 billion €. Depending on the product, Motion Tech serves as first-tier supplier for automotive OEMs (original equipment manufacturers), as a second-tier supplier for module suppliers in the automotive industry and is also active in the after sales market.

In the investigated case, Motion Tech serves as first-tier supplier of modules for automotive OEMs. The outsourcing ratio is 30 %, with North America, Mexico, Western Europe and China as their main sourcing regions. The modules are manufactured in Germany and shipped to customers in North America, Eastern and Western Europe, Russia and China.

6.2 Supply Chain Volatility Measurement, Assessment and Evaluation of Results

In order to measure and assess the SCV of Motion Tech's supply chain, the company provided all necessary input data. The benchmarking results of the SCV measuring instrument are

outlined in Figure 17. In this case the benchmark was performed against the benchmarking input of manufacturers from the automotive industry (n=20).

Results	Score
Benchmarking with firms of Automotive	
Organizational Volatility	**4.33**
Intra-Organizational misaligment	4.00
Inaccurate forecasting	4.65
Vertical Volatility	**7.53**
Long lead times	9.72
Supplier lead time	10.00
Transportation lead time	7.00
Production lead time	8.00
Delivery lead time	10.00
Lead time variability	5.33
Behavioral Volatility	**4.50**
erratic behavior of customers	4.00
Erratic behavior of decision makers in the SC	5.00
Market-related Volatility	**2.00**
high level of competition	2.00
Overall Volatility Score	**4.59**

Figure 17 – Excerpt of SCV measurement resulting from a benchmark against manufacturers operating in the automotive industry (n=20)

6.2.1 Organizational Volatility

Motion Tech has an above average intra-organizational alignment with average levels of planning efficiency and an average level of assignment of roles and responsibilities. This was supported by Motion Tech employees as well. There are cross-functional S&OP teams in place that align supply and demand on a regular basis. Additionally, an automated decision-support system has been implemented that enables ad hoc decisions on special freight below a total volume of 20,000€. This enables Motion Tech to react very fast to a constantly changing environment without timely decision stages. However, for freight costs above 20,000€, all relevant stages and stakeholders have to be involved.

With regard to short-term forecasting (one month ahead), Motion Tech is among the best-in-class companies, with an MAPE of 2 %. For mid- and long-term forecasting (three to six months ahead), Motion Tech's accuracy was rated as average. The good result regarding the forecasting accuracy of Motion Tech was supported by the practitioners involved in the case study. They

stated that they understand forecasting as the core of successful volatility management. They invest a high amount of resources to improve forecasting quality and align the company with the results. On important aspect of their forecasting management is that Motion Tech does not automatically trust every customer demand forecast they receive from their OEM customers. Motion Tech implemented regular plausibility checks of received customer forecasts and evaluates them with the inclusion of their own market forecasts as well as their combined forecasts for all customers. According to them, this is of importance because, for some product types, but especially some regions such as China, the customer demand forecasts they receive are of particularly poor quality. Although, from this thesis's point of view, an adjustment of received customer demand forecasts has to be understood as erratic behavior, in the case of Motion Tech this seem to work very well. Nevertheless, at the moment those plausibility checks are mostly done manually, which takes a lot of time and is prone to errors. However, Motion Tech is testing a pilot in the North American market where they try to automatically check plausibility of received forecasts by challenging them with their own market forecasts as well as combined forecasts of all customers in that region. In addition to checking customers' demand forecasts, Motion Tech also actively discusses those forecasts with their customers in order to understand customer demand behavior as well as to improve the forecasting quality.

6.2.2 Vertical Volatility

The dimension of *Vertical Volatility* is assessed by measuring the two SCV sources *long lead times* and *variable lead times*. According to the SCV assessment, supply chain volatility at Motion Tech is mostly induced by the dimension of *vertical volatility*, more specifically by very long lead times across the whole network. Their average supplier lead time of 90 days for A-level components ranks among the worst 20 % of all benchmarking participants in the automotive industry. The same holds true for the delivery lead time of 20 days to their main customers, which also ranks among the worst 20 % of all benchmarking participants in the automotive industry. Consequently, Motion Tech should focus on reducing their lead times significantly in order to reduce volatility along their SC. This result was also supported by both employees of Motion Tech. They argued that their SC network is internationally dispersed and, especially on the supply side, a large share of suppliers for their plant in Germany originate from North America and China. They agreed with the recommendation that they should strongly focus on localizing their supply base in order to reduce volatility. In fact, they want to change this in the long term, since the mindset in the company has changed in recent years and most people are aware that long delivery times severely restrict the flexibility of the network.

According to *variable lead times*, Motion Tech achieves a 90 % on-time delivery rate for their suppliers and 92 % on delivery reliability to their customers. According to the benchmark this is an average result leading to a medium degree of volatility induced by variable lead times. However, it has to be mentioned that Motion Tech argued that those delivery reliabilities are often bought at a high price. To ensure them, they often have to rely on costly special freight. That being said, it has to be observed that this circumstance is not shown or measured in the assessment instrument, meaning that companies can have good scores in the benchmark but do not necessarily manage their volatility cost-efficiently. This aspect was outside the scope of the measuring instrument, but definitely remains an area for improvement for future research.

6.2.3 Behavioral Volatility

The dimension of *Behavioral Volatility* in assessed by the measurement of the SCV sources *erratic behavior of customers* as well as *erratic behavior of decision makers in the SC*. According to the assessment, the level of Behavioral Volatility at Motion Tech is below average. Motion Tech does not perceive a high level of erratic customer behavior because, from their point of view, their customer demand behavior is relatively predictable. However, what challenges them are short-term changes of already placed orders. Although Motion Tech has implemented different decision support systems for managing short term volatility, some analyses and decisions are performed manually, leaving room for erratic behavior of decision makers. However, reducing the erratic behavior of decision makers should not be the main priority for Motion Tech when trying to reduce volatility in their SC.

6.2.4 Market-related Volatility

The lowest share of SCV at Motion Tech is induced by the dimension of *Market-related Volatility*, which is measured by the level of competition within the market from Motion Tech's point of view. According to them, they have around three relevant competitors in their market, but the level of competition is relatively low, which is also supported by the SCV assessment. Since their products are mostly highly customized products, their customers are not able to replace them as their supplier at short notice. To not induce volatility due to a high number of customized product variants Motion Tech tries to offer product variety to the customer but to reduce internal product variety by a sophisticated level of standardization and modularization.

6.3 Evaluation of Supply Chain Volatility Management Framework

Over the course of the discussion with Motion Tech's employees about the SCV assessment presented in the previous section, different management approaches to deal with volatility have been discussed. In general, it can be said that all strategies discussed can be assigned to the management clusters of the SCV management framework (see Figure 16, page 112). Motion Tech understands forecasting as a core management concept for dealing with volatility and has in the past initiated different approaches to increase their own forecasting quality, but has also discussed forecasts jointly with their customers. To align the organization, they are focusing on facilitating cross-functional exchange and have implemented a structured S&OP process. Additionally, to increase the speed of decisions within the organization, an automated decision support system is in place to initiate special freight deliveries at short notice. Although the assessment showed that Motion Tech's supply chain lead times are too long, leading to a relatively inflexible SC network, they are nevertheless aware of this circumstance and try to increase their network flexibility by localizing their supply side.

When confronted with the framework, both Motion Tech employees agreed that all approaches they undertake to deal with volatility can be assigned to at least one of the seven management clusters of the SCV management framework. From their own point of view, they argued that they are comparatively successful in implementing strategies belonging to the internal management clusters but can improve in strategies that include customers and suppliers. They stated that this is a challenge because their customers' and suppliers' information systems are not well integrated into their own system, but they are working on this. With regard to the management cluster of *Data Governance*, they implemented one SAP system for the whole company to ensure clarity and intelligibility as well as real-time availability of data. However, to efficiently exchange data with suppliers and customers they face several legal issues.

Regarding the management cluster of *Supply Chain Flexibility*, they argued that in the special case of the automotive industry they are often not allowed to increase *partner flexibility* by having multiple sources of supply. This is particularly the case because every part of a supplier must be tested and certified by the automotive OEM due to security reasons. Therefore, it is not intended by the OEM that their first- and second-tier suppliers themselves also implement dual sourcing strategies.

6.4 Summarizing Evaluation

Through a case study at a supplier for the automotive industry, the application of the SCV assessment tool, including the measuring instrument as well as the management framework, has been demonstrated. By getting feedback from employees of the case study company it can be said that, in this specific case, the SCV measurement and assessment was possible and the result corresponded to the perception of the interviewed employees. As was also discussed, strategies to deal with volatility could be assigned to the framework. This being said, for this specific case, the measuring instrument as well as the SCV management framework were helpful and provided valuable insights for the case study company. Nevertheless, over the course of the discussion process, some limitations of the measuring instrument as well as the SCV management framework were identified that should be pointed out.

First, the measuring instrument assesses the volatility performance in certain areas of volatility management but does not relate this performance with the resulting costs of achieving a good performance score in a particular category. For example, if a company achieves very high on-time delivery rates on the supply and demand sides, the company gets a low volatility score for the source of *variable lead times*, which indicates to them good volatility management performance in that category. But the measuring instrument does not take into account at what cost this performance has been achieved. In the described case, the company argued that they invest a lot into special freight to maintain good on-time delivery rates. The relationship between cost and volatility management performance certainly is of importance but was beyond the scope of this thesis and still remains an area for future research. Second, the SCV management framework (see Figure 16, page 112) outlines the core management clusters of successful volatility management, but the case study has shown that the design of a particular management cluster depends on the individual case and cannot be carried out in the same way in every company and every industry. For example, the framework suggests increasing partner flexibility (e. g., dual sourcing) to increase supply chain flexibility, but in the described case this was not possible since OEM customers restrict the case study company to just one supplier per component. Furthermore, it has to be said that the measuring instrument and the management framework provided valuable insights and recommendations for the case study company, but this does not necessarily mean that it is generally applicable. To accomplish that a multitude of cases should be investigated, which remains an area for future research.

7. Overall Summary and Outlook

7.1 Summary and Contribution Value

The overall goal of this thesis was to develop an assessment tool to control supply chain volatility. With the support of the tool, practitioners should be enabled to perform a case-based evaluation of the state of SCV of a product's SC. More precisely, they can: (1) measure the state of volatility management performance for four distinct dimensions of SCV, (2) assesses the peculiarity to identify areas to focus on when managing volatility and (3) develop strategies dealing with SCV. To achieve the aforementioned goal, the thesis follows a cumulative approach leading to three consecutive articles that are subsequently synthesized and extended to the intended SCV assessment tool.

The first article ("*Much discussed, little conceptualized: supply chain volatility*") developed a conceptual framework that outlines the sources and dimensions of SCV. Therefore, a data-triangulation was performed incorporating a systematic literature review of 2,789 peer-reviewed articles and a group exercise among 23 SCM practitioners building on the NGT methodology. Through a structured and unbiased synthesis process a conceptual framework consisting of 20 meta-sources that contribute to five distinct dimensions of SCV was proposed. Subsequently, a classification scheme has been proposed to delineate the SCV dimensions according to three characteristics (*relative deviating impact*, *repetitiveness* and *influenceability*). By including feedback from 17 additional SCM practitioners who were not involved in the previous steps of the process, 15 propositions were advanced that seek to delineate the SCV dimensions according to the proposed characteristics.

The developed conceptual framework of the first article was the basis for the following articles. Nevertheless, this conceptualization also provides value for researchers in this field since it condenses and extends a variety of research on the sources of SCV, leading to a consistent taxonomy that builds a basis for future research. For SCM practitioners, the framework helps to structure a complex phenomenon that challenges them on a regular basis. Additionally, the propositions provide an indication for practitioners about the impact, repetitiveness and influenceability of the five dimensions of SCV. Based on those results, practitioners should start to manage *organizational volatility* first since it comprises a medium *relative deviating impact* but high *repetitiveness* and a high degree of *influenceability*.

The second article identified the most important sources of SCV and strategies for dealing with them. The article builds upon the framework of the first article and aims to assess the impact of SCV sources of the first four dimensions of SCV, excluding the fifth dimension (*institutional and environmental volatility*). Therefore, a two-stage research approach was applied incorporating a group exercise with 17 SCM practitioners. In the first stage, the AHP methodology was applied to assess the impact of sources and dimensions of SCV. According to the AHP result, *intra-organizational misalignment*, *inaccurate forecasting*, *long lead times*, *erratic behavior of decision makers in the SC*, *erratic behavior of customers* and *high level of competition* are the six most important sources of SCV. In the second stage NGT methodology was applied to identify strategies for dealing with those sources.

The second article is the first of its kind that seeks to assess the impact of SCV sources on SCV, which is of utmost importance for practitioners who need to prioritize their volatility management efforts. According to the results, the dimension of *organizational volatility* induced the largest share of SCV at the focal firm. For managers, this means that they should focus on mitigating volatility originating in the focal firm itself before initiating SCV management initiatives with customers or suppliers, which is also consistent with the recommendations of the first article.

The third article proposed a measuring instrument that assesses the volatility management performance of a product's SC. More precisely, by incorporating an industry benchmark of 87 manufacturing companies that includes quantitative and qualitative performance data, the measuring instrument assessed SCV induced by the first four dimensions of SCV. The article builds upon the conceptualization of the first article and incorporates the assessment of volatility sources from the second article. Additionally, building on the performance data, the current state of SCV management performance is discussed and further contextualized by the production strategy (make to order/assemble to order and make to stock) of a focal firm.

The third article contributes to an urgent need of practitioners who are seeking to assess their own volatility management performance for their specific case. By applying the proposed measuring instrument, practitioners will be enabled to identify areas to focus on when managing SCV since they obtain insights into whether in their case SCV is induced by themselves, SC partners or the competition in the market. Additionally, due to the incorporation of an industry

benchmark, practitioners will be enabled to compare their volatility performance against competitors.

By incorporating the results of the three consecutive articles, an SCV assessment tool was developed in chapter 5. This assessment tool combines the measuring instrument from the third article with a SCV management framework to enable practitioners not only to measure and assess the current state of volatility, but also to initiate purposeful strategies for dealing with it. The proposed SCV management framework (see Figure 16, page 112) was developed by synthesizing a multitude of SCV management strategies that have been collected throughout the research process of the thesis including multiple workshops and case studies. The framework consists of seven SCV management clusters that are structured into management clusters that can be managed by the focal firm itself and management clusters that include SC partners. For every management cluster the core antecedents are outlined.

To evaluate the applicability and validity of the SCV assessment tool, a case study in the automotive industry was conducted and described in chapter 9. The state of SCV management of the case study company was measured and assessed, and strategies were discussed. The measuring instrument has appropriately measured the state of SCV in the specific case and the SCV management framework proved its relevance. Nevertheless, the case study application showed some limitations of the SCV assessment tool that are, among others, discussed in the following section.

7.2 Limitations of the Thesis and Future Research

Although this thesis contributes to research and practice in different ways, as described in the previous section, this thesis also has some limitations that have to be pointed out. The following section acknowledges this and outlines the limitations of the three articles as well as the thesis in general, including the SCV management framework. Furthermore, possible directions of future research will be discussed.

For the first article, the literature reviewed was restricted to peer-reviewed journals only. Although this may introduce the risk of missing out important aspects, the incorporation of an additional group exercise to identify sources of SCV from a practitioner's point of view mitigated this risk substantially. Additionally, the developed propositions that seek to delineate

the five dimensions of SCV were based on feedback from 17 SCM practitioners. Since 17 is a comparatively small number of people for building propositions, further quantitative testing of those propositions would be necessary.

The second article aimed to assess the impact of the sources and dimensions of SCV through an AHP among SCM practitioners. It has to be stated that this assessment was done excluding the fifth dimension of SCV – *institutional and environmental volatility* – which is a restriction. Future research on the impact of SCV sources should take this into account and extend the study to include those sources since they are of relevance for practice, especially in the context of complex global supply chains. Moreover, the assessment of the impact is based on the perceptions of the included SC practitioners, which means that effects that are not directly observable are not covered in this approach. This could be investigated by a more detailed quantitative analysis applying structural equation modelling or other techniques, which was outside the scope of this study. However, since this was the first approach to assess the impact of SCV sources, the study provides insights for practitioners on which sources to prioritize when managing SCV.

The third article proposed a measuring instrument that incorporates a volatility management performance benchmark among 87 manufacturing firms from different industries. Although the number of participants is high enough to derive reliable benchmarking values, further contextualization regarding different manufacturing industries was not reasonably possible for all manufacturing industries but would provide more insights for practitioners that seek to benchmark themselves against competitors from the same industry. However, the third article contextualizes this benchmark regarding the production strategy of the focal firm, which can be understood as a first approach to a benchmark that considers the context of the focal firm. Additionally, the case study from the automotive industry described in chapter 1 makes a first attempt to apply the measuring instrument taking only manufacturers from the automotive industry (n=20) into account. Nevertheless, future research should increase the number of benchmarking participants to propose more reliable benchmarking values for all manufacturing industries. Additionally, the supply chain position of the manufacturer in a certain manufacturing industry could be a valuable contextualization, since second-tier suppliers are confronted with other restrictions than OEMs.

After synthesizing the results of those three articles, an SCV assessment tool was proposed that enables SC managers to perform a case-based evaluation of their volatility management performance, prioritize areas to focus on and manage volatility by incorporating insights from the SCV management framework. It has to be stated that this SCV assessment tool was developed for the use in manufacturing industries. Without doubt, retailers and logistics service providers also suffer from volatility, but if they intend to assess their state of SCV management, further refinements of the assessment tool have to be made by future researchers. Moreover, as pointed out before, the developed assessment tool assesses the volatility management performance in certain areas of volatility management but does not take into account the costs that occurred to achieve this level of volatility management performance. This being said, a manufacturer can on the one hand be very good at managing volatility, but on the other hand he can induce very high logistics costs for achieving this performance. Research on cost-efficient management of SCV is not existent but remains an important area for SCM research. Nonetheless, the results from this thesis can be a basis for extended research in this area.

Finally, this thesis should be understood as a call for further quantitative research on SCV. Although this thesis supports the advancement of SCV, some of the results that have been derived need quantitative testing to provide more reliable recommendations for practitioners. Nevertheless, it can be said that the thesis contributes to the field of SCV research since it provides a coherent taxonomy and a valuable tool for practitioners who seek to control supply chain volatility.

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9. Appendix: SCV management tool box

Table 26 – List of strategies dealing with intra-organizational misalignment

Time Horizon	SCV Management Strategies
Short-term	**Proactive communication of problems** • Instead of hiding problems that can have devastating effects on business performance, people have to communicate them proactively without getting blamed **Weekly S&OP meetings** • Regular meeting to synchronize all activities along corresponding departments/functions within the company **ETD/ETA transparency** • Create transparency on ETDs/ETAs within the company instead of leaving it to purchasing **Concentration of responsibilities** • Concentration of all responsibilities in one person or department instead of spreading them among different departments **Increase inter-personal contact** • Stimulate personal contact via events and activities across departments and business units and thereby improve cross-department/cross-level communication
Mid-term	**Internal risk assessment** • Among all relevant stakeholders, identify possible sources of intra-organizational misalignment on a regular basis **Goal alignment** • Departmental goals have to be aligned with company goal **Flexible materials planning** • Agreed contractual flexibilities have to integrated into the materials planning process **Increase cultural understanding** • Raise commitment by building cultural competencies within the company to avoid costly misunderstandings

Time Horizon	SCV Management Strategies
	Multi-cultural employee base • Diversify employee base to align your company culturally **Job rotation** • Allow job rotation to spread expertise and experience within the company **KPI reduction and alignment** • alignment of management team by harmonized KPIs • reduction of KPIs should be targeted • switch from KPIs for departments/functions to purpose-driven company-wide KPIs (total profit, customer satisfaction etc.) **Knowledge sharing** • Promote department integration to increase collaboration, knowledge sharing and gain expertise for forecasting and planning process • Encourage internal/external communication to gain perspective and expertise **Clear top-down alignment strategy** • cascades through the organization • responsibilities rather concentrated in one person that in multiple • can be re-adjusted bottom-up **Agile project management** • Early involvement of logistics in development process and following stages to include often underestimated topics like customs or packaging • rolling test-assess-change cycles among all relevant department to ensure feasibility on all stages **Standardized decision making and approval processes** • reduce the effect of erratic decisions of individuals by cross-departmental approval including logistics • nevertheless, speed of decision process should not be hindered **Lean communication** • short communication chains • clear responsibilities

Time Horizon	SCV Management Strategies
Long-term	**Company-wide database on contractual agreements** • To close the gap between sales and logistics, a database is needed that includes important contractual agreements that have been agreed with the customer (e. g., volumes, flexibilities, prices, etc.) • An SC-wide cloud database could be expanded to customers and suppliers as well • Database rights and responsibilities must be chosen wisely, clarified at an early stage, and put into practice accordingly **Internal value stream visualization and optimization** • Cross-functional visualization of internal value stream → identification of problems → mitigation → definition of clear organizational procedures/workflows about internal information flows that cover all company actions end-to-end **Lean-organization** • lower number of hierarchy levels • consistent centralized or decentralized organizational approach throughout the organization **Communication language** • development of clear company-wide code of communication to increase speed of communication as well alignment among different departments

Table 27 – List of strategies dealing with inaccurate forecasting

Time Horizon	SCV Management Strategies
Short-term	**Forecasting transparency** • Increase transparency of forecasting models used • Calculations and assumptions have to be transparent, comprehensive and well-documented **Exception management** • Concentrate on outliners (situations where forecast and actual demand strongly differ from another), and identify what went wrong in order to mitigate outliers in the long-term **Data-sharing incentives** • Create incentives for customers (e. g., price promotions) to share their stock levels and other relevant data to increase forecasting accuracy **Determination of clear forecasting responsibilities** • Reduce/eliminate influence of stakeholders on the forecasting process through clear delineation of responsibilities **Provision of rolling forecast to supplier** • to help supplier better preparing for upcoming orders and consequently reducing lead times • have to be binding to a certain extend to initiate activities at supplier
Mid-term	**Forecasting-process-alignment** • Forecasting models used have to be aligned with the product-related production and distribution processes; criticism by process owners has to be considered **Aligned and standardized internal forecast** • defined standards for forecasting • globally (all regions) and on all department levels • same source of data • underlying models and assumptions have to be transparent • expectations on accuracy of forecasts have to be defined

Time Horizon	SCV Management Strategies
	Constant forecasting adjustment • Controlling and adjusting forecasts on a regular basis throughout the company and the SC • Assumptions made must also be challenged and updated on a regular basis **Close communication loop along the SC** • Integrated system with supplier and customer to share relevant data for more accurate forecasts • Frequent communication with customer and supplier about forecasting changes and their reasons rather than just updating them • Honest feedback in all directions, no finger-pointing **Market research** • identification and management of market trends and risks early in advance
Long-term	**Statistically sound forecasts** • Build forecasts on the basis of statistics instead of financial goals by incorporating other aspects as well (if applicable, weather, social media data, etc.) • Establish product life-cycle-dependent customer demand profiles building on comparisons with different product types **Better understanding of product and its customers' needs** • Build up an understanding of the product in all departments instead of leaving this to sales • Intra-organizational communication of relevant customer data from sales through all departments • Better analyses of the causes of consumption to better forecast customer demand **Forecasting CIP (continual improvement process)** • In case of inaccurate forecasts, trace back the root causes and challenge current models and assumptions • Continuous, iterative process of small improvements • Lessons learned have to be disseminated

Table 28 – List of strategies dealing with long and variable lead times

Time Horizon	SCV Management Strategies
Short-term	**Emergency plans** • Define clear emergency concepts in case lead time deviations are experienced at an early stage • Allow for higher spending on transportation in emergency cases; clear cut-off values have to be defined **Incentives of suppliers** • Encourage supplier to proactively communicate lead-time changes **Inter-organizational quality management teams** • Form such interdisciplinary and cross-company teams in order to identify sources of lead time variabilities and tackle them together **Suppliers' documentation duties** • Require supplier to document processes clearly, including the implementation of common milestones • constant re-evaluation necessary **External on-site supplier audits** • supplier audits by external specialists to identify process inefficiencies **Joint carrier selection process** • Implement standardized carrier selection process together with supplier instead of leaving carrier selection to the supplier **Early involvement of supplier** Involve supplier early in the product development process to allow long-term planning and adjustment instead of just requiring steady supply from the start without any involvement

Time Horizon	SCV Management Strategies
Mid-term	**Value stream optimization** • Bring relief to the critical path by intensively analyzing networks and processes that have been built up over years without lead-time optimization in mind **Contractual volume flexibilities** • Delays in supply often arise from order quantities that have not been contractually agreed upon • Include volume flexibility into the contract combined with a flexible pricing system **Widen LSP base** • Diversify LSP base to reduce dependency/ increase flexibility **LSP flexibility** • Arrange for flexible agreements with a broad LSP base instead of relying on just one **Lead time transparency** • Current planning processes often do not incorporate this appropriately • Incorporate lead-times of sub-components in logistics planning (and ERP system) to ensure simultaneous arrival **Alternative routes** • use alternative routes to avoid capacity shortage in peak seasons (e. g. new silk road from China to Germany) **Flexibilization of transport modes** • rethink transportation networks regarding their modes of transport • from China to Germany, transportation by train is 4x more expensive and transportation via airplane 10x more expensive than traditional ship transportation **End-to-end lead time monitoring** • Measure end-to-end lead time and monitor it in ERP system • statistically acknowledge the variability of lead times in the planning processes

Time Horizon	SCV Management Strategies
	Process standardization • Define and standardize processes along the SC mutually (supplier & focal firm) • Standardize necessary information to facilitate information exchange • implement common process controlling **Value stream optimization** • In depth analysis of current customer order process including suppliers' processes in order to to bring relief to critical path **Coaching** • Actively enhance supplier's quality through onsite coaching • Joint communication of issues to create awareness of the consequences of unstable lead times provided by the supplier **Supplier selection process** • Create profound multi-criterion supplier selection process including quality norms and logistics capabilities • More focus on speed than on cost • Standardized approval process **Asset invest** • Invest in own assets (e. g. trucks) to overcome dependence on LSP **Replenishment alignment** Align replenishment strategies along the supply chain to prevent capacity shortages and reduce total lead time
Long-term	**Localization/Regionalization** • Move production closer to the customer, as well as using local suppliers • Some back-shoring/localization trends can be observed, evolving 3D printing can potentially accelerate progress **SC Flexibilization through dual/multi sourcing** • For the most important/strategic parts, search for an alternative supply strategy to reduce dependency and risk of stock outsCross-

Time Horizon	SCV Management Strategies
	regional and/or cross-product line backup sources of supply have been proven to work well • Successful companies tell their suppliers if there is a backup source, and communicate to both of the quantities the other gets in order to create awareness and increase competition among them **3D printing** • Currently economically unfeasible for mass production in most cases, workshop participants are of the opinion that it is just a matter of time until 3D printing becomes more feasible, and lead times will be drastically reduced **Rolling manufacturing site** • In some cases, manufacturing steps such as curing or outgassing can be realized during transportation to reduce unnecessary waiting times **Postponement** • Movement of order-decoupling-point closer to the customer in order to ensure late individualization **Long-term partnerships** • Commit to long-term partnerships with suppliers and/or LSPs to gain priority treatment (in case of China, make use of Guanxi to establish long-term trust and loyalty) **IT infrastructure** • Build up inter-organizational IT systems to enable speed of communication and transparency/traceability of capacities along the SC **Increase logistics flexibilities** instead of trying to perfectly forecasting customer demand, increase logistics capacities to cope with short-term demand fluctuations

Table 29 – List of strategies dealing with erratic behavior of decision makers in the SC

Time Horizon	SCV Management Strategies
Short-term	**Workload-reduction** • Reduction of exhaustion and stress of employees **Allow mistakes (once)** • Encourage employees in telling the truth • Mistakes can happen once but should not happen twice
Mid-term	**Robust processes/process reengineering** • Uninterruptible/gapless end-to-end processes with clear responsibilities that are resistant to failure • People act irrationally because they are given freedom/room to maneuver • Evaluate intra- and inter-organizational processes on a regular basis for early detection of errors **Goal alignment** • Intra-organizational alignment of goals and incentives through all departments and management levels **Root cause analysis** • whenever erratic behavior occurs that induces volatility, the drivers behind such behavior have to be analyzed and understood • open and honest communication of problems without any blaming rather than hiding them • continuous improvement process **Proactive risk management** • Proactively analyze processes • anticipate and assess erratic behavior • mitigate possibility and/or impact of erratic decisions • continuous process **Cross-departmental goal alignment** • same goals lead to less erratic decisions within the organization
Long-term	**Organizational learning as a continuous improvement process** • Problems that occur have to be traced back to their roots to identify causes of interruptions in process chains

Time Horizon	SCV Management Strategies
	• No blaming of individuals allowed • Incorporation of 'lessons learned' and follow-up to improve communication processes; specific effects of misbehavior have to be shown to the people within the organization to create awareness • Resources and capacities for organization learning have to be ensured and responsibilities need to be clarified • Concentrate on often-repeated problems first **Culture of errors** • It's okay to talk about errors in order to mitigate them proactively in the long-term • Implement culture in all departments and on all hierarchy levels • Intra- and inter-organization communication code necessary

Table 30 – List of strategies dealing with erratic behavior of customers

Time Horizon	SCV Management Strategies
Short-term	**Incentive system** • Implement an incentive system that leads the customer to proactively communicate demand changes that it observes in its customer demand **Buffer stock contracts** • Integrate buffer stocks in contractual agreements to increase delivery reliability for the customer and to secure profitability for the manufacturer
Mid-term	**Support of customer in its forecasting** • Data analysis of combined customer demand patterns to support customers in their forecasting based on a larger amount of data **Joint communication and discussion of customer demand behavior with the customer** • If customer regularly changes its demand to a certain extent (numerical boundaries must be defined), the manufacturer has to show the customer the consequences of its demand behavior • To better understand the customer's demand behavior and to adjust its own forecasts accordingly, insights into the sales of the customer as well as its planning processes are helpful • Joint analysis and discussion of gathered data **Frozen-zones** • Limit customer demand changes by implementing time windows where demand changes are not allowed **Root cause analysis for customer behavior** • analyze behavioral patterns of customer and understand the cause of certain behavior • joint analysis with customers is beneficial for both sides **Customer segmentation** • categorize different customer groups and define customized strategies dealing with them instead of one-size-fits-all approaches

Time Horizon	SCV Management Strategies
	Transfer of demand planning competencies
	• send best demand planners to customers in order to transfer strategies/concepts for demand forecasting to the customer in order to reduce unpredictable demand behavior of customer
	Capacity insurance program
	• customer has to buy production strategies early in advance
Long-term	**Dual sourcing**
	• Two suppliers for important components to increase flexibility in meeting customer demand changes
	Component standardization
	• reduce complexity of forecasts by increased number of standard parts
	Product variety reduction
	• decrease number of product variants offered at the market to decrease the level of internal competition

Table 31 – List of strategies dealing with high level of competition

Time Horizon	SCV Management Strategies
Mid-term	**Low cost as USP** • Differentiation from competitors by focusing on cost reduction **Innovation focus** • Stabilize market share by clear focus on innovative ideas to gain market share **Product configurator** • Offering a product configurator to the customer that pretends to offer a high number of product variants, but that in fact involves a low number of components at the manufacturing site due to a sophisticated level of modularization • If not currently implemented in any form, rethinking of product development is necessary and requires know-how
Long-term	**Big Data market research approaches** • In cooperation with research institutes/universities • In-depth Big Data analysis of social media channels (Facebook, forums, blogs, etc.) to derive customer requirements • Obtaining a comprehensive picture of customer requirements assists in reducing the number of product variants → just produce what the customer needs, instead of hoping the customer will buy what you are offering **Strategic partnerships with competitors** • Partnership on large scale projects that are beneficial for all parties • Has been done in the past, but depends strongly on individuals **Increase innovation capabilities** • Focus on innovation assists in setting a company apart from its competitors

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This doctoral thesis seeks to contribute to research on supply chain volatility by three individual research studies. The goal of the thesis is to develop an assessment tool that enables supply chain managers to critically evaluate the current state of supply chain volatility of a product's supply chain. Building on a systematic literature review and insights from two group exercises with supply chain managers, the thesis develops a conceptualization of the dimensions and sources of supply chain volatility. Based on that, the impact of supply chain volatility sources is assessed by applying an Analytic Hierarchy Process and strategies dealing with the most important sources are developed. Subsequently, a supply chain volatility assessment tool is developed that is based on a performance benchmark among 87 manufacturing firms. Additionally a supply chain volatility management framework is proposed that outlines the main management areas and antecedents of successful supply chain volatility management.

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