Integration of Knocked-Down Supply Chains and Global Manufacturing Networks

by

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“Progress cannot be generated when we
are satisfied with existing situations.”

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Taiichi Ohno

Writing this thesis has been a long journey. This journey was fascinating and challenging at the same time, especially when I think of all these delightful insights on the one hand and the tiring, however, revealing setbacks on the other hand. I experienced myself in various different situations and this thesis has helped me to shape my personality. I am thankful that I got the opportunity to conduct this research and to experience this in my life.

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Abstract

Global manufacturing networks and the underlying global supply chains form the centerpiece of global automotive production. Over the last decades, original equipment manufacturers established overseas plants in the course of their expansion strategy and global manufacturing networks evolved. Original equipment manufacturers employed global supply chains to ship all parts pre-assembled and arranged in kits to the overseas plants in order to overcome an unsatisfactory level of qualification of the local work force and an insufficient supplier base. These global supply chains are called knocked-down supply chains. The overseas plants have matured into fully-equipped plants by gradually taking over value-adding processes. As a consequence, the global manufacturing networks and overseas plants have shifted their focus away from simplification toward performance. The underlying knocked-down supply chains, however, have not adapted and still feature high inventories, lead times and costs.

Even though knocked-down supply chains play a key role in global manufacturing networks, they have not been integrated. It is not possible to evaluate the fit of knocked-down supply chains and global manufacturing networks and to accordingly derive the requirements. Despite the intense effort to reduce inventories and lead times in the factories, there is little research on potential improvement levers in the context of knocked-down supply chains.

This Thesis intends to explore how knocked-down supply chains can be aligned with global manufacturing networks. It conducts a cross-case study of six global original equipment manufacturers in order to provide an overview of current knocked-down supply chains and global manufacturing networks. While taking into consideration the theory of transaction cost economics, the Thesis develops an integrated framework that matches knocked-down supply chains and global manufacturing networks and identifies weak spots in supply chain performance. The Thesis applies a two-fold approach and employs analytical modelling and simulation studies. In the first step, the Thesis explores the general working principle of knocked-down supply chains and the interdependencies between individual transport legs by means of intermodal transportation. Gaining impetus from the literature on lean management – a research stream that explicitly targets performance improvements, the Thesis identifies improvement levers and subsequently evaluates their effect on knocked-down supply chains. The Thesis shows that the supply chain performance of knocked-down supply chains and thus the fit with the global manufacturing network can be improved and derives recommendations for implementation.

List of Abbreviations

CKD	completely knocked-down
GMN	global manufacturing networks
MKD	medium knocked-down
OEM	original equipment manufacturer
PBP	part-by-part
SKD	semi knocked-down
SCP	supply chain performance
TCE	theory of transaction cost economics
xKD	knocked-down

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1 Introduction

1.1 Problem Formulation and Motivation

Global Automotive Supply Chains

Global manufacturing networks (GMNs) and their global supply chains have been the backbone of automotive production and the basis for the continuous growth of the original equipment manufacturers (OEMs) for the last decades (Meyer and Jacob 2008). The automotive industry is known for its complexity and high competitiveness (Song 2009). Recent trends, however, have intensified the demanding conditions. Digitalization, sustainability and electric transportation represent enormous challenges for OEMs and have high disruption potential (Opazo-Basáez, Vendrell-Herrero and Bustinza 2018). Consequently, OEMs aim to improve the efficiency of their entire global manufacturing network in order to strengthen their market position and to subsidize the massive investments that go along with carbon reduction and new digital and electrical products (Szalavetz 2019). The underlying global supply chains play a key role in this venture.

Global supply chains link the various suppliers and plants of a GMN and date back to a time when OEMs started to shift their focus toward emerging markets to open up sales opportunities (Koehne 2013). In turn, the respective markets introduced market entry restrictions combined with high import tariffs, asking OEMs to establish production facilities with value-adding activities in order to create jobs and to promote the local economy (Choi, Narsaimhan and Kim 2012). The prevailing qualification level and supplier base in the overseas markets were insufficient for car production, though (Tucher 1999). OEMs thus have installed so-called knocked-down (xKD) supply chains that ship all parts required in order to produce a car, pre-assembled and arranged in kits, from the plant that originally produces the car to overseas plants (Tucher 1999; Song 2009). In other words, OEMs have imported parts of cars rather than complete cars (Choi, Narsaimhan and Kim 2012).

There are four types of xKD supply chains that primarily differ with respect to the aggregation level of the parts and the required facilities at the overseas plant (Schulz and Hesse 2009; Klug 2010). Semi-knocked-down (SKD) supply chain is the first type and ships partially-disassembled cars which are reassembled at the overseas plant (Schulz and Hesse 2009; Koehne 2013). Easily-handled parts such as tires and seats are taken off the car and shipped in a kit to the overseas plant (Schulz and Hesse 2009). In medium knocked-down (MKD) production, the overseas plant entirely assembles the cars and accordingly the MKD supply chain delivers the required assembly parts as well as the painted bodies in the form of kits (Schulz and Hesse 2009; Song 2009). Completely knocked-down (CKD) supply chains represent the third type. They ship all parts in the form of kits to overseas plants that carry out the entire production process from the body shop to the assembly line (Freyssenet, Shimizu and Volpato 2003; Koehne 2013). Part-by-part (PBP) supply chains omit the kitting process in contrast to CKD supply chains and ship all parts in separate boxes, volume-optimized and without a reference to a dedicated car (Schulz and Hesse 2009; Klug 2010).

XKD supply chains were designed in the initial phase of global production and have barely been adapted since (Tucher 1999; Trippner 2006; Song 2009). The primarily goal of xKD supply chains was to enable overseas plants to produce highly-complex products despite a lack of substantial pre-conditions (Klug 2010; Koehne 2013). Kits simplify the logistics und production processes at the overseas plants and deliver all parts belonging to a certain car and a certain production step in a conjoined form (Klug 2010; Koehne 2013). XKD centers provide a special overseas packaging since xKD supply chains ship parts through different temperature zones that often involve high humidity and the fact that maritime high-cube containers and continental trucks vary significantly dimension-wise (Klug 2010). The supply chain performance (SCP) of xKD supply chains has been low, though. XKD supply chains are typified by long lead times, high buffer levels and shipping costs independently from the xKD supply chain type (Trippner 2006; Song 2009; Erfurth and Bendul 2018). At xKD centers, OEMs hold buffers of up to one month for two reasons (Tucher 1999, Trippner 2006; Song 2009). Firstly, they want to ensure all the parts required for packing a specific kit or container are available to avoid disturbances and time-intensive repacking operations (Schulz and Hesse 2009; Song 2009). One can imagine that missing parts highly affect the xKD center´s efficiency since one car consists of more than 1,000 parts where each is assigned a dedicated position in this concept (Klug 2010). Secondly, OEMs aim for a high delivery reliability at the container dispatch in order to prevent delivery delays which potentially result in expedited shipping and soaring air freight costs (Schulz and Hesse 2009). On the downside, these high buffers lead to prolonged lead times, multiple handling and extensive storage space requirements. The impact on costs is significant since OEMs and their original plants are located in industrialized countries with high labor and real estate costs and xKD supply chains usually supply emerging markets (Schulz and Hesse 2009). All this highlights the importance of xKD centers and likewise emphasizes the special role of the subsequent long-haul transportation. The maritime transport leg bridging the global distance inevitably involves a long transportation time and low service frequency and results in high costs (Schulz and Hesse 2009; Song 2009). Whereas OEMs usually negotiate from a position of strength, the market power in the maritime business is negligible. Ocean vessels carry up to 21,000 containers whereas OEMs ship only a few containers on each of them (Fehse 2016). In a nutshell, the SCP of xKD supply chains is low and the main determinants, the xKD center and the long haul, neither have been investigated separately nor combined.

Global Manufacturing Networks

XKD supply chains are closely related to GMNs. A GMN can generally be understood as a network of globally-dispersed plants where each plant holds a dedicated strategic role (Ferdows 1989). There are five different phenotypes of GMNs. The phenotypes mainly differ with respect to the working principle and thus the role and capabilities of the plants (Meyer and Jacob 2008).

In the context of GMN, global supply chains hold a coordination role and target the appropriate management of the available assets and infrastructure by aligning the material flow with the capabilities of the plants (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999). Meyer and Jacobs (2008) translate these coordination requirements into transaction costs and incorporate this perspective into their framework. Transaction costs describe the effort that is involved in order to transfer products to further downstream stages of the supply chain and thus is closely-related to SCP which determines the effort by means of lead time, reliability and costs (Mohammady 2012). The framework enables the determination of the coordination requirements in terms of transaction costs depending on the respective GMN phenotype (Meyer and Jacob 2008). This also implies that the GMN phenotypes have different coordination requirements which directly affect the SCP expectation for the underlying global supply chain.

In the automotive industry, OEMs established their first overseas plants decades ago (Lehmann 2002; Meyer and Jacob 2008). In the meantime, some of the overseas plants have developed into fully-equipped plants (Lehmann 2002; Meyer and Jacob 2008). Volkswagen, as an example, shipped only two percent of its parts via xKD supply chains to its Chinese plants back in 2000 (Lehmann 2002). Accordingly, the GMNs of the OEMs have developed, too and thus the coordination requirements have changed (Meyer and Jacobs 2008). However, there is no research approach that integrates xKD supply chains and GMNs. The GMN coordination requirements consequently remain unconsidered when planning and managing xKD supply chains (Pontrandolfo and Okogbaa 1999; Meyer and Jacob 2008). We have shown that xKD supply chains barely have evolved and are still typified by a low SCP (Song 2009). It is to reason that xKD supply chains do not meet the coordination requirements of the GMNs.

Intermodal Transport Chains

Intermodal transportation is a research field that explicitly analyzes transport chains with multiple transport legs regarding performance and interdependencies. Intermodal transportation is defined as the movement of goods in one and the same loading unit or vehicle that successively uses two or more modes of transportation without handling the goods themselves in changing modes (Economic Commission for Europe 2001). A usual intermodal transport chain consists of three transport legs which are called pre-, long- and post-haul and transports a container as a universal loading unit via different modes of transport (Macharis and Bontekoning 2004; Crainic and Kim 2005). The container is first collected from the shipper by a truck in the course of the pre-haul before it is transshipped to a train or vessel that carries the container on the long-haul (Macharis and Bontekoning 2004; Crainic and Kim 2005). The post-haul ships the container eventually from the destination terminal to the receiver – again by road (Macharis and Bontekoning 2004; Crainic and Kim 2005). The long-haul represents the main advantage of intermodal transportation and enables companies to take advantage of economies of scale and thus to achieve low transportation costs and emissions (Zhang and Pel 2016). From a transportation perspective, xKD supply chains can be understood as intermodal transport chains. The processes surrounding the xKD center represent the pre-haul, the maritime transportation serves as the long-haul and the hinterland transportation to the overseas plant serves as the post-haulage.

The research on intermodal transportation that aims to identify improvement levers or the most promising transport chain solution first and foremost compares multiple alternatives by means of costs (Janic 2007; Hanssen, Mathisen and Jorgensen 2012). Existing research works compare transport routes that employ different transport modes or deviating distances of the long-haul (Janic 2007; Hanssen, Mathisen and Jorgensen 2012). There is no research that employs multiple performance indicators in order to analyze transport chain alternatives. Transportation time as a common logistics goal is – if at all – considered as an auxiliary condition that has to be complied with in order to qualify as a valid alternative (Kreutzberger 2008; Verma and Verter 2010). With regard to transportation time and transport time reliability, there has not been an analysis conducted on an entire transport chain consisting of multiple transport legs. Researchers have focused on selected sections of an intermodal transport chain, e.g. the transshipment terminals or different transport modes for a specific transport leg (Rizzoli, Fornara and Gambardella 2002; Sgouridis, Makris and Angelides 2003; Wiegmans, 2010). Research lacks an approach that investigates the connection of the different transport legs as well as the overall effect on transportation time and transport time reliability. As a result, it is not possible to evaluate how the adaptation of one transport leg will affect subsequent transport legs and the entire transport chain.

In summary, literature on intermodal transportation forms a basis for analyzing xKD supply chains and provides insights in particular with regard to costs. This research stream, however, lacks a systematic analysis on transportation time and transport time reliability in order to enable researchers and practitioners to assess the consequences of adapting intermodal transport chains.

Lean Management in Global Supply Chains

Lean management is a research approach that aims for performance improvements and is widely applied in the production and supply chain environments – particularly in the automotive industry (Womack, Jones and Roos 1990). The central idea of lean management is to achieve "more with less" by avoiding waste in all respects (Ohno 1988; Womack, Jones and Roos 1990). Lean management represents a set of tools for the optimization of production systems and targets the elimination of all non-value-adding activities within an organization (Shah and Ward 2007). The general understanding of lean management is that it can be applied essentially anywhere (Levy 1997). In the context of global supply chains, however, there has been a debate for more than 20 years (Berger, Tortorella and Rodriguez 2018; Lorentz, Kumar and Srai 2018). One group of researchers states that global supply chains cannot be fast and seamless by definition as they have long lead times and low shipping frequencies which fundamentally contradict the philosophy of lean management (Cusumano 1994; Levy 1997; Holweg, Reichhart and Hong 2011; Stanczyk et al. 2016). Another group of researchers, however, argues that lean management positively affects the SCP of global supply chains and diminishes the negative effects of long-distance transportation (Fawcett and Birou 1992; Cheng 2011; Golini, Caniato and Kalchschmidt 2016; Lorentz, Kumar and Srai 2018).

Researchers have suggested measures to improve the SCP during the course of research on lean management in global supply chains (Krueger 2004; Salmi 2006; Staudacher and Tantardini 2009; Cheng 2011; Golini, Caniato and Kalchschmidt 2016). One measure, for example, is the consolidation of multiple parts into one single shipment in order to reduce the order lot size (Staudacher and Tantardini 2009; Cheng 2011). However, there is no research that combines the various measures of lean management in global supply chains. Research lacks an analytical investigation of these measures to either support or reject the applicability of lean management in global supply chains, too (Staudacher and Tantardini 2009; Cheng 2011; Stanczyk et al. 2016). The existing literature on lean management in global supply chains has discussed the measures solely in a qualitative manner (Staudacher and Tantardini 2009; Cheng 2011; Stanczyk et al. 2016).

With regard to xKD supply chains, research on lean management in global supply chains can be a basis for identifying potential improvement levers. So far, there has not accordingly been an analysis of the respective measures in the context of xKD supply chains. An integration of lean management into global supply chains and xKD supply chains appears to be promising for both research streams. XKD supply chains can serve as a usage case for lean management in global supply chains and thus contribute to the ongoing debate about the applicability of lean management and xKD supply chain can gain impulses for potential SCP improvements.

Research Gaps

The research streams that have been presented contain research gaps that hinder the realization of xKD supply chains that successfully support GMNs. The literature on GMNs shows that GMNs have evolved over time in the automotive industry whereas xKD supply chains have barely developed and feature a low SCP. This results in a potential misfit of the actual SCP of xKD supply chains and the requirements of the supplied GMNs. Intermodal transportation and lean management in global supply chains are two research streams that provide impetus to identify and evaluate possible improvement levers, but lack both a holistic perspective and analytical investigations. We have identified the following research gaps:

1) There is consensus that xKD supply chains are characterized by poor SCP. There is barely any research on potential improvement levers, though. There has not been a systematic investigation and evaluation of improvement levers with regard to SCP and their interdependencies among each other. Research also lacks an implementation approach for the improvement levers that considers the vital importance of xKD supply chains for overseas plants and the looming risk of soaring air freight costs in case of process failure.

2) XKD supply chains and GMNs are closely-related, but have not been integrated yet. It is not possible to match the coordination requirements of the various GMN phenotypes with the characteristics of the xKD supply chains as a consequence. There is no connection between them. XKD supply chains cannot meet the coordination and performance requirements of GMNs, and hence support them appropriately.

3) Research on intermodal transportation that analyzes alternative transportation solutions or improvement levers considers solely costs as a decision variable. This perspective is one-dimensional and neglects the effects on other essential performance indicators such as transportation time and transport time reliability, though. Intermodal transportation research that addresses particularly transportation time and transport time reliability, on the other hand, focuses on selected parts of an intermodal transport chain and not on the entire transport chain. Consequently, there is no understanding of the interdependencies among various transport legs within one intermodal transport chain with respect to these two performance indicators.

4) With respect to lean management in global supply chains, there is no profound overview of the several measures introduced by researchers. Each research work concentrates on a selection of the measures and non has analyzed them holistically. The suggested measures have not been transferred to xKD supply chains, either. Researchers argue qualitatively and have not conducted analytical investigations that quantify the effect of lean management measures on the SCP of global supply chains. As a result, there still is an ongoing debate on the applicability of lean management in global supply chains.

1.2 Research Objective

This research aims to explore the relationship between xKD supply chains and GMNs and to develop improvement levers that adapt the SCP of xKD supply chains to the GMN requirements. Hence, this research work addresses the following main research question:

"How can xKD supply chains be aligned with the GMN in order to increase the SCP in terms of lead time, inventory level and costs?"

In order to answer the main research question, the following sub-research objectives have been established:

1) Integrate xKD supply chains and the GMN and analyze the fit of currently operated xKD supply chains and the respective GMNs.

The first step in addressing the research question is creating a connection between xKD supply chains and GMNs. A comprehensive review of literature on GMNs, with special emphasis on the individual GMN phenotypes and the coordination role of the underlying supply chains, serves as a basis for obtaining the requirements for xKD supply chains. An analysis of currently operated xKD supply chains as well as employed GMNs with respect to SCP enables the examination of the fit and the highlighting of discrepancies. These discrepancies can then be analyzed in subsequent research steps.

2) Analyze how transport legs of an intermodal transport chain affect the transportation time and transport time reliability of the entire intermodal transport chain.

The second research objective intends to transfer knowledge on comparing alternative transport solutions and improvement levers from intermodal transportation to xKD supply chains. An understanding of the overall working principle of xKD supply chains has been established. Literature on intermodal transportation, however, disregards the effects on transportation time and transport time reliability in this respect. Literature falls short of an understanding of interdependencies among transport legs – in particular with regard to transportation time and transport time reliability. An analysis is carried out that explores the effects of adapting individual transport legs to transportation time and transport time reliability to the entire intermodal transport chain. The benefits are two-fold. On the one hand, the results pinpoint improvement levers in order to address the previously-identified SCP deficits of xKD supply chains. On the other hand, the analysis depicts the independencies among the transport legs and enables the assessment of the effect of adapting one transport leg to the entire transport chain.

3) Identify and evaluate improvement levers in order to enhance the SCP of xKD supply chains by transferring measures from lean management to global supply chains in order to align xKD supply chains with the requirements of GMNs.

Based on the SCP evaluation of xKD supply chains and the understanding gained of interdependencies within intermodal transport chains, the third research objective aims to explore improvement levers for xKD supply chains. Lean management in global supply chains is an approach that aims at performance improvements which have not been applied to xKD supply chains. The Thesis conducts an intense literature review on lean management in global supply chains and compiles the proposed measures. An analysis investigates the proposed measures when they are applied to xKD supply chains with regard to the SCP. In summary, all findings collectively serve as a basis for drawing conclusions on how to improve the fit and SCP of xKD supply chains with regard to the requirements of GMNs.

1.3 Course of Research

In order to answer the research question presented in the previous section, the Thesis will be structured into five chapters including this introductory chapter as shown in Figure 3. Chapters 2, 3 and 4 present the main papers of this research.

The goal of the first paper presented in Chapter 2 is to develop an integrated framework that aligns xKD supply chains with GMNs and to analyze the fit of currently operated xKD supply chains and GMNs. A two-fold research approach is applied that primarily involves literature review and cross-case study research. The literature review describes the state-of-the-art of the respective research fields and forms the basis in order to derive key characteristics of GMN phenotypes and xKD supply chain types that further serve as distinguishing determinants for the categorization of GMNs and xKD supply chains. Based on this, a cross-case study of six globally-producing OEMs analyzes currently employed GMN phenotypes and xKD supply chain types. By means of the theory of transaction cost economics (TCE), the paper develops an integrated framework that enables the alignment of the xKD supply chains with GMNs by using transaction costs as a vehicle in order to express the coordination requirements of GMNs. The paper investigates the fit of the xKD supply chains and GMNs of the selected OEMs and generates initial ideas for improvement measures. The results are discussed with experts from OEMs as well as their service providers.

Outline	Methods & Theories	Objective
Introduction		• formulate problem and present motivation, research gaps, research objectives and course of research
Paper 1: Integration of global manufacturing networks and supply chains: a cross-case comparison of six global automotive manufacturers	• literature review • transaction cost economics • interviews with experts • cross-case study	• integrate xKD supply chains and GMN phenotypes • analyze the current performance of xKD supply chains and the GMN coordination requirements • determine misfits and starting points for potential improvement measures
Paper 2: Transportation time and reliability in intermodal transport chains	• literature review • analytical modeling • discrete event simulation	• understand interdependencies between sub legs • analyze the effects of adapting sub legs on the total intermodal transport chain • establish a basis for analyzing transportation time and reliability of an intermodal transport chain
Paper 3: From lean factories to lean global supply chains – implications for supply chain performance and costs in global, intermodal automotive supply chains	• literature review • Interviews with experts • cross-case study • discrete event simulation	• transfer lean management to xKD supply chains • identify and investigate improvement levers for xKD supply chains on supply chain performance • assess the applicability of lean management in global supply chains given the example of xKD supply chains
Discussion and Conclusion:		• present contribution to the several research fields • present implication for practice and managerial contribution • present limitations • present future research opportunities

Figure 1: Thesis Outline, Methods and Objectives

The second paper intends to gain an understanding on how individual transport legs of an intermodal transport chain depend on one another. It further aims to define transportation time and transport time reliability for intermodal transportation in order to establish a set of performance metrics instead of transportation costs only when analyzing various transport alternatives in this context. A literature review carves out the working principle of intermodal transport chains and displays current knowledge on comparing alternative intermodal transport solutions. Given the already-identified research gaps, the paper develops a mathematical model that describes the transportation time and transport time reliability of intermodal transport chains. Combined with a discrete event simulation, the paper studies various parameter set-ups for single transport legs including different probability distributions and displays the effects on the transportation time and transport time reliability of the entire intermodal transport chain.

Chapter 4 presents Paper 3 which targets the identification and evaluation of improvement levers for xKD supply chains by transferring knowledge from lean management to global supply chains. An intense literature review on lean management in global supply chains is conducted and the individual measures of the several research works are compiled into one approach. The paper applies the identified measures to xKD supply chains and explores the effects on the SCP. Therefore, the paper performs a discrete event simulation. A cross-case study complements the simulation study and analyzes the current SCP of xKD supply chains. In this way, the initial parameter set-up can be established and the results can be validated. The paper investigates the individual measures solely and in combination and explores the potential SCP considering a set of SCP indicators.

Chapter 5 concludes this Thesis. It summarizes the key contributions to the several research streams, outlines the implications for practice and presents limitations as well as future research opportunities.

Contributions of Publications to Research Questions and the Thesis Structure

The content of this Thesis is structured into five chapters and three main papers. Figure 2 displays each publication´s contribution to the research questions of this Thesis. Contributions marked without brackets indicate the main focus of the respective paper whereas markers with brackets illustrate adjacent contributions to a research question.

	Paper 1 Chapter 2	Paper 2 Chapter 3	Paper 3 Chapter 4
Research Question 1	x		(x)
Research Question 2		x	
Research Question 3	(x)	(x)	x

Figure 2: Overview of Publications´ Contribution to the Research Questions

The main focus of the first paper is the integration of xKD supply chains and GMN phenotypes and the analysis of the according fit of current OEMs. The integrated framework that is developed basically lays the foundation for this research as it aligns xKD supply chains with GMNs and makes it possible to derive the respective requirements. Whereas former researchers hypothesized that xKD supply chains do not meet the expectations, this integrated framework systematically derives the requirements and assesses the fit. In combination with the cross-case study, this paper discloses the weak spots in currently employed xKD supply chains and thus pinpoints subsequent research demands which essentially structures this research. The paper further develops an initial hypothesis on how to improve the SCP of xKD supply chains and thus the fit with the corresponding GMNs.

The second paper approaches the research problem from a different angle. Taking the perspective of intermodal transportation, this paper analyzes the interdependencies among individual transport legs and investigates the impact of each transport leg on the entire transport chain´s performance. This enables us to assess the impact of measures on intermodal transport chains which, in turn, allows us to focus on the most promising improvement levers in the course of Paper 3. The second paper also establishes the basis for analyzing all relevant SCP metrics of intermodal transport chains and xKD supply chains since it defines transportation time and transport time reliability in this context.

Based on this, the third paper transfers improvement measures from lean management in global supply chains to xKD supply chains and evaluates the overall SCP achievable. On the one hand, the paper tackles the deficiencies revealed in the course of the first paper. On the other hand, the paper focuses on the improvement measures that are most promising in keeping with the findings of Paper 2 and considers a comprehensive set of SCP metrics including transportation time and transport time reliability. In this way, the third paper identifies and analyzes improvement levers in order to enhance the SCP of xKD supply chains in order to improve the fit with the corresponding GMNs.

Chapter 5 presents the conclusion of this Thesis and outlines the contributions of the papers to the research objectives and the overall research question.

2 Paper 1: Integration of Global Manufacturing Networks and Supply Chains: A Cross-Case Comparison of Six Global Automotive Manufacturers

Authors: T. Erfurth, J. Bendul

Status of the Publication: Published in the International Journal of Production Research. 2018, 56 (2), pp. 1-23

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Contribution of T. Erfurth to the Work: Conducted the cross-case study and secondary data research and wrote all sections of the manuscript. Contributed to the development of the integrated framework of the xKD supply chains and GMNs and the interpretation of the results.

Contributions of the Co-Author: J. Bendul contributed to discussions on the development of the integrated framework of the xKD supply chains and the GMN, jointly interpreted results, reviewed, streamlined and helped to write all sections of the manuscript.

Contributions of the Paper to the PhD Project: This paper conducts a systematic cross-case study and provides an overview of current GMNs and xKD supply chains in the automotive industry. The paper develops an integrated framework that aligns xKD supply chains with GMNs by means of TCE. On this basis, the fit of currently employed xKD supply chains and GMNs is evaluated and deficits are discussed in detail. The paper proposes hypotheses on potential improvement levers and suggests further issues to investigate.

Integration of global manufacturing networks and supply chains: A cross case comparison of six global automotive manufacturers

Striving for new business opportunities automotive equipment manufacturers (OEMs) established overseas plants in emerging markets and global manufacturing networks evolved. In this regard so-called knocked down supply chains have been the key for the establishment of successful overseas operations. Importing all parts required from the original plants in form of easy to be handled kits secures a high product quality and stable supply despite lacking qualification of local workforce and supplier bases. Over time the overseas plants and global manufacturing networks have matured by increasingly taking over value adding processes and integrating local suppliers. However, the supply chain structure and management have not been adapted accordingly and still comprise high inventory buffers and lead times. There is little research on the integrated design of global manufacturing networks and knocked down supply chains. This research aims to contribute to close this research gap by means of a cross-case study with six globally operating OEMs investigating the fit of knocked down supply chains and global manufacturing networks. On the basis of transaction cost theory, we develop an integrated framework to align global manufacturing networks and knocked down supply chain design that can serve as guideline to open logistics performance and cost potentials.

Keywords: global supply chains, supply chain network design, manufacturing networks, global manufacturing, automotive industry, completely knocked down, knocked down supply, transaction costs, cross case study

1. Introduction

In course of an accelerating globalization and saturation of the traditional automotive markets original equipment manufacturers (OEMs) have shifted their focus towards less mobilized markets (Köhne 2013). In order to comply with prevalent market entry policies OEMs established plants in markets abroad and global manufacturing networks (GMNs) emerged (Choi, Narasimhan and Kim 2012). Within these markets OEMs faced the challenge to secure high quality products and stable supply despite commonly lacking qualification levels and supplier bases (Tucher 1999). As a consequence, OEMs have employed cost-intensive knocked down (xKD) supply chains to ship all parts required to manufacture a car, pre-assembled and arranged in kits, from the original to the overseas plant (Tucher 1999; Song 2009).

Over time the overseas plants have constantly developed to self-sustained plants and meanwhile source carefully selected parts via xKD supply chains only instead of generally all (Jacob and Strube 2008). As plants in traditional markets, overseas plants increasingly aim for performance and cost efficiency (Schulz and Hesse 2009). While the scope of parts has been adapted the underlying structure and working principle of theses xKD supply chains have remained the same (Trippner 2006). Thus, the xKD supply chains - designed in the initial phase of manufacturing network growth - do not meet present performance requirements and comprise high WIP levels and lead times contrary to regular automotive supply chains (Trippner 2006; Song 2009)

There is little research on performance of xKD supply chains in general and possible improvement measures in particular (Song 2009). Hence, the guiding research question is: *How can xKD supply chains be aligned to GMNs in order to increase performance in terms of WIP level, lead time and costs?* This research aims at analyzing the fit of xKD supply chains and GMNs as well as integrating them to improve the performance in a way that xKD supply chains are capable to meet present and future requirements.

For this, an encompassing literature review on GMNs, the resulting performance requirements for the underlying supply chains and xKD supply chains is accomplished. Theoretical guidance is provided by the Theory of Transaction Cost Economics (TCE) as it establishes the basis to align xKD supply chains with GMN by means transaction costs (Mohammady 2012). A cross-case study of six globally operating OEMs is accomplished to evaluate the fit of manufacturing network and supply chain design and to derive recommendations on improvement potentials and on the general design of xKD networks.

The remainder article is structured as follows. In section 2, a profound literature review on GMNs, xKD supply chains and TCE is presented and the main research gap is derived. Section 3 specifies the cross-case methodology, for which the main findings are presented and discussed in section 4. Section 5 gives a conclusion and shows further research opportunities.

2. State of the art

Several research streams demonstrate the importance of the proposed research problem and provide relevant input. Research on GMN introduces GMN phenotypes in the automotive industry and derives their individual coordination requirements that address the management and infrastructure of GMNs (Shi and Gregory 1998). XKD supply chains hold the respective coordination role that is primarily affected by their performance (Pontrandolfo and Okogbaa 1999). TCE allows expressing both the coordination requirements of GMN as well as the performance of the xKD supply chains in terms of transaction costs and thus, enables us to match xKD supply chains with GMN and to improve the performance if necessary (Grover and Malhotra 2003).

2.1 Globalization of automotive production

In the 20s century, the automotive industry has been reshaped by an accelerating globalization. Driven by technological innovations and emerging markets OEMs have adapted their business strategies and with them their GMNs (Jacob and Strube 2008).

GMNs can be understood as networks of plants with dedicated strategic roles that are globally dispersed (Ferdows 1989). In the automotive industry GMNs operate on global scale and have experienced several development stages (Lehmann 2002; Jacob and Strube, 2008). Meyer and Jacob (2008) provide a classification that explicitly considers these two characteristics. It distinguishes between five GMN phenotypes that differ primarily in their working principle (Meyer and Jacob 2008). The classification allows assigning phenotypes to OEMs and to derive the corresponding xKD supply chain requirements via transaction costs (Meyer and Jacob 2008).

Volkswagen is one example showing that manufacturing networks evolve over time and that in particular in the automotive industry the manufacturing networks have passed different stages of GMN phenotypes: When Volkswagen re-launched its car production back in 1945 it produced all cars in Wolfsburg and thus a *world-factory* was born (Grieger and Lupa 2015). In the 1950s when export sales grew Volkswagen founded its first overseas plant in Brazil that assembled imported car kits from Germany (Grieger and Lupa 2015). Driven by market restrictions asking for foreign direct investments, Volkswagen´s GMN steadily transformed to a *hub-and-spoke-network* with additional overseas plants in South Africa, Australia and Mexico characterized by strong support from its headquarters (Ferdows 1997; Schulz and Hesse 2009; Grieger and Lupa 2015). In the following years the number of Volkswagen´s overseas plants grew while their local value added rose and the GMN evolved to a *local-for-local-network*. So was the local value added of the Volkswagen Santana in China 98% in 2000. Since then the material flow between the markets has flourished and Volkswagen established xKD centers in former emerging markets to ship parts to further overseas markets but also to their European counterparts (Lehmann 2002; Fehse 2016). As a result Volkswagen´s GMN has transformed into a *web-structure-network*.

The evolution of Volkswagen´s GMN shows how the *maturity of the overseas plants* has resulted in changes in different *material flow structures between plants*.

Different measures can be used to evaluate *maturity* and *material flow structure* (table 1).

Even though the material flow represents a distinguishing determinant for GMN phenotypes in the automotive industry and furthermore holds the according coordination role there is no research on the resulting requirements for xKD supply chains (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Stremme 2000; Meyer and Jacob 2008). Thus, the GMN coordination requirements remain unconsidered when planning xKD supply chains which potentially leads to a misfit and restricts xKD supply chains from optimally supporting the respective GMN phenotype with adequate performance (Shi and Gregory 1998; Meyer and Jacob 2008).

2.2 XKD supply chain design and operations

The performance and stability of the xKD supply chains are crucial factors to enable OEMs to launch and operate overseas plants by stepwise increasing the value added and complexity in the overseas markets (Schulz and Hesse 2009; Choi, Narasimhan and Kim 2012). However, so far there is no specific research that addresses the specific requirements of xKD production on supply chain design and management (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Stremme 2000; Meyer and Jacob 2008).

The core task of an xKD supply chain is the delivery of all parts required to manufacture a car, pre-assembled and arranged in kits, from the plant originally producing the car to the overseas plant (Tucher 1999). In other words xKD supply chains import parts of a car and not the car as a whole (Choi, Narasimhan and Kim 2012). XKD supply chains are first and foremost required to comply with prevailing market entry restrictions and to avoid high customs of up to 300% both asking for an increased local value added when sales volumes grow (Schulz and Hesse 2009; Klug

2010; Köhne 2013). The local value added is calculated based on the OEM´s total fleet sold within the market and hence, OEMs establish overseas plants and xKD supply chains for their volume products (Schulz and Hesse 2003; Köhne 2013). In course of a so-called feasibility study an OEM defines a limited number of product configurations to be produced overseas, for example three different engines, eight colors and four interiors of a candidate car model, to reduce process complexity and to attract as many customers as possible simultaneously (Schmidt 2009; Klug 2010; Köhne 2013). Luxury car models and highly equipped cars of the OEMs are shipped on parallel fully build up (FBU) from the original plant and thus benefit custom-wise from the locally produced cars (Tucher 1999). Small and budget car models, however, are usually not considered for supplying overseas markets as the comparably high transportation costs for ocean shipping exceed the expected returns (Tucher 1999; Schulz and Hesse 2009; Stade 2016). In a nutshell, xKD supply chains enable OEMs to enter emerging markets despite prevailing market entry restrictions, high customs, an insufficient supplier base and low qualification level (Schulz and Hesse 2009; Choi, Narasimhan and Kim 2012).

So-called *xKD centers* consolidate the parts to be shipped and pack them into overseas packaging (Schulz and Hesse 2009; Song 2009; Klug 2010). Special overseas packaging is required due to much more demanding environmental conditions and diverging dimensions of maritime transportation (Klug 2010). Subsequently, xKD centers arrange the parts in kits according to the production pitch and load them into sea freight containers ready for shipment to the overseas plant (Schulz and Hesse 2009; Song 2009; Klug 2010).

With an increasing share of local value added the xKD supply chain types semi (SKD), medium (MKD) and completely knocked down (CKD) as well as the part by part (PBP) stepwise bridge the gap between either full build up (FBU) delivery or total local production (Freyssenet, Shimizu und Volpato 2003; Schulz and Hesse 2009; Song 2009; Klug 2010; Choi, Narasimhan and Kim 2012; Köhne 2013). Whereas SKD entails the shipment of nearly finished cars that solely lack a few parts such as tires, seats or engine, CKD and PBP supply chains ship all parts disassembled to the overseas plants producing the entire car (figure 1). In this order the *shipping volume per car* and *average box size* decrease as fewer parts and most notably less volume intense parts are shipped (Schulz und Hesse 2009; Song 2009; Klug 2010). In PBP supply chains, however, the various parts numbers are not arranged in kits that comprise the exact number of parts required to manufacture a specific car lot, for instance six cars. Instead, PBP supply chains ship parts similarly to usual continental transport services in separated boxes where each box contains carries as many parts as possible of one specific part number. (Schulz and Hesse 2009; Song 2009). Thus, both the *scope of delivery* as well as the *packaging concept* can be used to distinguish different types of xKD supply chains (table 1).

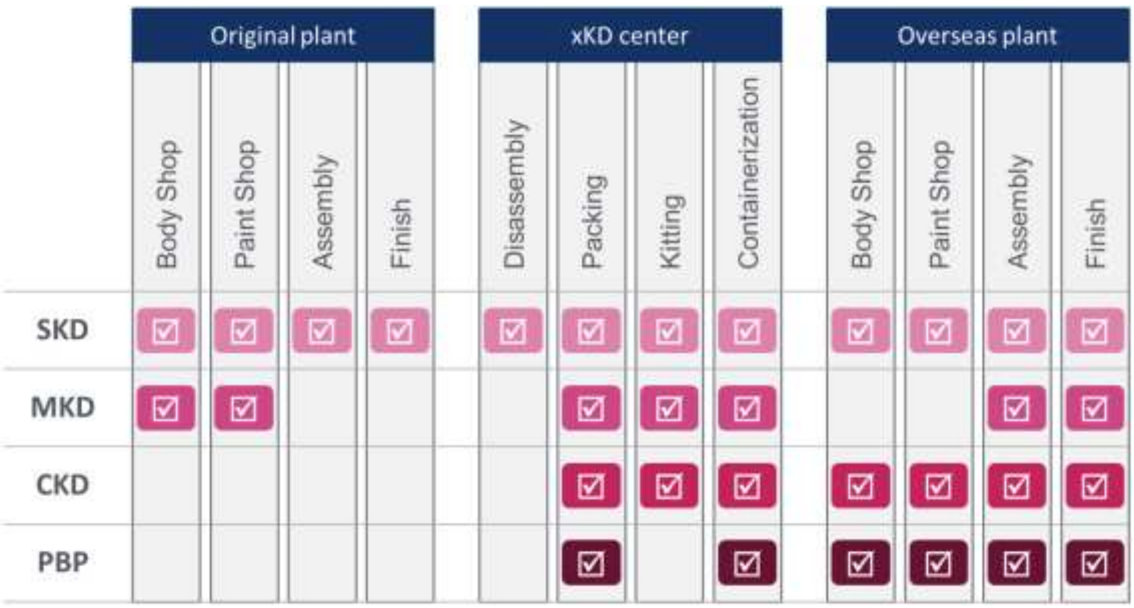

Figure 1. xKD supply chain types (adapted from Fehse [2016]).

Despite their importance for globalization of automotive industry, structure and management of xKD supply chains have not changed significantly while GMNs have developed as shown for the Volkswagen example (Lehmann 2002; Trippner 2006; Song 2009). Research on xKD supply chains has not even systematically assessed or compared different xKD supply chains of various OEMs to identify best practices (Lehmann 2002; Song 2009). There is also no research on how these xKD supply chains comply with the coordination respectively performance requirements arising from the respective GMNs as well as on individual improvement levers to adjust them (Trippner 2006; Song 2009). Thus, xKD supply chains are still characterized by excess inventories and long idle times independent from the underlying GMN and xKD supply chain type. OEMs hold buffer inventories of up to one month at their xKD centers in order to avoid expediting shipping costs (Camuffo and Volpato 2002; Trippner 2006; Song 2009; Talavera 2015). The results are aging stock, increased capital lockup and restricted flexibility (Talavera 2015).

2.3 Transaction Cost Economics in global supply chains

The integration of xKD supply chains and GMNs becomes clearer and richer if examined from a theoretical perspective. We consider implications of theories that explore the fit of supply chain structures based on coordination requirements.

Network Theory analyzes relations between linked plants and suggests that strong ties provide greater reliability while loose ties enhance flexibility and thus to choose the xKD supply chain type appropriately (Theorelli 1986). Resource Dependency Theory argues that in case a firm becomes overly dependent on others, such as an overseas plant on original plants, it strives to strengthen its position for example by adopting an xKD supply chain with higher local value added (Pfeffer and Salancik 1978). Resource-Based View examines how resources lay a foundation for competitive advantage and hence provide an argumentation line to adopt a local value added respectively xKD supply chain dependent on disposable resources within the market (Barney 1991). Agency Theory investigates opportunistic behavior of an entity that acts on behalf of another and suggests to balance interests via incentives and thus to adjust the xKD supply chain type to affect the overseas plant´s incentive (Eisenhardt 1989a). TCE analyzes whether to keep or outsource a process based on transaction costs between organizations and suggest choosing xKD supply chains dependent on the transaction costs involved (Williamson 1975). From these theories, TCE is the only theory that takes a process perspective and thus enables us to match xKD supply chains and GMN and likewise identify potential improvement levers to enhance their performance. As a result we employ TCE for theoretical guidance.

In context of automotive GMN, TCE fundamentally contributes to address the two major challenges raised by the research question. On the one hand, TCE comprises an approach to explain the suitability of xKD supply chain types to the requirements of OEMs and thus their GMNs. On the other hand, TCE provides the opportunity to identify levers to adjust the performance with regard to WIP level, lead time and cost in a way that xKD supply chains meet the coordination requirements of GMNs.

With regard to the first challenge, TCE can be employed to allocate the value adding activities between overseas market and headquarters whereas xKD supply chains represent the according implementation medium (Stölzle 1999; Schulz and Hesse 2009; Bremen et al. 2010; Klug 2010; Mohammady 2012; Köhne 2013). While in SKD supply chains almost finished cars with a low local value added are shipped, in CKD supply chains the overseas plants manufacture the cars completely and major shares of the parts are sourced locally (Schulz and Hesse 2009; Klug 2010; Köhne 2013). Thus, TCE can be used to explain how OEMs decide for a specific xKD supply chain design.

Transactions are the central element within TCE. They represent transfers of products to further downstream stages which cause transaction costs (Williamson 1975;

Dietl 1991; Mohammady 2012). Transaction costs account for efforts involving information, communication and coordination and relate to processes of searching, initiation, execution, adaptation and controlling (Dietl 1991; Clemons et al. 1993). In case of high transaction costs, TCE proposes a high level of vertical integration and vice versa (Picot 1991; Grover and Malhotra 2003). If the transaction costs for an increased local value added in the overseas market exceed the equivalent manufacturing costs at the original plant, the OEMs will keep the current value added allocation and thus choose a higher level of vertical integration (Bremen et al. 2010).

There are three transactional dimensions that drive transaction costs: asset specificity, uncertainty and infrequency (Williamson 1975). Asset specificity refers to the transferability of assets that support a given transaction and in case of high specificity have little value outside the transactional relationship (Grover and Malhotra 2003). In xKD supply chains the xKD centers constitute the major assets. They are highly capital- and labor-intensive and solely operated for xKD businesses (von Tucher 1999; Song 2009; Fehse 2016). The main lever to reduce their asset specificity is to increase the throughput respectively decrease the lead time (Tucher 1999; Song 2009; Fehse 2016).

Uncertainty covers unanticipated changes in circumstances that surround transactions (Grover and Malhotra 2003). Automotive industry – in particular in emerging markets – has to be flexible to react on strong market fluctuations. XKD supply chains are the basis to create this flexibility by frequent delivery order updates and short lead times (Trippner 1999; Lehmann 2002; Song 2009).

In the realm of TCE infrequency is the rate of reoccurrence of transactions (Williamson 1975; Rindfleisch and Heide 1997). It is also primarily dependent on the market demand that triggers the production (Lehmann 2002; Choi, Narasimhan and

Kim 2012). However, OEMs can adapt the shipping frequency to provide a more stable and levelled supply (Lehmann 2002; Pires and Sacomano Neto 2008).

Table 1. Case study determinants.

	Determinant	Description	Measure
Global manufacturing networks	*Maturity of overseas plants*	… refers to the capability of an overseas plant to produce cars self-sustained	• xKD shipping volume per car • responsibility for order placement • presence of xKD centers
	Material flow between the plants	… refers to the sources and drains of xKD supply chains as well as their direction	• overseas plants • bi-directional xKD supply chains
xKD supply chains	*Scope of delivery*	… refers to the required shipping volume per car and the local value added at the overseas plant	• xKD shipping volume per car • responsibility for order placement • presence of xKD centers
	Packaging concept	… distinguishes between kit and box supply to the overseas plant	• kit or box supply • average box size
Transaction Cost Economics	*Asset specificity*	… refers to the limitation of assets to a distinct xKD supply chain in GMNs	• throughput of xKD center • lead time in xKD center
	Uncertainty	… refers to the demand characteristics and their influence on xKD supply chain	• frequency of delivery order updates • lead time in xKD center
	Infrequency	… describes the shipping frequency of xKD supply chains	• shipping frequency of xKD supply chains

Table 1 summarizes the determinants and measures derived from literature suitable to distinguish different types of xKD supply chains from the perspective of TCE. These measures also show that the performance of xKD supply chains influences the involved transaction costs. An improved performance in terms of reduced WIP levels, lead times and costs positively affects the corresponding transactional dimensions and hence the transaction costs. As a result, the performance of xKD supply chains needs to be improved in these terms in case a GMN involve coordination requirements that ask for lower transaction costs. Thus, TCE does not only explain how to align xKD supply chains to GMN but also how to improve their performance if necessary.

2.4 Research gap and objectives

Several research streams provide fundamental insights on this research topic. However, there is no approach that integrates GMNs and xKD supply chains (Pontrandolfo and Okogbaa 1999; Lehmann 2002). Even though the material flow represents a distinguishing determinant for GMN and xKD supply chains furthermore hold a coordination role, xKD supply chains have not been assessed regarding their compliance with GMN coordination requirements (Pontrandolfo and Okogbaa 1999; Stremme 2002; Meyer and Jacob 2008). Thus, existing research approaches neither allow evaluating nor aligning xKD supply chains with regard to GMN coordination requirements (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Stremme 2000; Meyer and Jacob 2008). As a consequence, the coordination requirements of the individual GMN phenotypes remain unconsidered when planning and managing xKD supply chains (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Stremme 2000; Meyer and Jacob 2008). Hence, GMN and xKD supply chains cannot be matched and their fit cannot be analyzed (Shi and Gregory 1998; Meyer and Jacob 2008). The drawback is a diverging development of GMN and xKD supply chains for the last decades (Lehmann 2002; Song 2009).

Given the fact that xKD supply chains have been characterized by high buffers and long lead times while GMNs have continuously developed an integration of GMN and xKD supply chains bears great potentials in terms of logistics performance and cost (Shi and Gregory 1998; Camuffo und Volpato 2002; Trippner 2006; Meyer and Jacob 2008; Song 2009; Talavera 2015). Incorporating TCE allows aligning GMNs and xKD supply chains via transaction costs (Stölzle 1999; Bremen et al. 2010; Mohammady 2012). On the one hand xKD supply chains can be matched with the coordination requirements of GMNs and on the other hand potential improvement levers can be identified systematically (Stölzle 1999; Bremen et al. 2010; Mohammady 2012).

3. Methodology

3.1 Research design

This research employs an exploratory multiple-case study to analyze GMNs and xKD supply chains of six OEMs as well as their fit using transaction costs. On this basis we develop an integrated framework that aligns xKD supply chains with GMN requirements and derive propositions on how to increase the performance of xKD supply chains in terms of WIP level, lead time and costs. For theoretical foundation we apply TCE to harmonize the local value added via xKD supply chain types with the coordination requirements resulting from the GMN phenotypes by means of transaction costs.

From the available empirical research methods the case study approach is selected as it is highly applicable for the research questions how or why and investigates contemporary events where researchers have no behavioral control (Yin 2014). In particular, a multiple-case embedded design is chosen to consider both, the sub-research units GMN, xKD supply chain and transaction costs as well as the singularities of the OEMs, and to include replication logic for developing hypotheses (Yin 2014).

Throughout the case study we have performed an intense secondary data research via internet and literature and furthermore conducted semi-structured interviews with experts from OEMs and their third party logistics providers that operate xKD supply chains to ensure triangulation (Patton 2002). We have systematically analyzed the collected data based on the case study determinants we derived from literature as outlined in section 2. Following the recommendations of Yin (2014), the analyses have been carried out by two independent researchers and the final results were discussed and verified in course of two separate workshops with the interview partners as well as logistics and supply chain managers at Daimler and Volkswagen to validate the publicly available data and the findings as well framework derived. Table 2 presents the list of our interview and workshop partners.

Table 2. Interview and workshop partners from OEMs and logistics providers.

Company	Position	Name
Volkswagen	xKD Logistics Planner	anonymous
Volkswagen	xKD Logistics Analyst	anonymous
Volkswagen	International Logistics Manager	anonymous
Volkswagen	xKD Expatriate	anonymous
Audi	xKD Logistics Planner	anonymous
Audi	xKD Logistics Analyst	anonymous
Skoda	xKD Logistics Planner	anonymous
Skoda	xKD Operations Manager	anonymous
Daimler	Controlling	anonymous
Daimler	Logistics Planner	anonymous
Schnellecke	xKD Logistics Planner	anonymous
Schnellecke	xKD Operations Manager	anonymous
BLG	xKD Logistics Planner	anonymous
BLG	xKD Operations Manager	anonymous
Syncreon	xKD Operations Manager	anonymous

3.2 Data collection and analysis

Aiming for a rigor case study design this section emphasizes validity and reliability. Yin (2014) and Eisenhardt (1989b) define four criteria for rigor cases studies.

(1) Internal validity refers to causal relationship between variables and results of case studies (Yin 2014). In our research we target to identify the GMN phenotype and the xKD supply chain type per OEM as well as to assess their transaction costs. Guided by literature we have derived according determinants and measures that allow drawing distinct conclusions. These determinants represent the case study variables used for the structured cross-case comparison.

(2) Construct validity is concerned with the fit of the operational set of measures and the objective under investigation (Yin 2014). According to literature a clear chain of evidence and triangulation of multiple sources support rigor case studies (Gibbert, Ruigrok and Wicki 2008). We applied an iterative approach enabling us to simultaneously make progress and reflect on target conformity. We conducted intense secondary data research incorporating a variety of different sources from March 2016 until January 2017 to ensure data triangulation. The consulted sources were publicly available and ranged from academic articles and research theses over conference talks and lecturers to public reports as well as company websites and reports from respective OEMs and their service providers involved in xKD business. Additionally we conducted semi-structured interviews as well as workshops with experts to complement the data research with a methodological triangulation (Patton 2002).

(3) External validity relates to the analytical generalization of the findings (Yin 2014). In line with Eisenhardt (1989b) a sample of six cases forms a good basis for theory development and derivation of propositions. The six selected cases are BMW,

Daimler, JLR Jaguar Land Rover, PSA Peugeot Citroen, Renault Group and VW Group introduced by table 3.

Table 3. Choice of case studies for in-depth analysis on GMN and xKD supply chains.

	BMW	**Daimler**	**JLR**
Brands with xKD business	BMW	Mercedes Benz Cars	Jaguar, Land Rover, Range Rover
*Sales Volumes**	2.367.603 cars	2.197.956 cars	604.009 cars
*Sales**	86.424 Mio. €	89.284 Mio. €	27.065 Mio. €
*EBIT**	7.695 Mio. €	8.112 Mio. €	1.782 Mio. €
*Employees**	124.729	139.947	38.000
Car models for xKD supply chains	e.g. BMW 3series, X3, X5	e.g. Mercedes Benz C-Class, E-Class, M-Class	e.g. Range Rover Evoque, Discovery Sport
	BLG Logistics 2016; BMW 2017; King 2013; Kümmerlen 2015; Lorenz 2015; Malorg 2016; Quaas 2015; Schulze 2012; Seemmann and Schulze 2015; Venter 2011; Williams 2015.	Brandes 2010; Daimler 2017; Granzow 2013; Henry 2015; Mukadam 2014; Struss-V. Poellnitz 2011; Syncreon 2015; Weyerer 2012a; Weyerer 2012b.	Cambell 2016; Hansmann-Gross 2015; Hollmann 2016; Jaguar Land Rover Automotive plc 2017; Ludwig 2013; Ludwig 2014; Palmer and Jones 2016; Rogan 2013; Syncreon 2016.

	PSA	**Renault**	**VW**
Brands with xKD business	Citroën, Peugeot	Renault, Dacia	VW, AUDI, Skoda
*Sales Volumes**	3.150.000 cars	3.182.625 cars	9.729.000 cars
*Sales**	37.066 Mio. €	48.995 Mio. €	150.343 Mio. €
*EBIT**	2.225 Mio. €	2.386 Mio. €	4.668 Mio. €
*Employees**	138.000	124.849	496.771
Car models for xKD supply chains	e.g. Citroën C4, Peugeot 408	e.g. Renault Sandero, Dacia Logan	e.g. VW Golf, VW Passat, Audi A4, Skoda Octavia
	Gefco 2012; Guerrero 2014; IHS Automotive 2012; Ludwig 2011; PSAa 2017; PSA 2017b; PSA 2017c Rognon 2008; Schultze 2013.	CGT Renault 2016; Coia 2012; Faurecia 2017; Festinger 2010; Guerrero 2014; Renault 2013; Renault 2016; Renault 2017.	Fehse 2016; Gruenendahl 2014; Stade 2016; Volkswagen 2017.

** refers to the total business operations of the relevant brands with xKD business in fiscal year 2016*

In order to make the OEM`s and their xKD supply chains comparable, we focus on those brands and divisions that are concerned with passenger car business and that operate xKD supply. Motor bikes from BMW or Ducati as well as trucks from Daimler, Renault, Scania, MAN, or brands which do not operate xKD supply chains such as Smart, Porsche or Lamborghini have been excluded from our case study. Comparing the annual sales volumes and the actual sales reveals that the OEMs partially compete in different market segments. Nevertheless, the car models with xKD supply chains are high selling car models from the medium price segment of each OEMs´ product portfolio.

(4) Reliability copes with the repeatability of the study by later investigators trying to conduct the same study (Yin 2014). Additional to the already introduced measures securing the compliance with the first three criterions which represents a precondition for reliability, a case study protocol and database was created (Gibbert, Ruigrok and Wicki 2008). The database is shown on the bottom of the summarizing tables 4, 5 and 6.

4. Cross-case comparison findings

4.1 Global manufacturing networks

Maturity of overseas plants

The value added at the overseas plants differs eminently between the six OEMs. Whereas *VW* ships on average 0.4 m³ per car via xKD supply chains, *Daimler* ships more than 20 times as much. A low average shipping volume per car, like at *BMW*, *PSA*, *Renault* or *VW*, indicates mature plants that almost entirely manufacture cars in the overseas markets. However, the overseas plants run by *Daimler* as well as *JLR*, that just has opened its first overseas plant in 2014 (Ludwig 2014), are less mature and strongly rely on deliveries via xKD supply chains.

With respect to the responsibility for placing delivery orders only *Renault* and *VW* have put their overseas plants in charge. This also implies that their overseas plants are in charge of production and volume planning too (Schulz and Hesse 2009; Song 2009). Usually these tasks are performed centrally and thus *Renault´s* and *VW´s* overseas plants appear to be more mature.

The presence of exporting xKD centers in overseas markets underlines the previous findings. Except from *JLR* all OEMs investigated have established at least one exporting xKD center in an overseas market. *BMW*, *Daimler* and *PSA* operate one respectively two overseas xKD center. *VW* and *Renault*, however, operate twice as many and hence have more mature overseas plants at their disposal that proactively contribute to the GMN by supplying other plants.

Material flow between plants

The number of overseas markets that operate xKD centers also affects the material flow (Lehmann 2002). *JLR* operates xKD center close to their headquarters only. Hence, there is just one origin of xKD supply chains. *BMW*, *Daimler* and *PSA* are a step ahead and have already established xKD centers in one or two overseas markets which represent additional origins of xKD supply chains. From our sample *Renault* and *VW* operate the most overseas xKD center. The resulting material flow is characterized by more origins and hence is more interconnected. Figure 2 gives an overview of the different global material flow networks.

The effect on the interconnectedness becomes even more apparent looking at figure 2. Five out of six OEMs investigated state that original plants do not only ship but also receive parts from their overseas counterparts. This underpins the development of overseas plants to equally mature plants and furthermore highlights their importance to the GMNs.

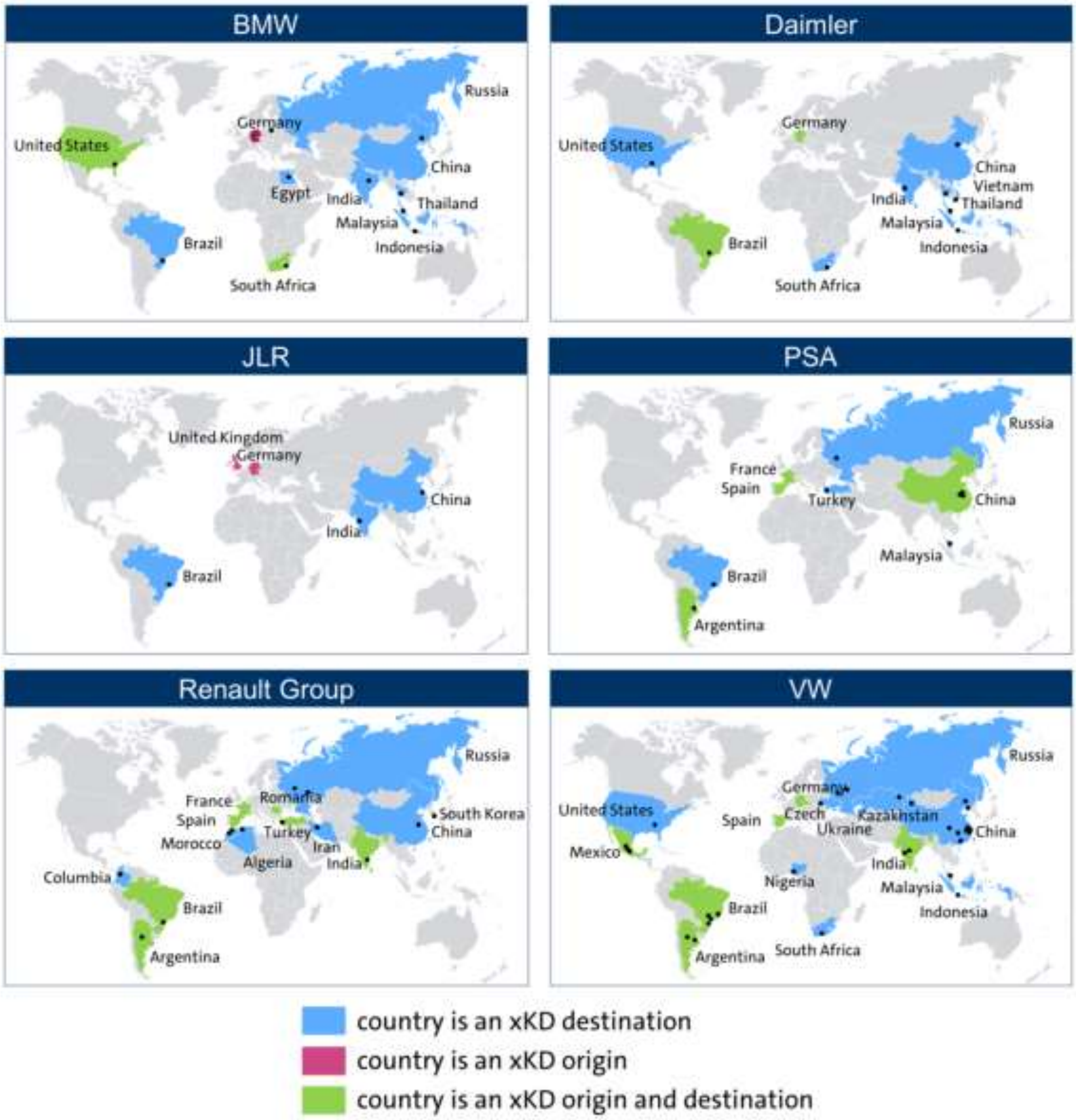

Figure 2. xKD origins and destinations.

Referring to the destinations within GMNs *BMW*, *Daimler*, *Renault* and *VW* supply a similar high number of overseas plants. *PSA* supplies less overseas markets and *JLR* only three. Even though the destinations vary among the OEMs, some overseas markets like China or Brazil are supplied by all of them. This indicates that the OEMs similarly prioritize overseas markets by referring to market size and entry restrictions (Schulz and Hesse 2009).

With regard to the material flow the OEMs mainly differ in their interconnectedness driven by the number of receiving and shipping overseas markets.

Even though *VW´s* and *Renault´s* GMN seem to be more advanced there is still room for improvement. Operating more overseas xKD center allows OEMs to better level production within the GMN, to quicker adapt to changing demands and to source more flexible from various locations.

GMN phenotypes of the OEMs

As discussed in section 2, the level of maturity of overseas plants continuously changes and therefore the tasks accomplish. The GMN are developing and often incorporate elements of different GMN phenotypes for different regions. However, usually one prevailing GMN phenotype can be identified for each network. The cross-case study findings are presented in table 4.

The GMN of *JLR* is an early stage of its development. Overseas production has been launched in 2014 and all overseas markets are supplied via its two xKD center in Mienenbüttel (Germany) and Coleshill (UK) (Ludwig 2014; Synchreon 2016). They are well located to consolidate the parts from the European continental as well as the British suppliers that usually supply the original plants in Birmingham and Liverpool (both UK). Thus, *JLR´s* overseas plants are supplied by the headquarters and the GMN forms a *hub-and-spoke-network*.

Daimler´s GMN comprises the highest average shipping volume per car among the OEMs investigated. Dependent on the size of the car as well as the packing and kitting concept either three or four cars fit into one 40' high cube container which gives us an estimated shipping volume of 17 to 23 m³ for an entire car (Stade 2016). On this basis *Daimler* imports roughly 50% of one car on average via its xKD centers in Germany and Brazil (table 4). *Daimler´s* GMN is characterized by overseas plants that

Table 4. Case study findings – GMN phenotypes.

Determinant	**BMW**	**Daimler**	**JLR**	**PSA**	**Renault Group**	**VW**	*Sub-conclusion*
Maturity of overseas plants	• **3.7 [m³/ car]** average shipping volume per xKD car	• **10.2 [m³/ car]** average shipping volume per xKD car	• n.a.	• **1.3 [m³/ car]** average shipping volume per xKD car	• **1.8 [m³/ car]** average shipping volume per xKD car	• **0.4 [m³/ car]** average shipping volume per xKD car	➔ Substantial differences indicate a very different plant maturity level of the OEMs
	• **Head quarter places delivery orders**	• **Head quarter places delivery orders**	• **Head quarter places delivery orders**	• n.a.	• **Overseas plant places delivery orders**	• **Overseas plant places delivery orders**	➔ Renault and VW´s overseas plant are more self-sufficient
	• **3 markets with xKD centers**: Germany, United States, South Africa	• **2 markets with xKD centers**: Germany, Brazil	• **2 markets with xKD centers**: United Kingdom, Germany	• **4 markets with xKD centers**: France, Spain, Argentina, China	• **8 markets with xKD centers**: France, Brazil, Argentina, Spain, Rumania, Turkey, India, South Korea	• **7 markets with xKD centers**: Germany, Spain, Czech, Mexico, Brazil, Argentina, India	➔ OEMs increasingly operate xKD centers in overseas markets too. The share of mature overseas plants is higher for PSA, Renault and VW.
Material flow between the plants	• **11 overseas xKD markets**: Egypt, India, Indonesia, Malaysia, Russia, Thailand, Brazil, China, US, Brazil, South Africa	• **10 overseas xKD markets**: Vietnam, Thailand, Indonesia, India, US, South Africa, China, Malaysia, South Africa, Brazil	• **3 overseas xKD markets**: China, Brazil, India	• **6 overseas xKD markets**: Malaysia, Brazil, China, Turkey, Russia, Argentina	• **11 overseas xKD markets** Algeria, India, Iran, Morocco, Russia, Turkey, China, South Korea, Argentina, Brazil, Colombia	• **13 overseas xKD markets**: United States, Mexico, Brazil, Argentina, South Africa, Nigeria, Russia, Ukraine, Kazakhstan, India, Malaysia, Indonesia, China	➔ JLR supplies the least overseas markets followed by PSA. The number of supplied markets for the remaining OEMs is similar.
	• **bi-directional material flows**	• **bi-directional material flows**	• **no bi-directional material flows**	• **bi-directional material flows**	• **bi-directional material flows**	• **bi-directional material flows**	➔ 4 out of 6 OEMs also operate both way xKD supply chains
	"local for local"	"hub and spoke"	"hub and spoke"	"web structure"	"web structure"	"web structure"	
	BLG Logistics 2016; King 2013; Kümmerlen 2015; Lorenz 2015; Malorg 2016; Quaas 2015; Schulze 2012; Seemmann and Schulze 2015; Venter 2011; Williams 2015.	Brandes 2010; Granzow 2013; Mukadam 2014; Struss-V. Poellnitz 2011; Syncreon 2015; Weyerer 2012a; Weyerer 2012b.	Hansmann-Gross 2015; Hollmann 2016; Ludwig 2013; Ludwig 2014; Palmer and Jones 2016; Rogan 2013; Syncreon 2016.	Gefco 2012; Guerrero 2014; IHS Automotive 2012; Ludwig 2011; PSA 2016; Rognon 2008; Schultze 2013	CGT Renault 2016; Coia 2012; Festinger 2010; Guerrero 2014; Renault 2013; Renault 2016.	Fehse 2016; Gruenendahl 2014; Herbermann 2016.	

are still very dependent on xKD deliveries and just two supplying countries and thus operates as a *hub-and-spoke-network*.

BMW ships a considerably lower volume per car via xKD supply chains and imports approximately 20% of the cars produced overseas (table 4). The value added in the overseas market clearly exceeds the share of the original plants and the major production steps are performed locally in the overseas markets. The focus of *BMW´s* GMN has shifted from the former dominant headquarters to the increasingly mature overseas plants and in parallel the GMN has evolved from a hub and spoke to a *local-for-local-network.*

PSA´s, Renault´s and *VW´s* GMN stand out due to a higher share of likewise shipping and receiving overseas markets and an even more reduced xKD shipping volume per car. They only import 2% to 10% of their cars produced in overseas plants (table 4). *Renault* and *VW* have even transferred the responsibility for placing xKD delivery orders from their headquarters to the overseas plants enabling them to manage their supply and production processes self-sustained (Schulz and Hesse 2009; Festinger 2010; Fehse 2016). The decision to import parts globally via xKD supply chain seems to have rather an economic background than to result from capability constraints within the overseas markets. Flexible and economic material flows have become a priority and the overseas markets actively participate by competitively delivering parts (Fehse 2016). As a consequence, the GMNs of *PSA, Renault* and *VW* have transformed from *local-for-local-networks* to *web-structure-networks*.

Figure 3 and table 4 present an overview of the findings. More precisely the GMNs follow a development path which is in line with Shi and Gregory (1998) and Meyer and Jacob (2008). As soon as an OEM enters a market via xKD supply chains it turns from a *world-factory* into a *hub-and-spoke-network.* Over time it develops to a *local-for-local-network* and eventually evolves to a *web-structure-network*. However, the case study findings also show that the OEMs that most notably offer premium products, namely *JLR*, *Daimler* and *BMW*, operate either *hub-and-spoke-network* or *local-for-local-networks* and not *web-structure-networks*. Higher sales margins and lower sales volumes constitute a different initial set up for these OEMs where transaction costs and flexible material flows are not top priority and thus cast a positive light on currently employed GMN phenotypes (Meyer and Jacob 2008; Song 2009). As a consequence, we cannot conclude that a more developed GMN phenotype is generally better. Instead, OEMs need to operate the GMN phenotype that suits most their business strategy. However, the general development path can be recognized among the premium OEMs too as *BMW*´s GMN has transformed to a *local-for-local-network*. Annual sales volumes of more than two million cars (table 3) which steadily grow also indicate that *BMW* and *Daimler* increasingly face the same challenges as *VW*, *PSA* or *Renault*. In the future, a *web-structure-network* might also become their favorable GMN phenotype.

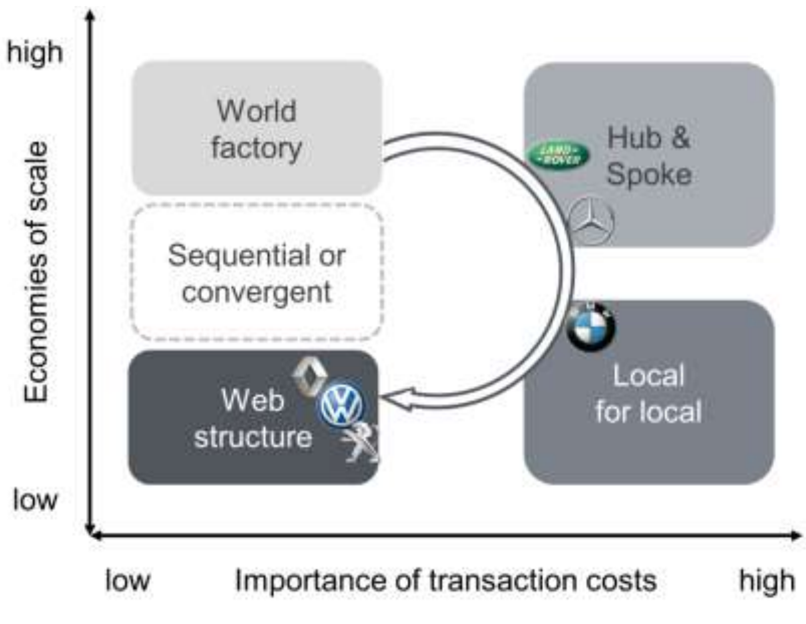

Figure 3. GMN phenotypes of the OEMs.

4.2 xKD supply chains types

Scope of delivery

Instead of applying one and the same xKD supply chain type to all overseas markets, OEMs rather select the most suitable one depending on the market environment. Besides market related aspects the decision is highly influenced by the individual set-up of an OEM in the market, in particular the production facilities, product structure and planned production volumes (Choi, Narasimhan and Kim 2012; Schulz and Hesse, 2009). Hence, the set-up is considerably different for OEMs entering the same market. For instance an OEM that has already operated a mature plant in a targeted overseas market can realize more easily an xKD supply chain type with a higher local value added than an OEM entering the same market for the first time (Schulz and Hesse 2009; Song 2009). It becomes apparent that when GMNs and their plants develop the primarily promoted xKD supply chain type changes.

On this basis the case study findings show that the average shipping volume per car varies significantly among the OEMs and indicates different predominant xKD supply chain types. *Daimler´s* average shipping volume per car sticks out and is the highest with 10.2 m^3 per car, whereas *BWW´s* is lower, however not as low as *PSA´s*, *Renault´s* or even *VW´s*. With a decreasing average shipping volume per car increases the share of xKD supply chains that facilitate a high local value added such as CKD or PBP (Schulz und Hesse 2009; Song 2009; Klug 2010).

Packaging concept

Apart from *Daimler* that solely ships kits, all other OEMs apply both kit packaging and separated box supply. In order to determine the predominant xKD supply chain type the average size of a box is revealing. *Daimler* ships boxes with an average volume of 8.7

m³, while *VW´s* boxes are less than 1 m³ (table 5). As a reference, a widely applied box in the European automotive industry to carry bigger parts on continental transports is the Gitterbox (Klug 2010). Its dimensions are 1.240 mm x 835 mm x 970 mm and the corresponding volume is 1 m³ (Klug 2010). Hence, the average boxes shipped by *Daimler* have the equivalent size of nine Gitterboxes. Boxes of that size are unrealistic for xKD supply chains that typically supply usual work stations and assembly lines such as CKD or PBP. They can neither be packed ergonomically nor be aligned to production work stations nor be transported by standard line feeding equipment (Klug 2010). The average size of *Daimler´s* boxes instead indicates a major share of car bodies transported and thus the predominant application of SKD or MKD supply chains. The boxes supplied by *Renault* and *VW*, however, do not differ significantly from usual continental boxes and are used for direct delivery to the assembly line like it can be found in PBP and CKD supply chains (Festinger 2010; Fehse 2016).

xKD supply chain types of the OEMs

JLR has just recently opened its first overseas plant in 2014 and currently operates three overseas plants in China, Brazil and India (Ludwig 2014). Even though the Chines plant in Changshu is supplied via CKD we can assume that the predominant xKD supply chain in the GMN is SKD (Rogan 2013; Palmer and Jones 2016). In particular as *JLR* cannot build on any production facilities in case of striving for new overseas business opportunities.

As previously outlined *Daimler´s* average box size indicates either predominant SKD or MKD supply chains. However, under consideration of the average shipping volume per car which equals round about 50% of a car *Daimler* predominantly ships MKD deliveries (table 5). In case of predominant SKD deliveries we would expect to import almost finished cars and thus a significantly higher shipping volume.

BMW´s shipping volume per car excludes largely shipped car bodies and thus, SKD and MKD supply chains. In comparison to *PSA*, *Renault* and *VW*, however, we can assume that *BMW* predominantly operates CKD supply chains. *BMW* ships significantly more parts and its overseas plants cannot order the parts themselves, which prevents *BMW* from utilizing the flexibility benefits PBP supply chains offers.

Taking into account the low shipping volumes per car as well as the average box sizes that allow direct deliveries to the assembly lines, *PSA*, *Renault* and *VW* predominantly operate PBP supply chains (Festinger 2010; Ludwig 2011; Fehse 2016).

The case study findings show that similarly to the GMN phenotypes the predominant xKD supply chain type changes along a development path too. At the beginning of overseas production OEMs predominantly operate SKD supply chains and over time move on to MKD, CKD and eventually PBP supply chains. The fact that the premium OEMs operate xKD supply chains entailing a lower local value added supports this finding. Lower sales within an overseas market require a lower local value added as the corresponding market entry restrictions and customs are mainly dependent on the annual sales volumes (Schulz and Hesse 2009; Klug 2010; Köhne 2013). As a consequence, the development path applies to all six cases as their common main target is to enter overseas market and increase sales. An overview of the findings presents table 5.

Table 5. Case study findings – xKD supply chain types.

Determinant	**BMW**	**Daimler**	**JLR**	**PSA**	**Renault Group**	**VW**	*Sub-conclusion*
Scope of delivery	• **SKD, MKD, CKD** according to the market environment	• **SKD, MKD, CKD** according to the market environment	• **SKD, MKD, CKD** according to the market environment	• **SKD, MKD, CKD** according to the market environment	• **SKD, MKD, CKD** according to the market environment	• **SKD, MKD, CKD** according to the market environment	➔ Thus, the xKD supply chain types coexist in the global manufacturing networks of the OEMs.
	• **3.7 [m³/ car]** average shipping volume per xKD car	• **10.2 [m³/ car]** average shipping volume per xKD car	• n.a.	• **1.3 [m³/ car]** average shipping volume per xKD car	• **1.8 [m³/ car]** average shipping volume per xKD car	• **0.4 [m³/ car]** average shipping volume per xKD car	➔ The share of the individual xKD supply chain types differ significantly among the OEMs.
Packaging concept	• **Kit supply , separated box supply**	• **Kit supply**	• n.a.	• **Kit supply , separated box supply**	• **Kit supply , separated box supply**	• **Kit supply , separated box supply**	➔ Daimler is the only OEM that solely delivers kits. The remaining OEMs adapt the packaging concept.
	• n.a.	• **8.7 [m³/box]** average box size of a handling unit	• n.a.	• n.a.	• **2.3 [m³/HU]** average shipment size of a Handling Unit	• **0.3 [m³/HU]** average shipment size of a Handling Unit	➔ Daimler delivers major and aggregated parts. Renault Group and VW ship minor and complementary parts to the overseas plants.
	"CKD"	"MKD"	"SKD"	"PBP"	"PBP"	"PBP"	
	BLG Logistics 2016; King 2013; Kümmerlen 2015; Lorenz 2015; Malorg 2016; Quaas 2015; Schulze 2012; Seemmann and Schulze 2015; Venter 2011; Williams 2015.	Brandes 2010; Granzow 2013; Mukadam 2014; Struss-V. Poellnitz 2011; Syncreon 2015; Weyerer 2012a; Weyerer 2012b.	Hansmann-Gross 2015; Hollmann 2016; Ludwig 2013; Ludwig 2014; Palmer and Jones 2016; Rogan 2013; Syncreon 2016.	Gefco 2012; Guerrero 2014; IHS Automotive 2012; Ludwig 2011; PSA 2016; Rognon 2008; Schultze 2013	CGT Renault 2016; Coia 2012; Festinger 2010; Guerrero 2014; Renault 2013; Renault 2016.	Fehse 2016; Gruenendahl 2014; Herbermann 2016.	

4.3 Transaction costs of xKD supply chains

TCE can be used to explain the differences between the predominant xKD supply chains by discussing the three transactional dimensions (Williamson 1975). An overview provides table 6.

Asset Specificity

Asset specificity refers to the limitation of xKD centers as major assets to certain xKD supply chains and their impact on delivery costs (Tucher 1999; Grover and Malhotra 2003; Fehse 2016). It is highly influenced by the utilization of xKD centers which can be characterized by their throughput. In this regard *PSA* and *VW* handle a 25% higher volume per covered square meter than the other OEMs enabling them to supply more xKD supply chains and overseas plants by the same xKD center. The overhead costs including property and building costs amongst others can be distributed on more shipments and thus the delivery costs per shipment be reduced. Keeping in mind that primarily low wage countries are supplied by xKD the impact on product and supply chain profitability is immense. (Jacob and Strube 2008; Fehse 2016). In 2013 for example Volkswagen built a new xKD center in Duisburg (Germany) which caused initial property and building costs of approximately 25 Mio. € (Duisport 2017). Consequently, we can assume that PSA´s and VW´s xKD supply chains feature a 25% lower asset specificity and transaction costs due to the increased throughput.

Uncertainty

Uncertainty covers unanticipated changes that surround xKD supply chains (Grover and Malhotra 2003). In particular as xKD supply chains supply emerging markets they need to be flexible to react on market fluctuations.

The first lever to reduce transaction costs resulting from uncertainty is to increase the frequency of delivery orders updates as it reduces the risk of shipping wrong parts or quantities (Song 2009). From our case study sample Daimler updates its delivery orders monthly while all other OEMs use a weekly frequency. As a result Daimler is not able to react as quickly as the other OEMs to changes in demand and thus takes higher chances of ageing stocks and expedited shipments.

Lead time is the second lever to influence the transaction costs incurred by uncertainty. Decreasing the lead time on the one hand enables OEMs to react more quickly and on the other hand reduces the inventory levels that potentially can be ageing. In xKD supply chains OEMs can actively influence the lead time within xKD centers as the other time components such as travelling and transit times are determined by the harbor and freight carriers (Trippner 1999; Lehmann 2002; Song 2009). The OEMs differ essentially regarding their lead time and buffers within xKD centers. Parts last for more than ten days in an xKD center at Daimler and for five days at *BMW* and *VW*. *Renault* handles the parts in two to four days within the shortest time which reduces the risk of ageing stocks and demand changes. Thus, we can assume that the transaction costs decrease in the same order.

Infrequency

Infrequency relates to the rate of reoccurrence of transactions and in case of xKD supply chains is dependent on the market demand that triggers the shipping volume via sales figures (Williamson 1975; Rindfleisch and Heide 1997; Lehmann 2002; Choi, Narasimhan and Kim 2012). However, the effect of demand fluctuations can be lessened by an increased shipping frequency providing a more stable and levelled supply (Lehmann 2002; Pires and Sacomano Neto 2008). All OEMs employ a weekly service via vessels for their regular shipments and refer to daily departures via air freight in case of expedited shipping (Festinger 2010; Ludwig 2011; Weyerer 2012; Quaas 2015; Fehse 2016; Hollmann 2016). Only OEMs supplying Russia such as *BMW*, *PSA* and *VW* use a daily rail service for the according xKD supply chain (Schultze 2013; Semmann and Schulze 2015; Stade 2016) . The OEMs do not differ with regard to infrequency and we can assume the according transaction costs remain unaffected.

Transaction costs of the OEM´s xKD supply chains

Based on the investigations above we aim at evaluating the transaction costs of the xKD supply chains using the same scale in order to establish a common basis to compare them and to assess the fit with the GMN requirements in a later step.

We can assume that *Daimler´s* xKD supply chains entail the highest buffers within their xKD center and the lowest delivery order frequency and hence are characterized by the upmost transaction costs. *BMW* and *JLR* both update their delivery orders more frequent and *BMW* furthermore holds less stock at its xKD centers. Hence, we can assume that the xKD supply chains of *BMW* and *JLR* incorporate lower transaction costs. From the remaining three OEMs, we can assume that *PSA* and *VW* entail the lowest transaction costs due to higher throughput rates at their xKD centers that reduce overhead and delivery costs. *Renault* holds the lowest buffers at their xKD centers. The effect of reduced inventory levels, particularly in times of low interest rates, does not match an increased throughput with direct impact on costs though. Thus, we can assume that the transaction costs involved in *Renault´s* xKD supply chains are in between *PSA*, *VW* and *BMW*, *JLR*.

While it is easy to understand that the transaction costs are high in case of Daimler it is more difficult to assess how low the transaction costs of *PSA´s* and *VW´s* xKD supply chains really are. Especially as both OEMs predominantly operate PBP supply chains and thus lead the development process of xKD supply chains as shown in section 4.2. The highest throughput at their xKD center helped them to decrease the asset specificity and to achieve the lowest transaction costs of the sample. However, considering the five day lead time at their xKD center we can assume that even *PSA* and *VW* still have a lot of room to improve their throughput and hence to decrease their transaction costs. By reducing the buffers at their xKD centers more packing stations can be installed to increase the throughput. *Renault* has already demonstrated that it is possible to run xKD centers with a shorter lead time of two to four days (table 6).

Taking into account that in *PSA´s* and *VW´s* PBP supply chains the kitting is obsolete we can assume that the operational processes at their xKD centers are comparable to usual transshipment processes like they can be found in cross docks (Song 2009). Cross docks, however, operate with a lead time of less than one day (Klug 2010).

All in all PSA and VW are characterized by the lowest transaction costs of the sample. However, comparing the performance of their xKD centers regarding lead time with Renault´s xKD centers or even cross docks we can assume that the throughput can roughly be doubled and thus the transaction costs be cut by half. An overview of the findings presents table 6.

Table 6. Case study findings – Transaction costs.

Dimension	**BMW**	**Daimler**	**JLR**	**PSA**	**Renault Group**	**VW**	*Sub-conclusion*
Asset specificity	• **12.2 [m³/m²] yearly throughput in the xKD center** based on the covered area	• **13.3 [m³/m²] yearly throughput in the xKD center** based on the covered area	• **12.7 [m³/m²] yearly throughput in the xKD center** based on the covered area	• **16,1 [m³/m²] yearly throughput in the xKD center** based on the covered area	• **13.1 [m³/m²] yearly throughput in the xKD center** based on the covered area	• **16.7 [m³/m²] yearly throughput in the xKD center** based on the covered area	➔ PSA´s and VW´s transaction costs are lower as their xKD centers are able to process a 25% higher volume
Uncertainty	• **Weekly delivery order updates**	• **Monthly delivery order updates**	• **Weekly delivery order updates**	• **Weekly delivery order updates**	• **Weekly delivery order updates**	• **Weekly delivery order updates**	➔ Daimler´s transaction costs are higher as the delivery orders are updated less frequent
	• **5 days average lead time in the xKD center**	• **>10 days average lead time in the xKD center**	• n.a.	• n.a.	• **2 to 4 days of average lead time in the xKD center**	• **5 days average lead time in the xKD center**	➔ Renault´s transaction costs are lower and Daimler´s are higher due the buffers resulting from the lead time
Infrequency	• **Weekly shipping frequency;** daily expedited shipping via air; daily shipping to Russia via rail	• **Weekly shipping frequency;** daily expedited shipping via air	• **Weekly shipping frequency;** daily expedited shipping via air	• **Weekly shipping frequency;** daily expedited shipping via air; daily shipping to Russia via rail	• **Weekly shipping frequency;** daily expedited shipping via air	• **Weekly shipping frequency;** daily expedited shipping via air; daily shipping to Russia via rail	➔ The OEMs do not differ with regard to transaction costs as all apply the same shipping frequency
	 BLG Logistics 2016; King 2013; Kümmerlen 2015; Lorenz 2015; Malorg 2016; Quaas 2015; Schulze 2012; Seemmann and Schulze 2015; Venter 2011; Williams 2015.	 Brandes 2010; Granzow 2013; Mukadam 2014; Struss-V. Poellnitz 2011; Syncreon 2015; Weyerer 2012a; Weyerer 2012b.	 Hansmann-Gross 2015; Hollmann 2016; Ludwig 2013; Ludwig 2014; Palmer and Jones 2016; Rogan 2013; Syncreon 2016.	 Gefco 2012; Guerrero 2014; IHS Automotive 2012; Ludwig 2011; PSA 2016; Rognon 2008; Schultze 2013	 CGT Renault 2016; Coia 2012; Festinger 2010; Guerrero 2014; Renault 2013; Renault 2016.	 Fehse 2016; Gruenendahl 2014; Herbermann 2016.	

4.4 Integration and fit of GMNs and xKD supply chains

This section aims at integrating GMNs and xKD supply chains as well as evaluating their fit. Therefore we discuss first the theoretical characteristics of the xKD supply chain types with regard to transaction costs and economies of scale, the dimensions used by Meyer and Jacob (2008) to distinguish GMN phenotypes, in order to establish a common basis. Subsequently we develop an integrated framework for GMNs and xKD supply chains and investigate the fit of the OEMs. We also compare the theoretical transaction costs resulting from the integrated framework with the actual transaction cost we observed in the case study. Finally we develop propositions for future improvement measures.

Transaction costs and economies of scale in xKD supply chains

TCE can be used to explain the differences between the individual xKD supply chain types. In contrast to FBU deliveries the importance of transaction costs is considerably higher for SKD, MKD and CKD supply chains. Instead of simply shipping finished cars theses xKD supply chains handle the immense product and process complexity and entail substantially higher coordination efforts (Schulz and Hesse 2009; Song 2009; Köhne 2013). In PBP supply chains the coordination effort is lower as overseas plants place delivery orders themselves and the parts are shipped in separated boxes without additional kitting and a rigid reference to a specific car which e.g. diminishes the risk of missing parts (Song 2009).

With regard to economies of scale the xKD supply chains differ too. In case of FBU and SKD deliveries the entire cars are manufactured at the original plant and represent additional production orders for already existing production facilities. The economies of scale are high. In MKD and CKD supply chains more and more new production facilities are installed that carry out production steps that previously have been conducted by the original plant only. The value added is increasingly shared among the plants and thus steadily decreases the economies of scale. In PBP supply chains the production set-up is very similar to CKD supply chains and simply the kitting process is skipped. Thus, the economies of scale remain on a similar level.

Considering the two dimensions transaction costs and economies of scale the xKD supply chain types can be allocated as shown in figure 4. In our case study we have discovered that the predominant xKD supply chain steadily develops from SKD to PBP (section 4.2). Thus, we have implemented these findings in figure 4 by arranging the xKD supply chain types as directed arrow in order to highlight the development path.

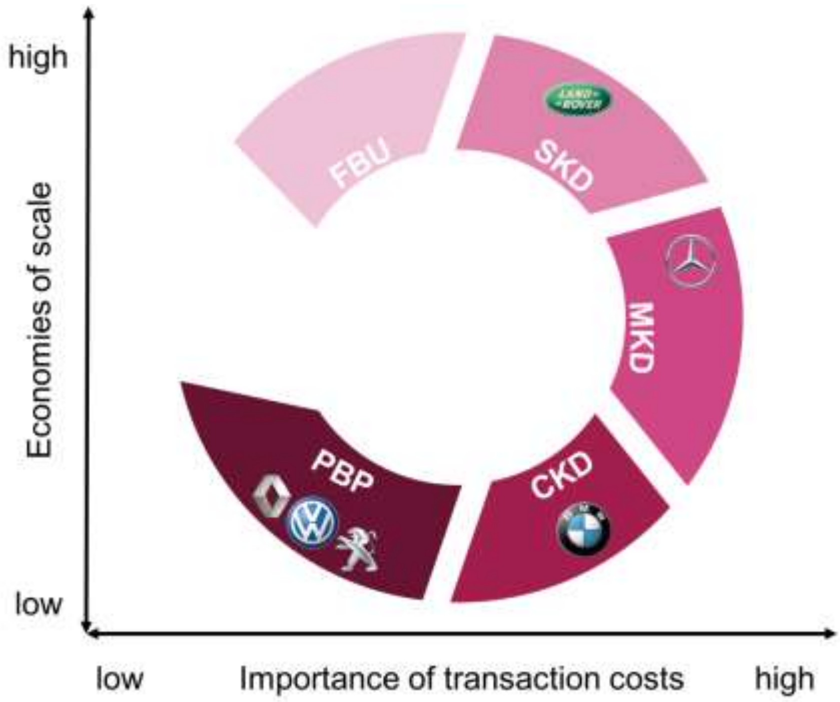

Figure 4. xKD supply chain types of the OEMs.

Integration of GMNs and xKD supply chains

Now we take on the classification framework from above (figure 4) distinguishing the individual xKD supply chain types and complement it with the GMN classification framework we adapted to the automotive industry (figure 3). Both frameworks comprise the same dimensions. In particular the transaction costs can be used to tie GMNs and xKD supply chains together. In context of GMN transaction costs can be understood as the coordination requirements which actually directly apply to xKD supply chains that hold the respective coordination role. As a consequence, GMNs and xKD supply chains can be integrated in one framework that simultaneously considers the coordination role of xKD supply chains and embeds the GMN requirements.

The case study findings have also shown that GMNs as well as predominant xKD supply chain change over time. Both seem to follow a predefined development path. As assumed at the beginning of our research GMNs and xKD supply chains develop in parallel (section 4.1 and section 4.2). In order to incorporate this finding we arranged GMNs and xKD supply chains as double sided arrow and the resulting integrated framework is depicted in figure 5.

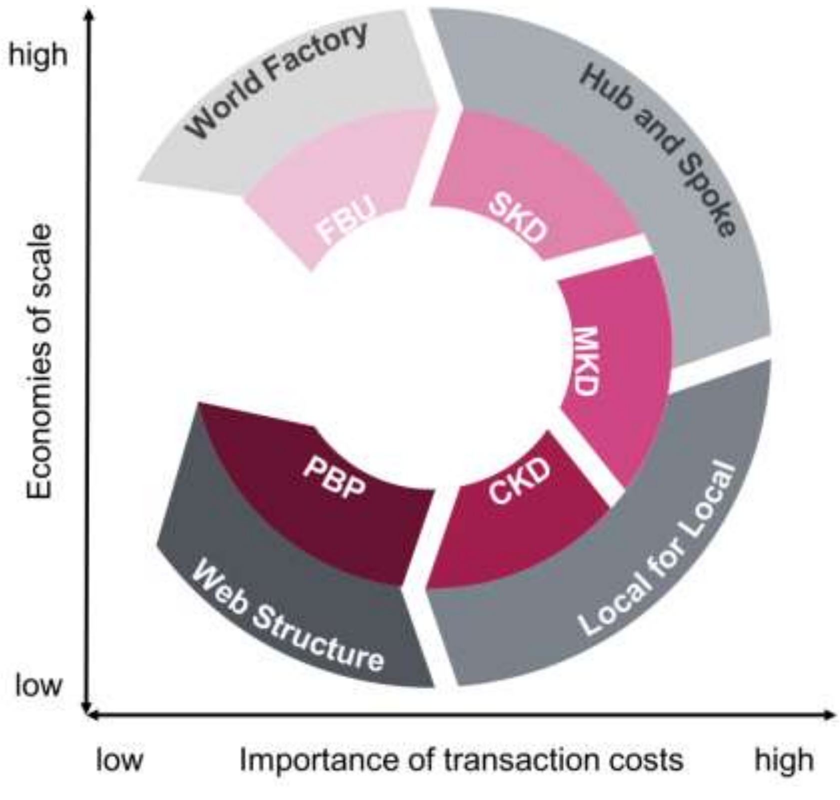

Figure 5. Integrated framework of GMNs and xKD supply chains.

The fit of the case study OEMs

Adding the OEM specific findings of the case study to the developed integrated framework gives us figure 6. By simply comparing the fit of GMN and xKD supply chain without considering transaction costs, it becomes apparent that all OEMs predominantly apply the xKD supply chain type that suits most their GMN phenotype. This substantiates our previous finding that OEMs operate the GMN phenotype and xKD supply chain combinations that are most beneficial for their business strategy. JLR, Daimler and BMW, producing premium cars, employ either a *hub-and-spoke-network* or a *local-for-local-network* and apply the corresponding SKD, MKD or CKD supply chains according to their development stage. PSA, Renault and VW sell substantially higher volumes and thus operate PBP supply chains for their web-structure-networks. As a consequence, it we cannot conclude that PBP supply chains are principally better than SKD supply chains.

Taking transaction costs into consideration the result turns out to be less unambiguous. While OEMs that operate predominantly SKD, MKD or CKD supply chains such as *JLR*, *Daimler* and *BMW* comply with the coordination requirements of the respective hub and spoke or *local-for-local-network* and incorporate a high importance of transaction costs. The predominantly applied PBP supply chain by *PSA*, *Renault* and *VW*, however, do not meet the coordination requirements of a *web-structure-network* as they still comprise comparably high transaction costs. In a *web-structure-network* ideally transaction costs can be neglected and parts easily be shipped between various plants involving very little coordination effort (Shi and Gregory 1998; Meyer and Jacob 2008). Key are short lead times, low buffers and low costs that facilitate a flourishing material flow in the *web-structure-network*. In summary the currently applied PBP supply chains by *PSA*, *VW* and *Renault* do not meet the performance goals.

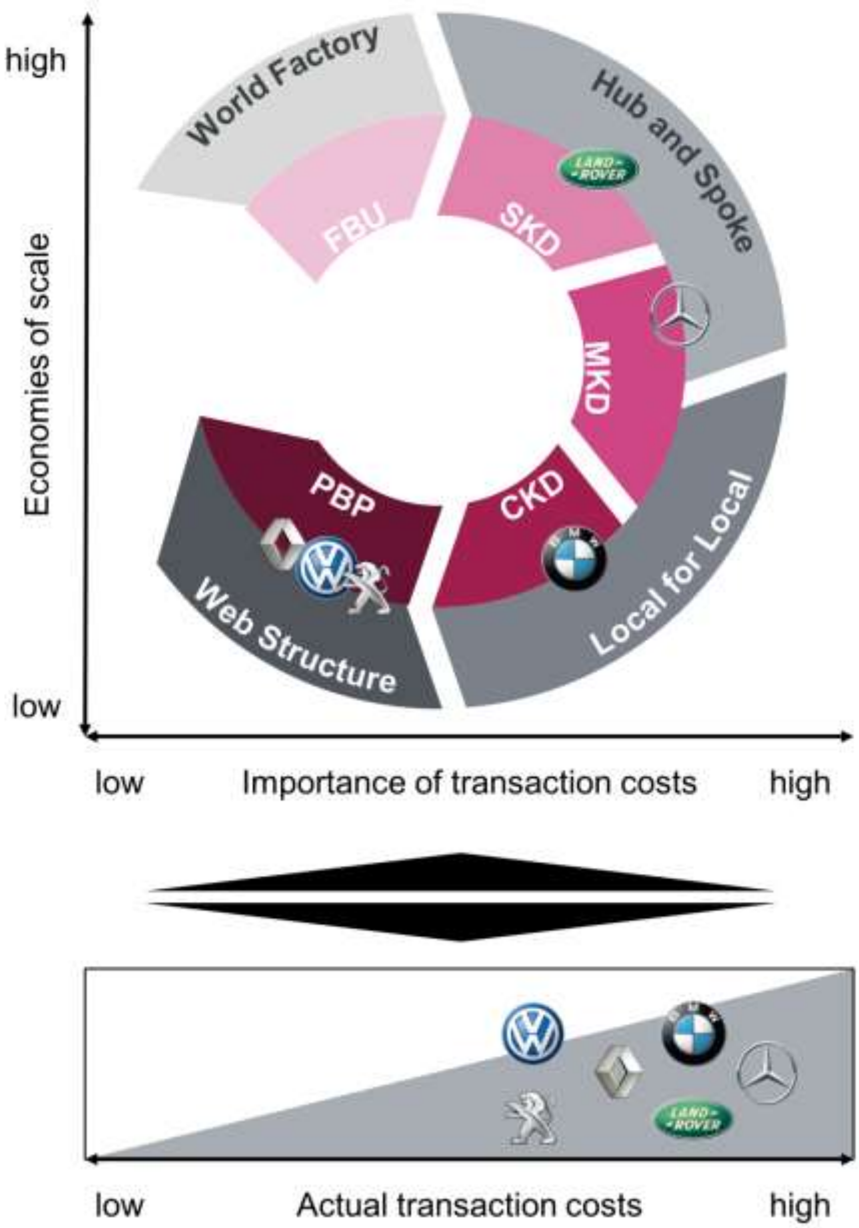

Figure 6. Fit of GMNs and xKD supply chains.

Potential performance improvements

Guided by transactional dimensions we subsequently derive hypothesis for PBP supply chains on future performance improvements that tackle transaction costs in particular.

Regarding asset specificity the throughput of xKD centers bears great potential. In PBP supply chains the kitting is omitted which offers new process opportunities. Analogous to cross docks in xKD centers high buffers can be reduced to add more workstations that increase the throughput and hence positively affect WIP level, lead time and costs via overhead savings. Thus, we can derive hypothesis 1:

H1: The higher the throughput of an xKD center in PBP supply chains, the lower are transaction costs and the higher is the performance in terms of lead time, WIP-level and costs.

Decreasing buffers and lead times in xKD centers not only affects indirectly asset specificity but also lessens the effects of uncertainty. Quick responses and diminished risks of ageing stock in case of demand changes reduce transaction costs and increase the performance. Thus, we can derive hypothesis 2:

H2: The lower the lead time within an xKD center in PBP supply chains, the lower are transaction costs and the higher is the performance in terms of lead time, WIP-level and costs.

A second lever to take care of the transactional dimension uncertainty represents the frequency of delivery order updates. More frequent updates allow to react flexibly to sudden changes in demand and to avoid expedited shipping costs. Hence, we can derive hypothesis 3:

H3: The more frequent the order cycle update in PBP supply chains, the lower are transaction costs and the higher is the logistics performance in terms of lead time, WIP-level and costs.

Infrequency depends on service frequency of the main haul. Daily rail deliveries have proved to be viable and already increased the performance. Thus, we can hypothesize:

H4: The higher the shipping frequency of the main haul in PBP supply chains, the lower are transaction costs and the higher is the performance in terms of lead time, WIP and costs.

5. Conclusion

This case study investigates six globally producing OEMs in order to explore the fit of the employed xKD supply chains and GMNs. An integrated framework is developed that enables OEMs to determine the predominant xKD supply chain type that is best suited to their GMN. We further discovered that automotive GMNs as well as the predominant xKD supply chains follow a mutual development path. On this basis OEMs can take decisions to prepare the next development steps for their GMN and xKD supply chains. OEMs vary with regard to their product portfolio and customer group among other and thus, the most suitable GMN and hence xKD supply chain can be different. However, OEMs have to be explicitly careful in case their GMN evolves to a *web-structure-network* as the according PBP supply chains face considerably different coordination requirements. Performance and efficiency becomes priority. In this regard the case study has shown that the PBP supply chains of the OEMs operating a *web-structure-network* incorporate insufficient high transaction costs and do not meet the according requirements. Thus, we have derived according measures and hypothesis for PBP supply chains to decrease transaction costs by increasing the performance in terms of lead time, WIP-level and costs.

This research fills important research gaps in the literature of GMN as well as of global and xKD supply chains. While existing research approaches on GMNs rarely considered effects on logistics processes and supply chains, we have developed an integrated framework that allows matching GMN phenotypes with global xKD supply chains (Pontrandolfo and Okogbaa 1999; Stremme 2000). We have furthermore incorporated a possibility to derive individual requirements for supply chains dependent on the GMN phenotype. With regard to xKD supply chains we have discovered that PBP supply chains face considerably different challenges than the other xKD supply chain types. We have explored the performance of currently applied xKD supply chains and proposed potential improvement levers. Throughout our research the TCE was in particular valuable. It enabled us to match GMNs and xKD supply chains as well as to establish a common basis in order to compare the performance of supply chains with the requirements of GMNs.

However, our research incorporates limitations. In order to explore the fit of GMN and xKD supply chains as well as to develop the integrated framework we conducted a cross-case study. Thus, the findings and results are qualitative, based on a sample and are difficult to be generalized. Even though the investigated OEMs commonly aim to increase sales volumes, the OEMs´ image, philosophy, product portfolio and customer structure differ and thus result in different combinations of GMN and xKD supply chain strategies. Our research focuses on performance dimensions that can be evaluated without access to sensitive data. Furthermore, we adapted the transactional dimensions to xKD supply chains, subsequently evaluated them and drew conclusions regarding their performance. As there is no absolute scale for transaction costs in context of GMN and xKD supply chains our approach and evaluation can be questioned, even though we did all to the best of our knowledge.

Future research should extent our research by conducting further case studies as well as large scale and quantitative analysis. The developed integrated framework for GMN and xKD supply chains should be tested and could possibly transferred to other industries and fields of application. Researchers, should also investigate the proposed hypothesis on potential improvements of PBP supply chains, for instance by means of a simulation study. In particular the influence and facilitating role of the omitted kitting process in case of PBP supply chains on the achievable performance should be analyzed.

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3 Paper 2: Transportation Time and Reliability in Intermodal Transport Chains

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Contributions of the Co-Author: J. Bendul contributed to the development of the analytical model and to the discussions on the discrete event simulation study, jointly interpreted results, reviewed and helped to write all sections of the manuscript.

Contributions of the Paper to the PhD Project: This paper establishes an understanding of the working principle of intermodal transport chains. An analytical model is developed which defines the transportation time and transport time reliability of an intermodal transport chain. The paper investigates how the individual transport legs affect the overall transportation time and transport time reliability by means of a discrete event simulation. XKD supply chains can be understood as intermodal transport chains from a transportation point of view. This research makes contributions towards exploring the interdependencies of the individual transport hauls and to identify potential improvement levers for xKD supply chains.

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TRANSPORTATION TIME AND RELIABILITY IN INTERMODAL TRANSPORT CHAINS

Toni Erfurth* · Julia Bendul**

Abstract: In recent years the role of sustainable and alternative transportation concepts has significantly grown in importance due to increasing freight transport volumes, congested roads and intensifying environmental problems. Various industries understand intermodal transportation as a solution and feasible alternative to unimodal road transportation, as it combines the strengths of different transportation modes. Long-haul transportation that usually is carried out by rail or waterborne transportation represents a key feature of intermodal transport chains distinguishing them from unimodal transport chains. However, so far there has been no systematic analysis of the effect of long-haul transportation on the performance of an intermodal transport chain in terms of transportation time and transport time reliability. The aim of this paper is therefore to analyze and evaluate the effect of long-haul transportation on performance by proposing an analytical and a simulation model. The analysis contributes to a better understanding of impacts resulting from different modal shares as well as influencing variables and enables to derive recommendations for future transport planning.

Keywords: Intermodal transportation, long-haul transportation, transportation time, transport time reliability.

1. Introduction

In recent years the role of sustainable and alternative transportation concepts has significantly grown in importance due to an accelerated globalization process. Facing the challenge of ever growing freight transport volumes, increasingly congested roads and intensifying environmental problems, different industries understand intermodal transportation as key to implement global sourcing and emerging market strategies. Intermodal transportation is less energy intensive than road transportation and enables transport planners to establish environmentally friendlier transportation solutions (Woodburn et al., 2007). In a nutshell, intermodal transportation is considered a strong competitor and feasible alternative to unimodal road transportation (Bontekoning, Macharis and Trip, 2004).

Nevertheless, intermodal as well as unimodal transportation solutions have to meet transportation time and transport time reliability requirements. Particularly in the light of widely applied just-in-time practices and quick response operations, transport time reliability is seen as the most important performance indicator along

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with transportation time itself (Dullaert and Zamparini, 2013; Taylor, 2013). Regarding intermodal transportation there is no approach that illustrates the effect of different modes of transportation on transportation time and transport time reliability for an end-to-end transport chain. Especially the impact of the transportation mode being assigned to the long-haul transportation which represents the main difference to unimodal transportation has not been stressed in this respect.

Hence, the underlying research question of this paper is: How does long-haul transportation affect the performance of an intermodal transport chain in terms of transportation time and transport time reliability? In a first step, the paper consults relevant literature. On the one hand it considers research that contrasts unimodal and intermodal transportation and thus, elaborates key characteristics and enablers of intermodal transport chains. On the other hand it reviews research works on transport time reliability in context of freight transportation in general and intermodal transportation in particular for suitable measures and existing approaches. Afterwards an analytical model is developed that describes a three stage intermodal transport chain in terms of transportation time and transport time reliability. To emphasize the effect of long-haul transportation the analytical model includes the possibility to continuously vary its share on the total transport chain. The results of the analytical model are then compared to the results of a discrete event simulation model. On this basis four simulation scenarios are defined that analyze the relations and dependencies within an intermodal transport chain with focus on long-haul transportation. This enables us to investigate the impact of long-haul transportation on transportation time and transport time reliability. The paper contributes to a better understanding of performance impacts of intermodal transportation and enables logistics practitioners to derive recommendations for future transport chain planning with regard to intermodal transportation.

The remainder of this paper is structured as follows. The second section reviews existing literature on the comparison of unimodal road and intermodal transportation as well as on transportation time and transport time reliability in particular regarding intermodal transportation. In the third section an analytical model is introduced that depicts an intermodal delivery process from a shipper to a receiver and highlights the effect of long-haul transportation on both performance measures. Based on this a discrete event simulation model is developed and simulation scenarios are outlined in the fourth section. The results are displayed in the fifth and then discussed with respect to the research question in the sixth section. Finally, in the seventh section a conclusion is provided and further research opportunities are described.

2. State of the art

2. 1. *Intermodal transportation*

In this section literature on intermodal transportation is examined that depicts the basic structure of these transport chains and that points out long-haul transportation as distinctive element.

Intermodal transportation is defined as the movement of goods in one and the same loading unit or vehicle that successively uses two or more modes of transportation without handling the goods themselves in changing modes (Economic Commission for Europe, 2001). The central idea behind intermodal transportation is to utilize the strengths of different modes of transportation by combining them in one integrated transport chain (Flodén, 2007). A shipment that is supposed to be transported from a shipper to a receiver via an intermodal transport chain is first collected and transferred to a terminal by a truck. Consecutively it is transshipped from the truck to a periodically departing train or vessel and then transported to the destination terminal, where it is transshipped to a truck again and finally delivered to the receiver. The collection part of the transport chain is called pre-haul and the distribution part post-haul, while the transport in between is named long-haul (Macharis and Bontekoning, 2004; Crainic and Kim, 2005). In order to take advantage of economies of scale and thus to achieve low transportation costs and emissions the shipments are consolidated at the terminal of origin prior long-haul transportation (Zhang and Pel, 2016).

In synchromodal transportation, a form of intermodal transportation, the carrier independently selects at any time the transport mode that is best suited to the operational circumstances based on a dedicated customer order (Verweij, 2011). In contrast to intermodal transportation in general the primary advantage results from flexible and real-time switching of transport modes rather than from highly utilized and environmental friendly long-haul transportation (Zhang and Pel, 2016). Thus, in course of this paper the effect of the facilitating and distinctive element of intermodal transportation in general, long-haul transportation is investigated.

2. 2. *Comparison of intermodal and unimodal transportation*

In this section research works are reviewed that contrast unimodal road and intermodal transportation and suggest approaches to determine the most suitable transportation concept for a specific transport task. To the best of our knowledge Kreutzberger´s research is the only one considering transportation time a decision variable or a constraint. Kreutzberger (2008) introduced different bundling networks to facilitate the required collection and distribution operations of an intermodal transport chain. These bundling networks are based on geometrically varied layouts and are evaluated by means of average distance and transportation time per vehicle. Subsequently the results are compared to the performance of an according unimodal road transportation network (Kreutzberger, 2008). Related approaches from transport research take transportation time into account when calculating transportation costs to distinguish transportation concept, but do neither include a constraint for a maximum transportation time nor show the impact on transportation time (Jourquin and Beuthe, 1996; de Jong and Ben-Akiva, 2007; Tavasszy, Ruijgrok and Davydenko, 2010; Zhang, 2013).

In context of contrasting unimodal and intermodal transportation the other approaches refer to costs only as decisive factor too. Thus, Verma and Verter propose a cost optimization model for hazardous goods to manage shipments in a transportation network while including transportation time requirements of shipments as a constraint. Consequently only feasible unimodal and intermodal transportation options are considered for each link to optimize routing in a transportation network (Verma and Verter, 2010). Further approaches study the break-even point between unimodal road and intermodal transportation by determining the transport distance that needs to be assigned to long-haul transportation. Hanssen, Mathisen and Jorgensen elaborate the effect of various cost components, e.g. pre- and post-haul transportation costs or handling costs, as well as total transport distance to be covered via long-haul transportation in order to favor intermodal transportation (Hanssen, Mathisen and Jorgensen, 2012). A similar approach is presented by Janic, but he distinguishes between internal costs which are directly related to the transport service itself and external costs accounting for environmental aspects, such as air pollution, congestion, noise and traffic accidents. Aside it is shown that an increase in service frequency has a promoting effect towards intermodal transportation (Janic, 2007). Concentrating on external costs Macharis and Van Mierlo develop a model that pinpoints the proportion of pre- and post-haul transportation to long-haul transportation so that intermodal transportation is still more environmentally friendly than unimodal road transport (Macharis and Van Mierlo, 2006).

Existing literature that compares intermodal to unimodal transportation is dedicated to identify the most promising transport solution and mostly determines the break-even point referring to the distance assigned to long-haul transportation. This implies that particularly the distance covered by long-haul transportation that appears as synchronizing transport element affects the suitability of intermodal transportation.

2. 3. *Transport time reliability in intermodal transportation*

In the following section literature is surveyed that elaborates transport time reliability and its metrics in freight transportation and refers to respective approaches in intermodal transportation. As just-in-time practices and quick response operations are widely applied in multiple industries, transportation time and transport time reliability are ubiquitous challenges to freight transportation and therefore are being seen as major performance indicators (Dullaert and Zamparini, 2013; Taylor, 2013). In general reliability itself relates to the ability of a system to perform to expectation under a given set of conditions (Nicholson et al., 2003). With regard to freight transportation, transport time reliability can be understood as the relative variation of transportation time (Winston, 1981). Various measures such as buffer time index or travel time index have been deployed, but the most common measure of transport time reliability represents the standard deviation (Lyman and Bertini, 2008; Taylor, 2013).

Existing literature concerning intermodal transportation that is dedicated to transport time reliability can be distinguished into research that investigates either container terminals (Sgouridis, Makris and Angelides, 2003; Rizzoli, Fornara and Gambardella, 2002) or the choice of transportation mode (Wiegmans, 2010). Container terminals are a focal point within an intermodal transportation network and are responsible for transshipment between the modes of transportation. They significantly determine the performance of a transport chain and thus, are analyzed individually in order to derive structural and operational improvements to operate them as efficient as possible. In existing approaches special attention is paid to influences like truck arrival pattern and to improvement suggestions as the adoption of computer aided management and automation or the application of advanced handling equipment (Sgouridis, Makris and Angelides, 2003; Rizzoli, Fornara and Gambardella, 2002). Regarding the choice of transportation mode Wiegmans transfers the concept of portfolio management from finance to freight transportation. Consequently, a transportation service can be understood as a portfolio of diverse transport chains including different transportation modes. The core idea is to enable companies to choose a portfolio that maximizes transport time reliability for a given cost level. The transport time reliability for each transport chain is given and just the share of this transport chain on the total transportation service can be varied. (Wiegmans, 2010)

There is some profound literature on transport time reliability and its metrics in general, but only little with respect to intermodal transportation. Particularly the impact of long-haul transportation as distinctive element of intermodal transport chains is underresearched. However existing research works highlight the requirement to consider interaction effects between linked transportation processes when analyzing transport time reliability in intermodal transport chains. Moreover it is indicated that the transport time reliability differs among the modes of transportation.

3. Analytical model

The analytical model developed within this paper reproduces an end-to-end transport chain to analyze the effect of long-haul transportation on the total transport time reliability and transportation time. In this respect it employs a probabilistic approach that considers transport time reliability aspects per transport leg via standard deviation to investigate the impact of long-haul transportation on the total intermodal transport chain (Lyman and Bertini, 2008; Taylor, 2013). The proposed model describes a transport chain from a shipper to a receiver that can be covered either by road only or by intermodal transportation consisting of pre- and post-haul transportation via truck and long-haul transportation via periodic train or vessel. The arrival rate is assumed to be exponentially distributed and thus, the time between arrivals $TT_{pre\ haul}$ and according time reliability $\sigma_{pre\ haul}$ are:

$$TT_{pre\ haul} = T \tag{1}$$

$$\sigma_{pre\ haul} = T \tag{2}$$

In case of unimodal road transportation for every arriving container a truck is available and ready to take it to the customer. In the second case, intermodal transportation, an arriving container is loaded on a periodically running train or vessel. Hence, it is possible only to transship the container every period P. Consistently with the cyclic train schedule there is a waiting time TT_{wait} and an associated waiting time reliability σ_{wait} for the arriving containers involved at the terminal of origin. They are defined as follows:

$$TTwait = \frac{P}{2} \tag{3}$$

$$\sigma_{wait} = \frac{P}{2\sqrt{3}} \tag{4}$$

The total transport distance L is separated into a long-haul and a post-haul part by implementing variable α. The transport distance via long-haul is $(1 - \alpha) L$ and the remaining transport distance covered by truck is given by αL. The transport mode being assigned to long-haul transportation collects all waiting containers from the terminal at the departure time and travels with velocity $v_{long\ haul}$. Furthermore we assume long-haul transportation to be deterministic with an unlimited loading capacity. Both rail and waterborne transportation that cover long-haul transportation employ time buffers to design robust shipping schedules and further update the velocity depending on the surrounding circumstances in order to avoid high costs of delay resulting from a decreased utilization of capital intense infrastructural assets (Kroon et al., 2006; Cacchiani and Toth, 2012; Wang and Meng, 2012; Lee, Lee and Zhang, 2015). Hence, the transportation time for the long-haul $TT_{long\ haul}$ is:

$$TT_{long\ haul} = \frac{(1-\alpha)}{v_{long\ haul}} L \tag{5}$$

As soon as the long-haul transport arrives at the destination terminal containers are instantaneously transshipped to already waiting trucks. At both terminals there is no time for handling movements considered. The remaining part of transportation is covered by a truck with velocity v_{truck} and the according transportation time is assumed to be exponentially distributed. Hence, the transportation time involved for the post-haul $TT_{post\ haul}$ and its transport time reliability are given as:

$$TT_{post\ haul} = \frac{\alpha}{v_{post\ haul}} L \tag{6}$$

$$\sigma_{post\ haul} = \frac{\alpha}{v_{post\ haul}} L \tag{7}$$

Thus, the transportation time TT involved for the total intermodal transport chain from the shipper to the receiver and the total transport time reliability σ are:

$$TT = T + \frac{P}{2} + \frac{(1-\alpha)}{v_{long\ haul}} L + \frac{\alpha}{v_{post\ haul}} L \tag{8}$$

$$\sigma = \sqrt{T^2 + \left(\frac{P}{2\sqrt{3}}\right)^2 + \left(\frac{\alpha}{v_{post\ haul}} L\right)^2} \tag{9}$$

The introduced analytical model enables us to calculate the transportation time and the transport time reliability for an intermodal transport chain and to study the effect of various parameter constellations representing different set-ups of the transport chain, particularly for long-haul transportation, on both performance indicators.

4. Simulation Model

Analyzing the effect of long-haul transportation on transportation time and transport time reliability requires the consideration of a whole transport chain including all three sub-transport processes, namely pre-, long- and post-haul transportation. Thus, the intermodal transport chain to be analyzed can be portrayed as an interconnected and complex system. Combined with the need to investigate the transport chain on a resolution that captures movements of single containers in order to account for interaction effects amongst others, a discrete event simulation is chosen to fulfill the outlined requirements (Robinson, 2004).

With regard to the stated research question, investigating the effect of parameters that can be attributed to long-haul transportation on transportation time and transport time reliability is highly interesting. The share on total transportation and hence the distance allocated to long-haul transportation is such an influencing parameter. It is widely understood as being decisive when contrasting unimodal road and intermodal transportation and has been deployed by existing literature to determine the break-even point (Hanssen, Mathisen and Jorgensen, 2012; Janic, 2007; Macharis and Van Mierlo, 2006). The research on hand therefore analyzes the effect of distance covered by long-haul transportation on transportation time and transport time reliability. Likewise a parameter that is directly related to long-haul transportation is the time between consecutively departing trains or vessels, also referred to as period. In this regard Janic highlights that an increase in service frequency of applied transportation modes for long-haul transportation can have a promoting effect towards intermodal transportation when both external and internal costs are considered (Janic, 2007). This parameter can be adjusted externally by service providers and policy makers to increase the attractiveness of intermodal transportation, which is especially interesting from a policy perspective as such improvement measures are widely looked for (Macharis, Caris, Jourquin and Pekin, 2011). In order to understand the big picture, it is important to consider interaction effects in an intermodal transport chain. Especially pre- and post-haul transportation represent essential transport processes that are directly linked to long-haul transportation and are dependent on spatial and temporal circumstances (Lyman and Bertini, 2008). Thus, this research examines the influence of different distributions being assigned to pre- and post-haul transportation on the performance of an intermodal transport chain depending on the share of long-haul transportation.

The intermodal transport chain being investigated in this paper is modelled in Tecnomatix Plant Simulation Version 11 (Siemens AG, 2014). The object-oriented simulation language allows the user to model the individual transport elements corresponding to their real-world counterparts. Transport components modelled in the simulation model presented are pre-, long- and post-haul transportation, two transshipment terminals as well as a supplier and a receiver. The supplier provides containers ready for shipment that are collected by a truck covering the pre-haul. Both processes together facilitate to establish an arrival rate of containers at the transshipment terminal of origin. Thus, a time between arrivals as well as an according distribution can be defined. Subsequently the containers are transshipped without handling time once a periodic train or vessel with infinite capacity departs. The mentioned period can be adapted and the distance to be covered by long-haul transportation and its velocity which is assumed deterministic can be varied. As soon as the train or vessel arrives at the terminal of destination the containers are transshipped to already waiting trucks, again with no handling time. The post-haul transportation can be modified in terms of velocity and distribution of transportation time. The transport distance of the post-haul can be adjusted too, but is depending on the share of long-haul transportation on the total transportation distance. The presented simulation study assigns train transportation to the long-haul and the initial parameter set-up is as follows:

- Time between arrivals at the terminal of origin: 24 hours,
- Distribution of time between arrivals: exponential,
- Period of departing trains: 24 hours,
- Total transport distance: 1000 kilometers,
- Velocity of the train covering the long-haul: 30 kilometers per hour,
- Velocity of the truck covering the post-haul: 50 kilometers per hour,
- Distribution of the truck transportation time: exponential.

On this basis four scenarios are explored with emphasis on the earlier described parameters that are especially interesting for intermodal transportation with regard to long-haul transportation. For each scenario the impact on transportation time and transport time is investigated. The first scenario systematically analyzes the effect on both performance measures in case of varying the distance covered by long-haul respective post-haul transportation. Consistent with the already introduced analytical model a variable (alpha) is implemented that portions the total transportation distance in two parts. In this scenario alpha runs from zero to one in hundredth steps and thus gradually increases the part covered by truck. The second scenario analyzes how the service frequency of the periodic rail line affects transportation time and transport time reliability. Therefore the time period of consecutively departing trains determining the service frequency is altered and thus in this scenario trains depart either every 12, 24, 36 or 48 hours. The two remaining scenarios both examine interaction effects within an intermodal transport chain, by adopting different distributions for processes linked to long-haul transportation. Hence, in the *third scenario* the time between arrivals at the terminal of origin and in the *fourth scenario* the transportation time covered by post-haul transportation is differently distributed. Besides the exponential distribution of the initial parameter set-up, a uniform and a Pareto distribution is applied. The latter distribution is chosen to represent the power law.

With respect to simulation quality requirements, in this simulation study 100 replications are performed with a run-length of 3650 days for each individual parameter set-up (Robinson, 2004).

5. Results

In this section the results of the discrete event simulation are shown for the individual scenarios.

In Figure 1 the results belonging to the first scenario are graphed as dashed green graphs. With an increasing share covered by truck transportation indicated by variable alpha, which ranges from 0 (representing train transportation only) to 1 (total distance covered by truck), the transportation time steadily decreases. The standard deviation serving as measure of transport time reliability grows and steepens with an increasing share allocated to truck transportation. Besides the dashed green graphs there are also black graphs in Figure 1 that portray the results of the analytical model with the same parameter set-up. With regard to transportation time and transport time reliability the dashed green and black graph coincide, thus the discrete event simulation model reproduces the expected results of the analytical model.

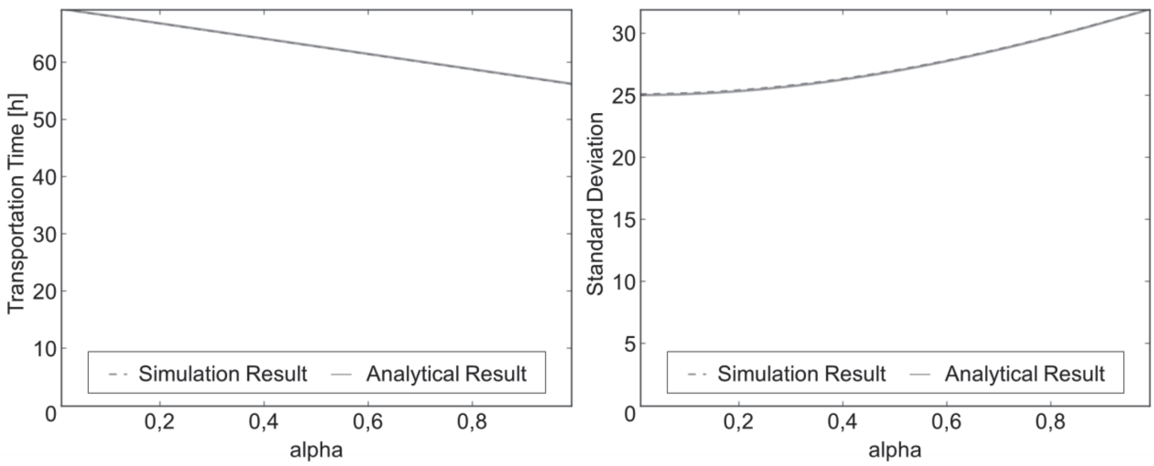

Figure 1. Results of the first scenario.

The results of the second scenario are plotted in Figure 2 and illustrate the effect of different service frequencies of a periodically running rail line by altering the time between departures (P). In view of transportation time a bigger temporal gap between departing trains leads to an increase in total transportation time. The resulting time difference remains unaffected by an increasing share of truck transportation. In terms of transport time reliability an increase in period P causes a growing standard deviation. The effect decreases with a longer distance covered by truck transportation, but does not vanish as the graphs converge but do not coincide for alpha close to one.

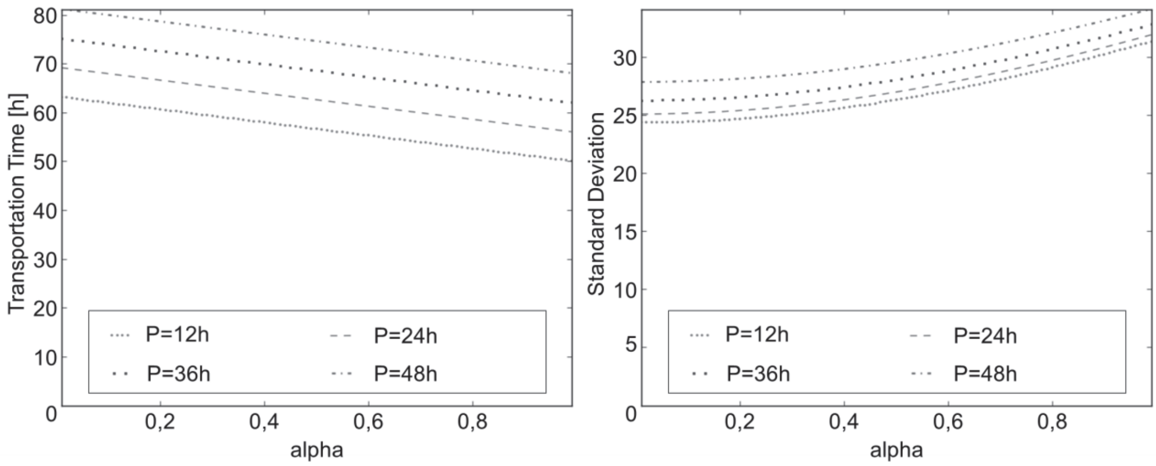

FIGURE 2: Results of the second scenario.

Different distributions for time between arrivals at the terminal of origin are object of investigation of the third scenario and the according results are shown in FIGURE 3. While the graphs for transportation time are coincident lines, the ones for transport time reliability differ significantly. Again the graphs converge with an increasing distance covered by truck transportation, but do not coincide with alpha close to one.

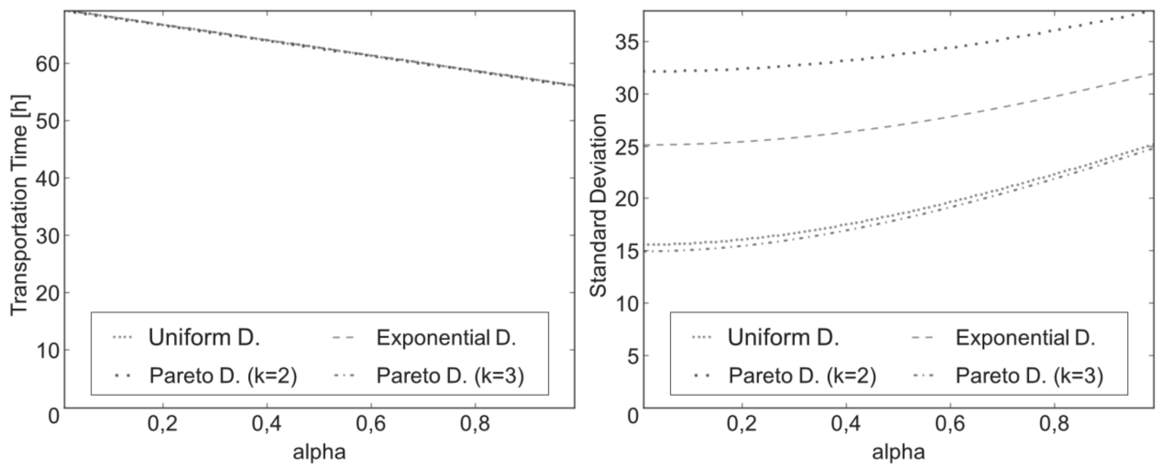

FIGURE 3. Results of the third scenario.

In contrast to the previous scenario different distributions are applied to the post-haul truck transportation in the fourth scenario. The according results are plotted in FIGURE 4. Once again the transportation time is depicted by coincident lines. The standard deviation instead diverges substantially with an increasing share of truck transportation. For alpha close to zero the lines almost coincide.

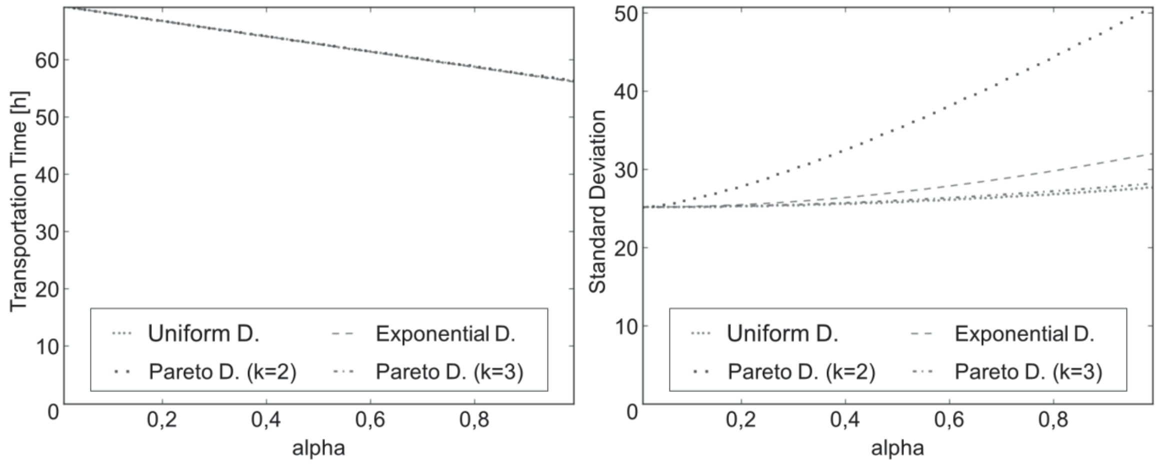

FIGURE 4. Results of the fourth scenario.

6. DISCUSSION

In this section the previously shown results of the simulation study are discussed with respect to the outlined research question.

An increasing service frequency of long-haul transportation has a promoting effect on both transportation time and transport time reliability which strengthens Janic´s observation (Janic, 2007). The simulation results show that by doubling the service frequency from a train departing every 48 hours to every 24 hours the transport time reliability increases by up to 10%. This effect slightly decreases with a decreasing share of long-haul transportation. In comparison to the effects of different distributions involved in pre- and post-haul transportation, the impact of an increased service frequency deployed by the transport mode that is assigned to long-haul transportation on transport time reliability is rather low. However, adapting the service frequency can help to meet transportation time and transport time reliability goals.

As already introduced, long-haul transportation does not only influence transportation time and transport time reliability directly via transport mode specific characteristics such as speed and time between departures. It also determines effects on these performance metrics that occur along an intermodal transport chain, e.g. in pre- and post-haul transportation. In this line the effect of differently distributed times between arrivals at the terminal prior to long-haul transportation on transportation time and transport time reliability is investigated. Diverse arrival pattern and different distributions for time between arrivals influence the transport time reliability by up to 50% depending on the prevailing distributions in our simulation experiments. With an increasing share of post-haul transportation respectively decreasing share of long-haul transportation the effect slightly decreases but still remains intense. The effect emerges as soon as a transport chain involves a transshipment of containers from one mode of transportation to another. Consequently this effect represents an immanent characteristic of intermodal transportation. The circumstance that this effect is an essential part of every intermodal transport chain and furthermore has such a high influence on transport time reliability highlights its importance. Therefore transport planners and logistics managers need to know the transport and production characteristics that account for the time between arrivals and that constitute the arrival pattern of incoming trucks in order to design transport chains that meet the company goals. With regard to the research question long-haul transportation influences the size of the portrayed effect and further causes the effect by its need for transshipment.

Subsequent to long-haul transportation different distributions for post-haul transportation influence the transport time reliability too. A differently distributed post-haul transportation affects the transport time reliability with around 50% on a similar relative level as pre-haul transportation. However the absolute effect size measured via standard deviation is even higher. In contrast to the effect incurred by pre-haul transportation this effect is highly dependent on the share of long-haul transportation on the total transport distance. With an increasing share of long-haul transportation the effect of different distributions for post-haul transportation diminishes and almost vanishes in case the total transport distance is almost entirely covered by long-haul transportation. Hence, transport planners and logistics managers first need to analyze the share of long-haul and post-haul transportation in order to set priorities right. Adapting post-haul transportation characteristics can represent a lever to influence the transport time reliability of an intermodal transport chain but is not necessarily one depending on the share of long-haul transportation.

In summary the simulation study shows that long-haul transportation highly impacts transportation time and transport time reliability and furthermore indicates the size of the individual effects related to long-haul transportation. The major impact on transport time reliability results from different distributions involved in the individual transport legs. While different distributions for pre-haul transportation respectively time between arrivals always have a major effect on transport time reliability in general, the effect of a differently distributed post-haul transportation is largely dependent on the share of long-haul and post-haul transportation. In case of an intermodal transport chain that incorporates a long-haul transportation that covers almost the entire transport distance, the arrival pattern of the pre-haul transportation is of utmost importance for the transport time reliability. If the share of post-haul transportation increases, though, the according distribution of the last transport leg rapidly gains in importance too. In a nutshell transport planners and logistics managers need to be aware of the investigated effects and need to determine the share of pre-, long- and post-haul transportation prior to planning and optimizing intermodal transport chains.

7. Conclusion, Implications and Future Research

Within this paper we developed an analytical model that enables us to pinpoint the effect of characteristic intermodal transport elements particularly long-haul transportation on transportation time and transport time reliability. Thus, it extends existing approaches that analyze the impact of long-haul transportation on the decision variable costs only by two additional dimensions, transportation time and transport time reliability.

On this basis we created a simulation model and conducted simulation studies with focus on long-haul transportation. Three effects on transport time reliability that occur in intermodal transport chains are shown and their relations to long-haul transportation are discussed. The effect of differently distributed pre-haul transportations highly impacts the transport time reliability but is just slightly influenced by long-haul transportation. Contrary the effect of different distributions for post-haul transportation on transport time reliability is dependent on the share of long-haul transportation and can have a profound impact too. By adapting the service frequency of long-haul transportation the transport time reliability can be improved directly. However, the effects of differently distributed transport legs appear to be higher in our simulation studies. The existence of these effects and the knowledge how to leverage them are especially relevant for policy makers and transport planners as they continuously strive for alternative and more sustainable transportation concepts.

However, the proposed analytical and simulation model incorporate limitations. In course of developing the models we made simplifications in order to investigate the impact of long-haul transportation on transportation time and transport time reliability and to avoid interfering effects. In real-world intermodal transport chains a restricted availability and a transshipment time at the container terminals as well as probabilistic long-haul transportations with a limited capacity amongst others have to be considered. But still the developed models as well as the investigated effects form a basis to analyze transportation time and transport time reliability in intermodal transport chains.

The paper contributes to intermodal transportation literature by first, adding transportation time and transport time reliability to performance metrics and considering them as decision variables for intermodal transport chains, and second, outlining the influence of long-haul transportation on them. Thus, logistics practitioners are enabled to assess the influence of characteristic parameters for intermodal transportation especially long-haul transportation when planning an intermodal transport chain or network.

Future research is required to question underlying assumptions and simplifications such as deterministic long-haul transportation, an infinite capacity of transport elements, and the negligence of handling times for transshipment processes. Furthermore sub-processes accounting for time between arrivals at the terminal of origin are modelled as one process in this research. Thus, future research might explicitly consider processes at suppliers or consolidation processes in hubs, cross docks or terminals.

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4 Paper 3: From Lean Factories to Lean Global Supply Chains – Implications for Performance and Costs in Global Intermodal Automotive Supply Chains

Authors: T. Erfurth, J. Arlinghaus

Status of the Publication: Submitted for publication in Supply Chain Management: an International Journal

Contribution of T. Erfurth to the Work: Conducted the discrete event simulation study and the cross-case study, carried out the analysis of the study, validated the results by conducting expert interviews, wrote all sections of the manuscript and contributed to discussions and interpretations.

Contributions of the Co-Author: J. Arlinghaus contributed to discussions on the simulation model and the applicability of lean management in global supply chains, interpreted results, reviewed and streamlined the manuscript and helped to write all sections of the manuscript.

Contributions of the Paper to the PhD Project: This paper transfers the concept of lean management in global supply chains to xKD supply chains and evaluates the compiled improvement measures. In order to analyze the measures in the context of xKD supply chains, SCP metrics are accordingly developed. A cross-case study forms the basis for experimentation and determines the status quo. The paper performs a discrete event simulation in order to analyze the improvement levers. Conclusions are drawn and the implications of managerial practices are suggested.

From Lean Factories to Lean Global Supply Chains: Implications for Performance and Costs in Global Intermodal Automotive Supply Chains

Purpose – The paper aims to explore improvement levers for overseas supply chains in the automotive industry, so-called knocked down supply chains, by adopting elements from lean management. Despite the extensive implementation of lean management in factories, there is no consensus about its effects on global transportation and the knocked down supply chains fail to meet the performance requirements. The paper hence intends to improve the performance of knocked down supply chains and to contribute to the debate about the applicability of lean management in context of global supply chains.

Design/methodology/approach – The paper employs three complementary research methods. Based on hypotheses that are derived from literature, the paper develops a discrete-event simulation to analyze the improvement levers and conducts a cross-case study combined with interviews with experts to lay the foundation and to validate the simulation results.

Findings – The paper identifies and analyzes four improvement levers gained from lean management. The paper shows that the supply chain performance of knocked down supply chains can be increased by ten percent with respect to costs and by four days with respect to lead time and inventory level.

Originality/value – The paper conducts the first quantitative investigation on the potential supply chain performance of knocked down supply chains and provides four improvement levers. It further provides evidence that lean management elements help to diminish adverse effects of global transportation.

Keywords: global supply chains, lean management, discrete-event simulation, supply chain performance, knocked down supply chains

1. Introduction

The automotive industry is currently facing dramatic challenges: Digitalization, electric transportation and sustainability are set to disrupt existing business operations (Opazo-Basáez *et al.*, 2018). Combined with recent global political developments , e.g. trade wars, the environment for original equipment manufacturers (OEMs) is more challenging than ever (Leung Chong and Li, 2019). OEMs need to improve the performance of their global manufacturing networks in order to strengthen their market position and to finance massive capital expenditures in upcoming years (Szalavetz, 2019). The global supply chains (SC) linking the various overseas plants and suppliers fail to meet the expectations of operational excellence in terms of lead time, inventory, delivery reliability and cost usually known in the automotive industry (Erfurth and Bendul, 2018).

OEMs have established overseas plants in foreign markets over the past decades - mainly to comply with market entry policies in course of their expansion strategy (Meyer and Jacob, 2008). In light of the inadequate local supplier base and level of qualification, OEMs have employed so-called knocked down (xKD) SCs that ship all parts required to manufacture a car, preassembled and arranged in kits, from the original plants to overseas plants, thus enabling them to manage the complexity of car production (Song, 2009). Overseas plants have advanced to become fully equipped plants and have consequently shifted their focus toward performance (Choi *et al.*, 2012; Talavera, 2015). There is, however, no consensus on the most promising setting of xKD SCs for achieving highest supply chain performance (SCP) (Song, 2009). Whereas European OEMs operate xkD SCs with high inventory levels and lead times, Japanese OEMs have partially incorporated lean management measures (Erfurth and Bendul, 2018; Itoh and Guerrero, 2020).

Lean management aims at performance improvement via by eliminating waste, and has been applied widely in the automotive industry (Womack *et al.*, 1990). Whereas the general understanding is that lean management can basically be applied anywhere, there has been ongoing debate about global SCs for over twenty years (Berger *et al.*, 2018; Lorentz *et al.*, 2018). By definition, global SCs cannot be as seamless and responsive as local SCs, thus rendering the implementation of lean practices difficult (Levy, 1997; Holweg *et al.*, 2011; Stanczyk *et al.*, 2016). Although researchers contend that lean management can help diminish the adverse impacts associated with global transportation and propose measures in their research on lean management in global SCs (Cheng, 2011; Golini *et al.*, 2016). Existing research studies have neither systematically transferred these measures to xKD SCs nor quantitatively investigated their impact on SCP in general, however (Cheng, 2011; Cherrafi *et al.*, 2016; Stanczyk *et al.*, 2016).

The guiding research question is, therefore: *How can the SCP of xKD supply chains be improved in terms of lead time, delivery reliability, inventory and costs by applying lean management practices to global SCs?* This study is intended to identify and evaluate improvement levers for xKD SCs, which have been adopted from lean management in global SCs. Moreover, it is also intended to contribute to the discourse the feasibility and means of transferring the philosophy of lean management to global SCs.

A systematic review of the literature on xKD SCs, lean management in global SCs and SCP serves as the basis for us to derive hypotheses about potential improvement levers to structure our research. We develop a discrete-event simulation study to analyze the improvement levers and conduct a cross-case study combined with interviews with experts to establish the initial scenario and validate the results.

This paper is structured as follows: The introduction is followed by a review of the literature streams, the derivation of hypotheses and an enumeration of the research gaps in section two. Section three presents the methodology and explains the simulation study and the complementary case study. The findings are presented in section four and discussed in section five. Section six concludes this paper, presents the theoretical and practical implications, outlines limitations and provides an outlook.

2. Theoretical Foundations

Several research streams provide input for the outlined research question. Literature on xKD SCs explains relevant process and network aspects. On this basis, we review literature on lean management in global SC to identify potential improvement levers for the formerly outlined xKD supply chains. We complement this by means of a review of SCP to introduce a set of metrics that allows us to measure the according effects. In total, this enables us to derive hypotheses on potential improvements by the application of lean management in global SC on xKD SC in the automotive industry.

2.1 Global Automotive Supply Chains

Over the last decades, OEMs have steadily pursued new sales opportunities and shifted their focus toward less mobilized markets in response to the saturation of traditional automotive markets (Koehne, 2013; Meyer and Jacob, 2008). OEMs have established assembly plants in emerging markets to comply with market entry restrictions and to avoid high tariffs (Klug, 2010; Koehne, 2013; Schulz and Hesse, 2009). OEMs have employed so-called xKD SCs to enable these plants to manufacture highly complex products such as cars and ship up to 3,000,000 m^3 or more than 40,000 high cube containers via xKD SCs (Song, 2009; Weyerer, 2012; Quaas, 2015, Fehse 2019). XKD SCs ship all parts required to manufacture a car, preassembled and arranged in kits, from the original plants to overseas plants (Schulz and Hesse, 2009; Song, 2009). In other words, xKD SCs deliver car parts rather than complete cars (Choi *et al.*, 2012).

There are four types of xKD SCs (see Figure 1) (Schulz and Hesse, 2009; Klug, 2010). In semi knocked down (SKD) SCs, cars are finished at the original plant, before being partially dissembled and sent in kits to the overseas plant where they are reassembled (Schulz and Hesse, 2009; Koehne, 2013). In medium knocked down (MKD) SCs, painted bodies are shipped together with kitted assembly parts arranged in kits, and are then shipped to the overseas plant where the cars are eventually assembled (Schulz and Hesse, 2009; Song, 2009). In completely knocked down (CKD) SCs, the overseas plant has its own paint and body shop and assembly line (Koehne, 2013). All parts are shipped in kits to the overseas plant that produces the entire. Part by part (PBP) SCs represent the fourth type. Rather than being kitted, parts are shipped individually in varietal boxes (Schulz and Hesse, 2009; Klug, 2010).

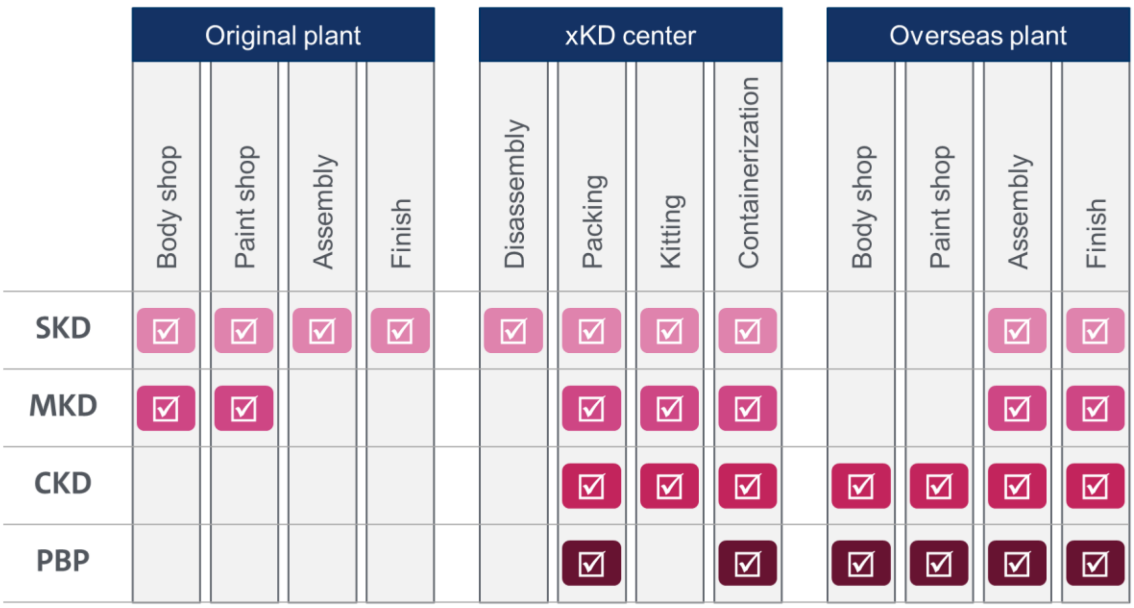

Figure 1: Types of xKD SCs (Erfurth and Bendul, 2018)

All types of xKD SC follow the same process (Figure 2). The xKD center where kitting and containerization are done receives weekly delivery orders from every overseas plant it supplies and forwards them consolidated to its suppliers (Klug, 2010). The parts are collected from the suppliers, bundled at cross-docks or milk runs, and are then shipped to the xKD center (Song, 2009; Klug, 2010). The parts are subsequently stored, before being released for packaging (Song, 2009; Freitas *et al.*, 2017). Parts in SKD, MKD and CKD SCs are packaged in kits, whereas parts in PBP SCs the are packaged in varietal boxes (Schulz and Hesse, 2009; Song, 2009). Overseas packaging is required since the dimensions of trucks and maritime containers vary and shipping conditions are challenging, e.g. temperature zones differ (Klug, 2010). The parts are subsequently loaded into a container and dispatched. A weekly container dispatch deadline at the xKD center for every destination represents the latest time at which a container can be dispatched to ensure it can be loaded to the weekly departing shipping line (Schulz and Hesse, 2009). Any parts that miss the container dispatch deadline must be shipped by air freight.

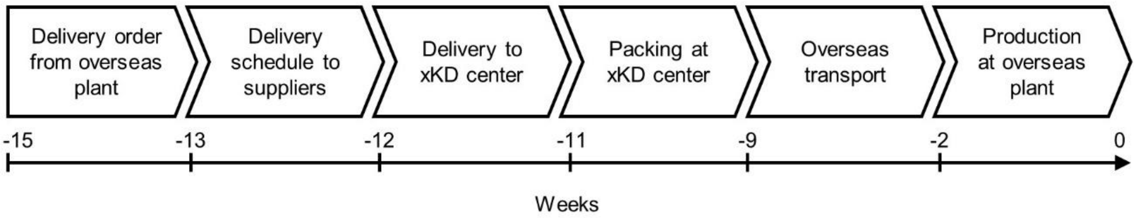

Figure 2: xKD SC process (Schulz and Hesse, 2009)

Erfurth and Bendul (2018) conducted a cross-case study to explore currently operated xKD SCs and discovered that xKD SCs are the backbone of the underlying global manufacturing networks and that they still feature a low SCP (Table I). In course of their research, they have demonstrated that overseas plants supplied by PBP SCs have substantially different requirements than those supplied by the three other types of xKD SCs (Erfurth and Bendul, 2018). While SKD, MKD and CKD SCs support market entries, PBP SCs supply fully equipped overseas plants (Schulze and Hesse, 2009; Klug, 2010). These overseas plants pursue profits by selling a high volume of products at a competitive price (Meyer and Jacob, 2008). The top requirement for PBP SCs is consequently high SCP in terms of lead time, delivery reliability, inventory and costs (Erfurth and Bendul,

Table I: Current status of xKD SCs (Erfurth and Bendul, 2018)

	BMW	Daimler	JLR
Brands with xKD business	BMW	Mercedes Benz Cars	Jaguar, Land Rover, Range Rover
Car models for xKD supply chains	e.g. BMW 3series, X3, X5	e.g. Mercedes Benz C-Class, E-Class, M-Class	e.g. Range Rover Evoque, Discovery Sport
Markets with xKD centers	3 markets with xKD centers: Germany, United States, South Africa	2 markets with xKD centers: Germany, Brazil	2 markets with xKD centers: United Kingdom, Germany
Overseas xKD markets	11 overseas xKD markets: Egypt, India, Indonesia, Malaysia, Russia, Thailand, Brazil, China, US, Brazil, South Africa	10 overseas xKD markets: Vietnam, Thailand, Indonesia, India, US, South Africa, China, Malaysia, South Africa, Brazil	3 overseas xKD markets: China, Brazil, India
Operated xKD SC types	SKD, MKD, CKD, PBP	SKD, MKD, CKD	SKD, MKD, CKD
Predominant xKD SC type	CKD	MKD	SKD
Shipping frequency to the overseas market	Weekly shipping frequency; daily expedited shipping via air; daily shipping to Russia via rail	Weekly shipping frequency; daily expedited shipping via air	Weekly shipping frequency; daily expedited shipping via air
Average lead time in the xKD center	5 days	>10 days	n.a.

	PSA	Renault	VW
Brands with xKD business	Citroën, Peugeot	Renault, Dacia	VW, AUDI, Skoda
Car models for xKD supply chains	e.g. Citroën C4, Peugeot 408	e.g. Renault Sandero, Dacia Logan	e.g. VW Golf, VW Passat, Audi A4, Skoda Octavia
Markets with xKD centers	4 markets with xKD centers: France, Spain, Argentina, China	8 markets with xKD centers: France, Brazil, Argentina, Spain, Rumania, Turkey, India, South Korea	7 markets with xKD centers: Germany, Spain, Czech, Mexico, Brazil, Argentina, India
Overseas xKD markets	6 overseas xKD markets: Malaysia, Brazil, China, Turkey, Russia, Argentina	11 overseas xKD markets Algeria, India, Iran, Morocco, Russia, Turkey, China, South Korea, Argentina, Brazil, Colombia	13 overseas xKD markets: United States, Mexico, Brazil, Argentina, South Africa, Nigeria, Russia, Ukraine, Kazakhstan, India, Malaysia, Indonesia, China
Operated xKD SC types	SKD, MKD, CKD, PBP	SKD, MKD, CKD, PBP	SKD, MKD, CKD, PBP
Predominant xKD SC type	PBP	PBP	PBP
shipping frequency to the overseas market	Weekly shipping frequency; daily expedited shipping via air; daily shipping to Russia via rail	Weekly shipping frequency; daily expedited shipping via air	Weekly shipping frequency; daily expedited shipping via air; daily shipping to Russia via rail
Average lead time in the xKD center	n.a.	2 to 4 days	5 days

2018). On the one hand, European OEMs operate PBP SCs just like their kitting counterparts, accepting long lead times and high inventory levels in particular at their xKD centers (Erfurth and Bendul, 2018). Japanese OEMs, on the other hand, take advantage of their suppliers' high delivery frequencies and short lead times at their xKD centers (Itoh and Guerrero, 2020). There are arguments for both approaches since smaller inventories and shorter lead times offset higher shipping costs for smaller shipments, given that shippers' long lead times and low service frequencies are unavoidable. We are not aware of any study that addresses this conflict and further analyzes potential improvement levers for PBP SCs with respect to SCP.

2.2 Lean Management in Global Supply Chains

Lean Management is an approach that to pursuing performance improvements systematically, which was developed by Ohno (1988) and Womack *et al.*, (1990). Lean management can be understood as a set of tools for optimizing production systems by eliminating all non-value adding activities (Shah and Ward, 2007). Lean management aims for just-in-time (JIT) delivery, low inventories, zero defects, flexible, small-batch and pull-driven processes, and close technical collaboration with suppliers (Levy, 1997).

Whereas the general understanding of lean management is that it can be applied essentially anywhere, there has been contentious debate about global SCs (Berger *et al.*, 2018; Lorentz *et al.*, 2018). One group of researchers contends that global SCs cannot be fast and seamless by definition and have long lead times and low shipping frequencies (Cusumano, 1994; Levy, 1997; Holweg *et al.*, 2011; Stanczyk *et al.*, 2016). Another group of researchers argues that lean management can positively affect global SCs and diminish adverse effects (Fawcett and Birou, 1992; Cheng, 2011; Golini *et al.*, 2016; Lorentz *et al.*, 2018). The following lean management measures in global SCs have been proposed:

- *Reduce the order lot size* per part by establishing consolidation centers prior to long distance shipping. Consolidating shipments to full container loads decreases the order lot size per part and supplier (Staudacher and Tantardini, 2009; Cheng, 2011).
- Performing *quality inspections prior to long distance shipping*, e.g. at suppliers' facilities, reduces the risk of defective parts and high air freight costs (Staudacher and Tantardini, 2009; Salimi, 2013).
- Employing *high delivery frequencies* from suppliers to the consolidation center, also known as *JIT delivery,* to connect suppliers with global SCs (Golini *et al.*, 2016). The general goal of JIT is to provide goods just in time for sale or assembly (Humphrey *et al.*, 1998). JIT deliveries entail small batches and high delivery frequency (Shah and Ward, 2007). This enables consolidation centers to operate more efficiently (Krueger, 2004; Cheng, 2011).
- *Reducing buffer times* across the SC to decrease inventories and shorten lead times (Krueger, 2004; Trippner, 2006). OEMs hold inventories at two positions in the SC, at the xKD center and at the overseas plant (Trippner, 2006). Whereas the inventory at the overseas plant serves as a safety stock contingent on the global SC performance first and foremost delivery reliability, the inventory at the consolidation center results from the underlying xKD process itself and can be adapted directly (Krueger, 2004; Trippner, 2006).

Researchers have discussed the applicability of lean management to global SCs purely qualitatively, pointing out the need for an quantitative study that quantifies the resultant effects (Staudacher and Tantardini, 2009; Cheng, 2011; Stanczyk *et al.*, 2016).

2.3 Global Supply Chain Performance

SCP measurement is crucial to companies' improvement of SCs (Beamon, 1999; Gunasekaran *et al.*, 2004). Performance measurement is defined as the process of quantifying the effectiveness and efficiency of actions (Neely *et al.*, 1995). Effectiveness can be understood as the extent to which a customer's requirements are met and efficiency as a measure of a business's economization of resources while providing a prespecified level of customer satisfaction (Mentzer and Konrad, 1991).

The selection of performance measures for SCs is a difficult task because of their complexity (Beamon, 1999). One single performance measure is insufficient since this ignores important interactions within SCs (Beamon, 1999). Too many performance measures are not useful, either (Gunasekaran *et al.*, 2004). Chae (2009) recommends to implement a small number of performance measures which are absolutely necessary rather than too many. SCP metrics should capture the essence of organizational performance and consist of a balanced selection of financial and nonfinancial measures (Gunasekaran *et al.*, 2004). In context of lean practices, delivery reliability is highly important for customers, which is non-financial but crucial to the company's success (Chan and Qi, 2003). The challenge is to define SCP metrics that fit the objective (Chan and Qi, 2003; Shepherd and Guenter, 2006). In case this is achieved by a selection of relevant measures, SCP measurement can be of great benefit for organizations and supply chains (Bai and Sarkaris, 2014). Arif-Uz-Zaman and Nazmul Ahsan (2014) and Ruiz-Benitez *et al.* (2018) all developed SCP metrics and studied the effect of lean management on SCs based on a case study and interviews with experts. We transfer the metrics to xKD SCs, factoring in our quantitative study. We therefore focus on the following SCP measures (Arif-Uz-Zaman and Nazmul Ahsan, 2014; Ruiz-Benitez *et al.*, 2018):

Table II: SCP metrics for the research study

	SCP measures	References
Operational SCP	- *Lead time* - *Delivery reliability* - *Inventory level*	*Chan and Qi, 2003; Arif-Uz-Zaman and Nazmul Ahsan, 2014; Prajogo et al., 2016; Ruiz-Benitez et al., 2018*
Economic SCP	- *Inbound transportation costs* - *Outbound transportation costs (container)* - *Outbound transportation costs (air freight)* - *Labor costs* - *Warehousing costs* - *Capital lock-up costs*	*Mentzer and Konrad, 1991; Chan and Qi, 2003; Song, 2009; Ruiz-Benitez et al., 2018*

2.5 Hypothesis Development

Based on the aforementioned literature review, we propose hypotheses about potential improvement levers for xKD SCs in this section. We therefore transfer lean management in global SCs improvement measures to xKD SCs, considering the SCP metrics derived. Given the substantially higher SCP requirements of the overseas plants supplied, we concentrate on PBP SCs.

PBP SCs have already implemented the first two measures of lean management in global SCs, namely the introduction of consolidation centers and quality checks prior to long haul transportation(Schulz and Hesse, 2009; Song, 2009). As for the third improvement lever, since xKD centers currently receive weekly or monthly deliveries from their suppliers, they have not employed JIT deliveries with high delivery frequency (Erfurth and Bendul, 2018). OEMs also keep large buffers at their xKD centers and consequently have not implemented the fourth improvement lever (Erfurth and Bendul, 2018). We therefore propose the following two hypotheses:

H1: The higher suppliers' delivery frequency to the xKD center is, the higher is the SCP of PBP SCs in terms of lead time, delivery reliability, inventory level and costs.

H2: The shorter the buffer time between arrival and dispatch at the xKD center is, the higher is the SCP of PBP SCs is in terms of lead time, delivery reliability, inventory level and costs.

In keeping with lean management in global SCs, we assume the SCP is highest when improvement levers are applied in combination and therefore formulate hypothesis H3 to study the overall effect:

H3: A combination of higher supplier delivery frequency and a shorter buffer time at the xKD center leads to an even higher SCP of PBP in terms of lead time, delivery reliability, inventory levels and costs.

Hypotheses H1 to H3 all focus on PBP SCs. We propose an additional hypothesis to compare the results to a kitting xKD SC:

H4: The SCP of PBP SCs in terms of lead time, delivery reliability, inventory levels and costs achievable by combining higher supplier delivery frequency of the suppliers and shorter buffer time at the xKD center is higher than that of xKD SCs that involve kitting.

2.4 Research Gaps and Objectives

The literature review reveals that research on SCP of xKD is rare. XKD SCs are typified by long lead times, high inventory levels and high costs. There is little research on potential improvement levers, though (Song, 2009; Schulz and Hesse, 2009). Erfurth and Bendul (2018) pointed out that PBP SCs in particular do not meet SCP requirements. There is no consensus on how to tackle this challenge. European OEMs argue that the overall long lead times and low service frequencies are the inevitable outcome of maritime shipping and that efficiency measures such as those introduced by Japanese OEMs also increase costs and the risk of process failure (Erfurth and Bendul, 2018; Itoh and Guerrero, 2020). No research addresses this conflict and explores improvement levers for PBP SCs (Erfurth and Bendul, 2018). Researchers highlight the need for quantitative research, such as simulation studies (Song, 2009; Talavera, 2015). The literature asserts that lean management can help diminish adverse effects of global shipping but lacks quantitative studies that quantify the effect of theoretically derived measures (Staudacher and Tantardini, 2009; Cheng, 2011; Stanczyk *et al.*, 2016). Itoh and Guerrero (2020) partially refer to lean management in global SCs when describing two Japanese OEMs' PBP SC but do not derive their measures systematically from literature on lean management in global SCs. The concept of lean management in global SCs has therefore not been transferred systematically to PBP SCs.

This study is intended to close the research gaps. We strive to identify and evaluate improvement levers that enhance the SCP of PBP SCs by means of lean management in global SCs. We examine lean management in global SCs measures on xKD SCs based on the hypotheses derived in Section 2.4, analyzing the effect of improvement measures applied singly and in combination. We then apply the same improvement levers to a kitting xKD SC to analyze the different conditions and compare the findings with PBP SCs. We are thus aiming to improve the SCP of xKD SCs as well as to contribute to the discourse about the applicability of lean management in global SCs.

3. Methodology

3.1 Research Design

Based on the four postulated hypotheses this research requires experimentation to explore the effects of the improvement levers. Experimentation with real world xKD SCs is impracticable since an analysis would require several changes to the operating xKD SCs, which would put the supply of overseas plants at risk and be very time consuming (Robinson, 2004). A research method that has been proven suitable for experimentation in the production and logistics environment is simulation study (Robinson, 2004; Rose und Maerz, 2011). A simulation model can be understood as a reproduction of a system on which experiments can be run in order to acquire insights that can be transferred to reality (Robinson, 2004). Simulation models enable researchers to analyze complex and interconnected systems such as xKD SCs with high variability (Robinson, 2004). Discrete-event simulations are a widely used for production and logistics (Rose and Maerz, 2011). Components in discrete-event simulations are modeled as objects with different states triggered by events or time (Law and Kelton, 2000).

The development of a simulation study requires knowledge of relevant and current processes and parameters in order to create the conceptual model as basis and realistic data to conduct a valid parameterization of the simulation model (Law, 2001; Robinson, 2004). While the process understanding has been gained via the literature research, we discovered a lack of current SCP and parameter availability (Song, 2009; Erfurth and Bendul, 2018). The required information are sensitive for OEMs and are barely available, thus, we complement the simulation study with a cross-case study to obtain the information necessary to derive an initial parameter setup as well as experimentation plan. An exploratory research method which is suitable for investigating real-life operations and obtaining current data is case study research (Yin, 2014). Case studies are particularly applicable in case there is neither control nor access to the research objective and information to be obtained (Yin, 2014). This research method provides the opportunity to employ a secondary data research via the Internet and literature to retrieve the information (Yin, 2014). Cross-case studies feature the advantage that by the investigation of multiple cases the generalizability of the results is strengthened (Yin, 2014). Hence, we conduct a cross-case study to retrieve information about current xKD SC to parameterize the simulation model.

In order to ensure the simulation model reproduces sufficiently accurate the actual system with regard to the research objective the simulation model is validated (Law, 2001). In two stages we involve semi-structured interviews with experts to ascertain the validity. Firstly, to assess the validity of the data retrieved from the cross-case study and of the simulation model based on the results of the initial simulation scenario and an examination the simulation model itself. Secondly, to discuss the simulation results after conducting the experiments for the four hypotheses to ensure the simulation model and chosen SCP metrics are sufficiently accurate and allow decision makers to draw conclusions. In this way, we validate the simulation model by considering data validity, model validity and experimentation validity (Law, 2001; Robinson, 2004).

As a consequence, this study employs three complementary research methods that enable us to conduct realistic experiments on this research topic. The corresponding research design is presented in Figure 3.

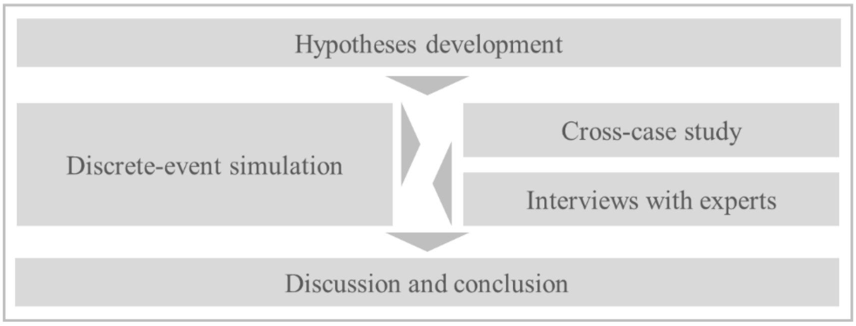

Figure 3: Research design

In the following sections we will develop the simulation model in detail. Section 3.2 introduces the discrete-simulation model including the parameters and variables. In Section 3.3. the SCP metrics is defined to evaluate the effect on the hypotheses. Given this, Section 3.4 conducts the cross-case study to explore the necessary data for parameterization and Section 3.5 develops the experiment plan to analyze the hypotheses on this basis. Section 3.6 contains the validation of the simulation model under consideration of the interviews with experts.

3.2 Simulation Model

The simulation model covers the xKD SCs from the suppliers to dispatch at the xKD center. We chose this scope in keeping with the hypotheses' focus on this particular segment of xKD SCs. Research in the adjacent field of intermodal transportation revealed that, while transport hauls can be analyzed individually, the findings are applicable to the overall SC, thus supporting our approach (Erfurth and Bendul, 2017). Figure 4 presents an overview of the simulation model.

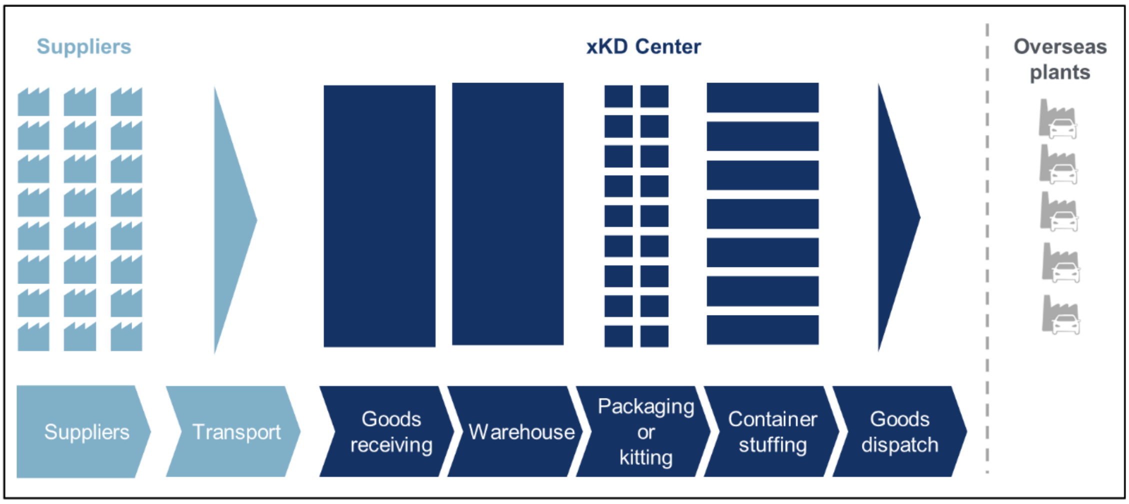

Figure 4: Overview of the simulation model

The simulation model reproduces an entire xKD center and thus operates multiple xKD SCs on parallel, instead of just one xKD SC. This enables us to examine interdependencies between xKD SCs, such as consolidated inbound shipments and mutual use of the packaging and kitting area, which determines the SCP in terms of lead time, inventory level, delivery reliability and costs (Song, 2009; Guerrero, 2014). From a process perspective, the shipments of the suppliers are first collected from a truck. According to the widely applied concepts in the automotive industry, such as area freight forwarder, milk runs, and cross docks, the shipments of multiple suppliers are consolidated and delivered as full truck loads to the xKD center (Song 2009). At the xKD center the parts are stored in the warehouse, until the packaging area pulls the parts depending on the due date. The parts are released and packed in varietal boxes or kits depending on the xKD supply chain type. Subsequently, the parts are moved to the container stuffing area, where the parts are bundled to a container load in container dispatch lanes (Fehse 2016). Once, a container load is completed the parts are loaded onto a container and dispatched. There is a weekly container dispatch deadline at the xKD center for each xKD supply chain depending on the overseas plant that describes the latest point a container can be dispatched in order to ensure customs clearance at the port (Schulz and Hesse 2009). All parts that miss the container dispatch deadline need to be shipped via air freight.

On this basis, we define three variables for our simulation model in order to analyze the hypotheses systematically (Table III).

Table III: Simulation model – Simulation variables

Variable	Definition
XKD supply chain type	The xKD supply chain type defines whether PBP or kitting xKD supply chains are employed.
Delivery frequency	The delivery frequency defines the number of deliveries per week and supplier.
Buffer time	The buffer time describes the time between the latest time of arrival and the container dispatch deadline at the xKD center.

We employ version 12 of Siemens Tecnomatix Plant Simulation software as it explicitly designed for discrete-event simulations and has been proved to be suitable in the context of production and logistics processes (Bangsow, 2020; Marasova *et al.*, 2020). This software provides pre-defined objects and gives you the opportunity to adapt the according behavior, constraints and settings by the implementation of so-called methods that can be modified by the application of the corresponding programming language SimTalk (Bangsow, 2020). This way, the xKD SC and according simulation model depicted in Figure 4 can be developed. Another advantage of Tecnomatix Plant Simulation presents the visualization opportunities that allow you to monitor the individual units and elements and thus to discuss the behavior and results with experts from practice without programming knowledge (Siderska, 2016; Bansow, 2020).

3.3 Simulation Model: SCP Implementation

Based on the scope and process of the simulation model outlined, we next implement the SCP metrics derived from Section 2.3.

Table IV presents the operational SCP metrics. We employ two SCP metrics for delivery reliability. The standard deviation of lead time represents the first metrics and considers parts unpunctual in case they are too early or too late (Erfurth and Bendul, 2017). Tardiness is the second metrics and considers parts unpunctual only if they are delayed, nevertheless they might have been too early (Vig and Dooley, 1991). We thus highlight the importance of the container dispatch deadline and the related potential negative consequences.

Table IV: Simulation model – Operational SCP metrics

Operational SCP Metrics		
Lead time	average lead time	average lead time at the xKD center from goods receiving to goods dispatch
Delivery reliability	standard deviation of the lead time	standard deviation of the lead time at the xKD center from goods receiving to goods dispatch
	average tardiness	average share of parts that exceeds the container dispatch deadline
Inventory level	average inventory level	average number of parts that are stored in the warehouse in order to be released for packaging or kitting

Table V: The simulation model's economic SCP metrics

Economic SCP metrics			
Inbound costs	$Costs\ per\ inbound\ shipment = c_{qm} * (1 - fdm)^{s_i} * sib$		
	Parameters:		Initial setup:
	c_{qm}	Transport costs for the 1st m³	30 EUR / m³
	f_{dm}	Degression factor	1%
	s_{ib}	Size of an inbound shipment [m³]	
	References: Bahrami, 2003; Krueger, 2004; Song, 2009; Linke, 2013		
Outbound costs (container)	$Costs\ per\ container\ shipment\ = c_{ctr}$		
	Parameters:		Initial setup
	c_{ctr}	Transport costs per container	1,400 EUR / container
	References: Song, 2009; Behrens and Picard, 2011		
Outbound costs (air freight)	$Costs\ per\ air\ freight\ shipment\ = c_{af}\ * saf$		
	Parameters:		Initial setup
	c_{af}	Air freight costs per m³ including	100 EUR / m³
	s_{af}	Size of an air freight shipment	
	References: Song, 2009; Behrens and Picard, 2011		
Labor costs	$Labor\ costs\ of\ the\ packing\ station = c_p\ *\ np$		
	Parameters:		Initial setup
	c_p	Costs per operator	50,000 EUR / operator
	n_p	Number of operators	250 operators
	References: Song, 2009; Weyerer, 2012; Hollmann, 2016; Volkswagen, 2019		
Overhead costs	$Overhead\ costs = \frac{i_{ps}}{d_{ps}} * (h * \frac{WIP_e}{WIP_{sq}} + (1 - h))$		
	Parameters:		Initial setup
	i_{ps}	Investment costs for a packing station	25,000,000 EUR
	d_{ps}	Contract duration with investor	5 years
	h	Share of xKD center that is dependent on WIP level (e.g. warehouse)	67 %
	WIP_{sq}	Average inventory level of the status quo	
	WIP_e	Average inventory level of the experiment	
	References: Automotive Logistics, 2012; Guerrero, 2014; Fehse, 2016; Syncreon, 2016		
Capital lock-up costs	$Capital\ lock - up\ costs = r * WIPe\ * v_{hu} * \frac{c_c}{v_c}$		
	Parameters:		Initial setup
	r	Interest rate	5%
	v_{hu}	Volume per handling unit	1 m³ / handling unit
	c_c	Costs per car	30,000 EUR
	v_c	Volume per car	23 m³ (3 cars per container)
	WIP_e	Average inventory level of the experiment	
	References: Song, 2009; Erfurth and Bendul, 2018		
Total costs	$Total\ costs = Inbound\ costs + Outbound\ costs\ (container) + Outbound\ costs\ (air\ freight) + Labor\ costs + Overhead\ costs + Capital\ lock - up\ costs$		

Table V presents the simulation model's economic SPC metrics . We adapted the cost functions introduced by Song (2009). Since cost parameters and information are highly confidential for OEMs, we conducted a literature review for each individual cost type and discussed the cost functions and parameters applied with experts in interviews to corroborate them. We fundamentally contribute to research on overseas shipping in general and xKD SCs in particular, by laying the foundation for financial evaluations in this and future research studies. Combined with the simulation results, this will enable researchers to discuss the effect of different parameter setups too.

3.4 Simulation Model: Cross-Case Study for Parameterization

Information on current xKD SCs is needed to adopt a realistic parameter setup for the simulation study and to obtain a validation basis (Law, 2008). A research method that targets to generate information on present events is case study research (Yin, 2014). Cross-case studies are a specific case-study type that explore multiple cases which benefits the generalizability of the results (Yin, 2014). A sample of six cases furnishes a good basis (Eisenhard, 1989). We thus study the following six OEMs: BMW, Daimler, JLR Jaguar Land Rover, PSA Peugeot Citroen, Renault Group and VW Group. We utilize sources from the Internet and literature and present them with the results of the case study.

This cross-case study intends to explore data that allows us to adopt realistic xKD SCs. Based on the already defined processes and SCP metrics, we derive simulation parameters that time or quantify each process step directly or in combination. Three of these parameters were defined as simulation variables in Section 3.2 and are part of the cross-case study too.

Figure 5 presents the simulation parameters and variables in relation to the corresponding process step.

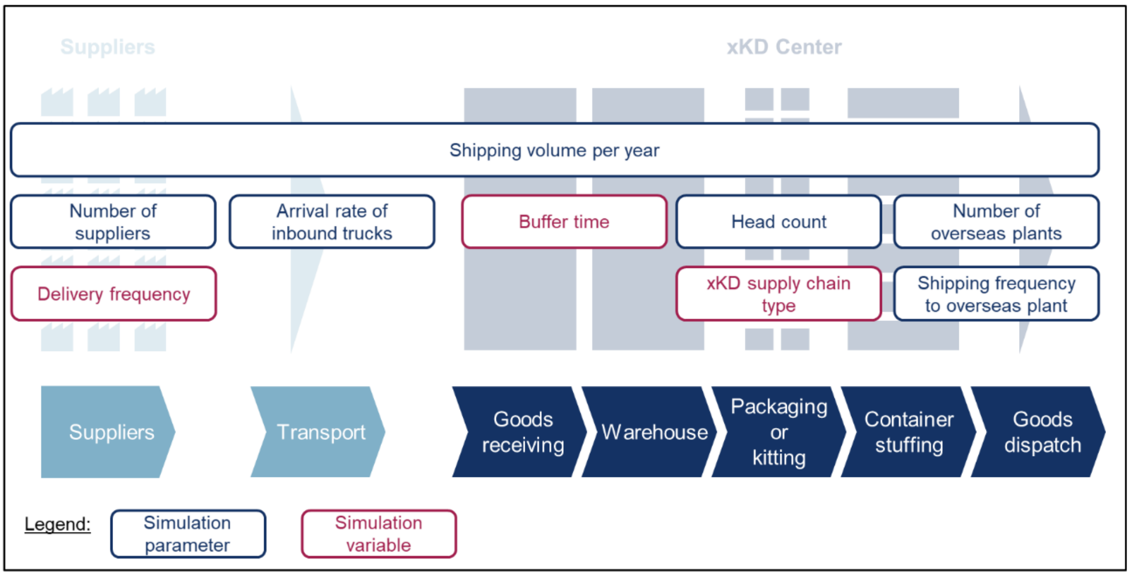

Figure 5: Cross-case study: Simulation parameters and variables

Table VI presents the findings of the cross-case study, which we discussed with experts from OEMs and their logistics providers in order to derive a parameter setup that describes the status quo. The last column of Table VI shows the parameter setup we applied to the simulation model to reproduce current xKD SCs.

From literature on transportation we adopt an exponentially distributed arrival rate of inbound trucks (Erfurth and Bendul, 2017). We assign a normal distribution to the packing times based on an analysis of data from real xKD centers (Figure 6).

Table VI: Cross-case study results

	BMW	Daimler	JLR	PSA	Renault Group	VW	Simulation model
xKD center (exemplary)	• Wackersdorf	• Bremen	• Mienenbüttel	• Le Havre	• Grand Couronne	• Wolfsburg	• Simulation model
Shipping volume per year	• 600,000 m³	• 3,000,000 m³	• 76,000 m³	• 610,000 m³	• 560,000 m³	• 300,000 m³	• 300,000 m³
Number of suppliers	• 1,300	• n.a	• 700	• 800	• 650	• 1,650	• 1,000
Delivery frequency	• Weekly	• Monthly	• Weekly	• Weekly	• Weekly	• Weekly	• Weekly
Arrival rate of inbound trucks	• 120 trucks per day	• n.a	• n.a	• 150 trucks per day	• n.a	• 50 trucks per day	• 50 trucks per day
Buffer time	• Ø 5 days	• Ø 10 days	• n.a	• n.a	• Ø 3 days	• Ø 5 days	• PBP: Ø 5 days Kitting: Ø 10 days
Head count	• 600	• 1,200	• 200	• n.a	• n.a.	• 300	• 300
xKD supply chain type	• Kitting	• Kitting	• Kitting	• PBP	• PBP	• PBP	• PBP or itting
Number of overseas markets	• 11	• 10	• 3	• 6	• 11	• 15	• 15
Shipping frequency to overseas plant	• Weekly	• Weekly	• Weekly	• Weekly	• Weekly	• Weekly	• Weekly
	Hoesamer, 2015; Lorenz, 2015; Quaas, 2015; BMW, 2019 BLG Logistics, 2020.	Struss-V. Poellnitz, 2011; Weyerer, 2012; Granzow, 2013; Mukadam, 2014.	Ludwig, 2013; Palmer and Jones, 2016; Hollmann, 2016; Syncreon, 2016.	Rognon, 2008; Ludwig, 2011; Gefco, 2012; Schultze, 2013; Guerrero, 2014.	Festinger, 2010; Renault, 2013; Guerrero, 2014; CGT Renault, 2016.	Herbermann, 2016; Fehse, 2019; Volkswagen, 2019.	

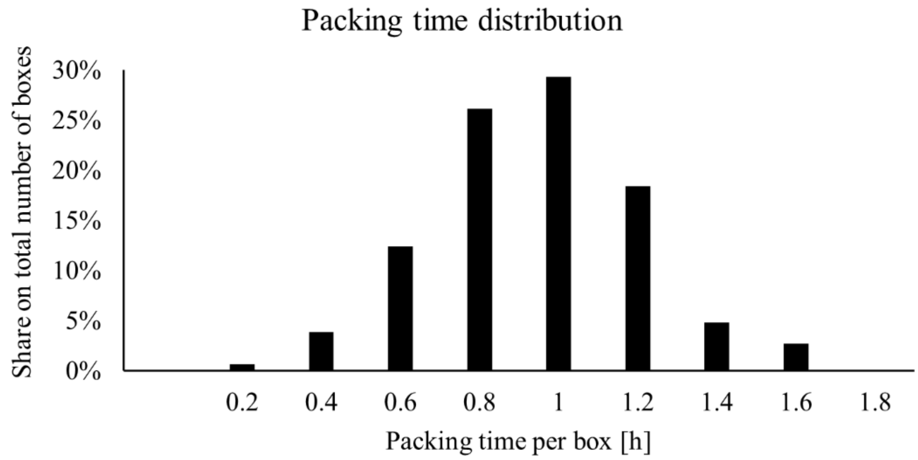

Figure 6: Packing time distribution in an xKD center (anonymized OEM)

We drew on the cross-case study and the interviews to define the simulation parameters and variables of current xKD SCs. The established parameter setup thus represents the status quo of current xKD SCs.

3.5 Simulation Model: Scenario Plan

Based on the simulation variables as well as their aforementioned initial setup and factoring in the hypotheses, we develop a scenario plan to structure our research (Table VII). A scenario can be understood as a simulation run under a specific set of conditions (Robinson, 2004). This set of conditions describe a combination of simulation variables values while the simulation parameters are kept constant (Robinson, 2004).

The cross-case study reveals that the buffer time is five days and the delivery frequency is one delivery per week in the initial scenario for PBP SCs. Since hypotheses H1 is intended to analyze the effect of increased delivery frequency on PBP SCs, we implement scenarios with two, five and ten deliveries per week and supplier. Since hypotheses H2 analyzes decreased buffer time, we define PBP SC scenarios with buffer times of four, three, two, one and zero days. In order to analyze the overall effect on PBP

SCs in course of hypotheses H3, we simulate the combination that arise from the simulation variable values of hypotheses H1 and H2. Hypothesis H4 compares the SCP of PBP and kitting xKD SCs achievable by applying the same improvement levers but employs a buffer time of ten days in the initial scenario.

Table VII: Scenario plan

Hypothesis	Scenarios	XKD supply chain type		Simulation variables Buffer time [days]		Delivery frequency [deliveries / week]
H1	1 to 4	(PBP)	x	(5)	x	(1, 2, 5, 10)
H2	5 to 9	(PBP)	x	(5, 4, 3, 2, 1, 0)	x	(1)
H3	10 to 24	(PBP)	x	(5, 4, 3, 2, 1, 0)	x	(1, 2, 5, 10)
H4	… 45 to 88	(Kitting)	x	(10, 9 ,8, 7, 6, 5, 4, 3, 2, 1, 0)	x	(1, 2, 5, 10)

We conduct 50 simulation runs for each scenario, each run simulating one full year with 365 days plus an additional warmup period. The warmup period ensures that the results are not biased by an inappropriate starting phase (Robinson, 2004). In our simulation model a warm-up period of 30 days provide an initial, stable system load. Research on simulation studies recommends the application of a run-length that is at least ten times warm up period (Banks *et al.*, 2001; Robinson, 2004). We adopt a run-length of one year to comply with this recommendation and to generate results that can be matched with business reports that are usually released on a yearly basis, too. In order to ascertain the number of replications we considered the confidence interval method by Law (2007) and specified the precision of output variable lead time and stock with five percent, given the initial scenario. We added additional number of replications to ensure stable results throughout all scenarios and hence, employed 50 simulation runs.

3.6 Simulation Model: Validation

A simulation model can be understood as a close approximation to an actual system, that is used as a surrogate for experimentation with the actual system (Law, 2001). In order to ensure that the results can be used to draw conclusion the simulation model is validated. Law (2008) defines validation as the process of determining whether a simulation model is an sufficiently accurate representation of the system for the particular objective of the study. The three main components to ascertain validation are data validity, model validity and experimentation validity (Robinson, 2004; Law, 2008). With respect to data validity we derived the data via a cross-case study of six OEMs to ensure a general and realistic parameter setup. At this stage we furthermore involved experts and addressed model validity too (Table VIII). We discussed the initial parameterization as well as the developed simulation model and results of the initial scenario that represents the assumed status-quo. We therefore utilized the immanent opportunity of a discrete-event simulations to go through the simulation model event by event to analyze the system behavior and implemented assumptions. In particular the possibility to observe the discrete-event simulation visually increased the understanding of the experts. The results were presented with the chosen SCP metrics and scales. The experts confirmed a sufficient accuracy and conformity of the simulation model to the real world and the research objective. In order to determine experimentation validity, we discussed the simulation results of the four hypotheses in an additional second stage with the experts later in time. The effects of the improvement levers on the operational and economic SCP were comprehensible. The experts underlined the benefit of the additionally provided formulas and assumptions of the economic SCP (Table V) as this helped them to adopt and compare the results to their company-specific settings. Overall, the experts rendered the simulation model to be comprehensible and sufficiently accurate to support the decision making process and support the validity of the simulation model.

Table VIII: Interviews with experts

Company	Position	Name
Volkswagen	xKD Logistics Planner	anonymous
Volkswagen	xKD Operations Manager	anonymous
Volkswagen	xKD Expatriate	anonymous
Audi	xKD Logistics Planner	anonymous
Audi	xKD Logistics Analyst	anonymous
Skoda	xKD Logistics Planner	anonymous
Skoda	xKD Operations Manager	anonymous
Daimler	Controlling	anonymous
Daimler	Logistics Planner	anonymous
Schnellecke	xKD Logistics Planner	anonymous
Schnellecke	xKD Logistics Planner	anonymous
Schnellecke	xKD Operations Manager	anonymous
BLG	xKD Logistics Planner	anonymous
BLG	xKD Operations Manager	anonymous
Syncreon	xKD Operations Manager	anonymous

In a nutshell, we ensured data validation by deriving a realistic parameter setup from the cross-case study of multiple OEMs and an assessment of the experts, we validated the simulation model by comparing it to process descriptions and an in-depth investigation together with the experts and conducted an experimentation validation by a discussion of the simulation study results with experts (Robinson, 2004). The integration of the experts additionally strengthens the credibility of the discrete-event simulation and thus, this research. Generally a simulation model and the corresponding results are credible if the decision makers and experts accept them as correct (Law, 2008).

4. Results

4.1 Hypothesis H1: Delivery Frequency Increase in PBP SCs

Hypothesis H1 is intended to explore the effect of increased supplier delivery frequency to the xKD centers on the SCP of PBP SCs. In keeping with the scenario plan, we vary only the variable of delivery frequency and keep all other variables consistent with the initial scenario. Figures 7 and 8 present the results of the simulation study.

An increase in delivery frequency lowers the average lead time and inventory level slightly. The standard deviation of lead time drops substantially, indicating improved delivery reliability. The standard deviation of the inventory level decreases too, albeit far less. The second delivery reliability measure tardiness is not affected.

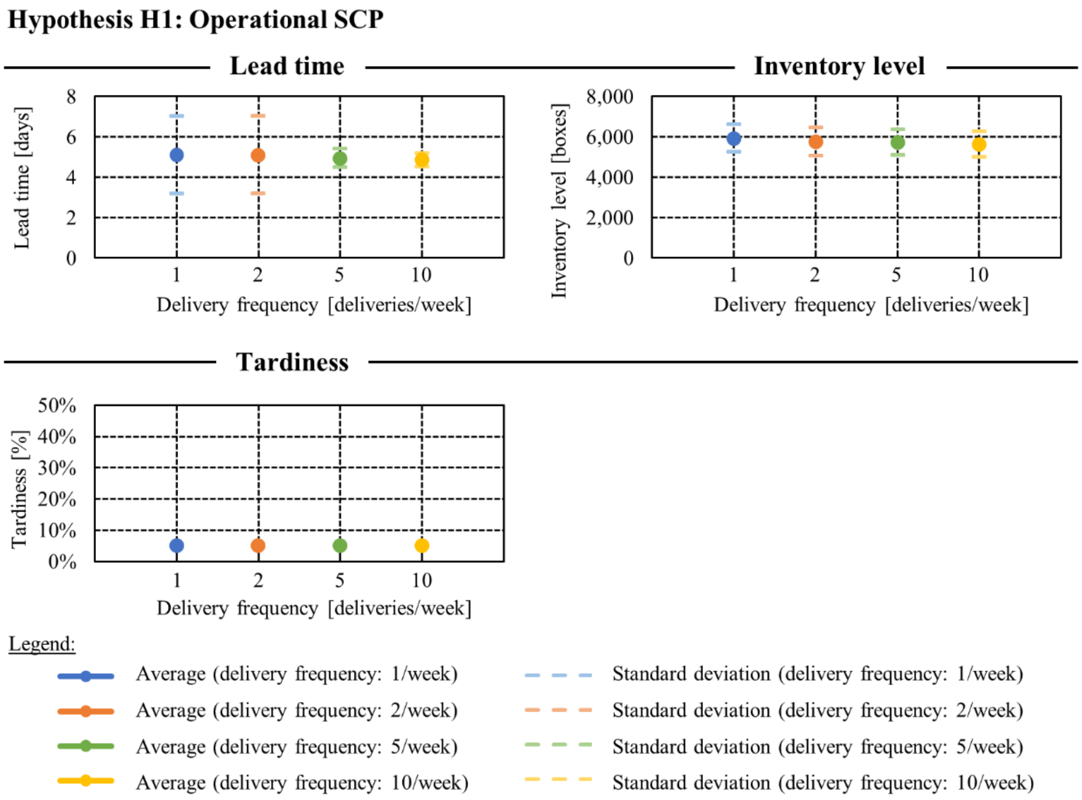

Figure 7: Hypothesis H1 – Operational SCP

Figure 7 shows that increasing delivery frequency has the greatest effect on inbound costs in the economic SCP. Inbound costs rise in a decreasing manner when delivery frequency is increased. On the other hand, capital lock-up and the associated costs as well as the overhead costs decrease marginally. The inbound cost incline, however, exceeds these effects and total costs grow.

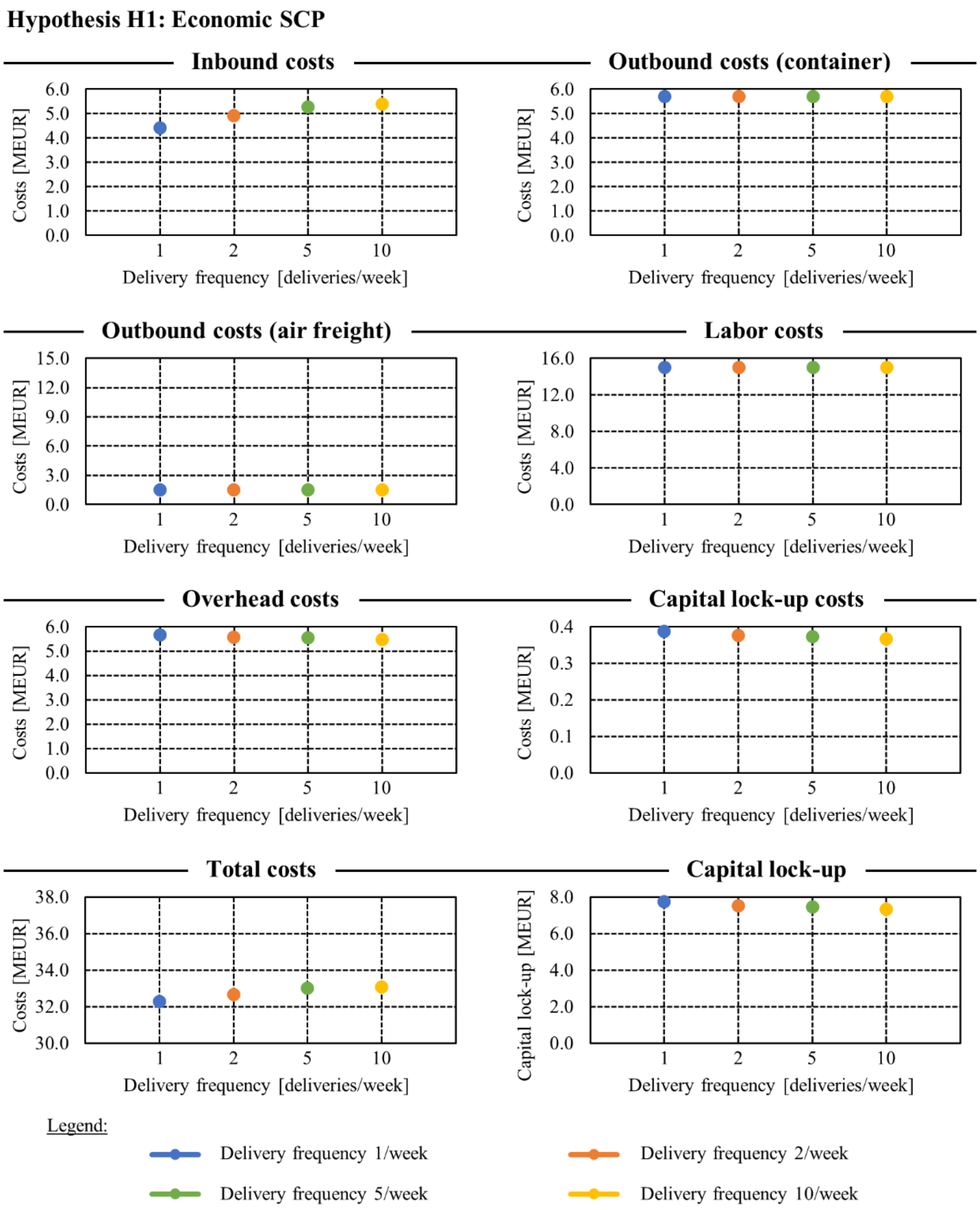

Figure 8: Hypothesis H1 – Economic SCP

The results of the simulation study show an ambiguous effect regarding hypothesis H1. Whereas the standard deviation of lead time is reduced and the lead time and inventory level are lowered slightly, total costs grow. Increasing delivery frequency does not therefore generally improve SCP and hypothesis H1 thus cannot be supported fully.

4.2 Hypothesis H2: Buffer Time Reduction in PBP SCs

Hypothesis H2 states reducing buffer time at the xKD center will increase the SCP of PBP SCs. As with hypothesis H1 and in keeping with the scenario plan, we alter only the variable of buffer time. The results are presented in Figures 9 and 10.

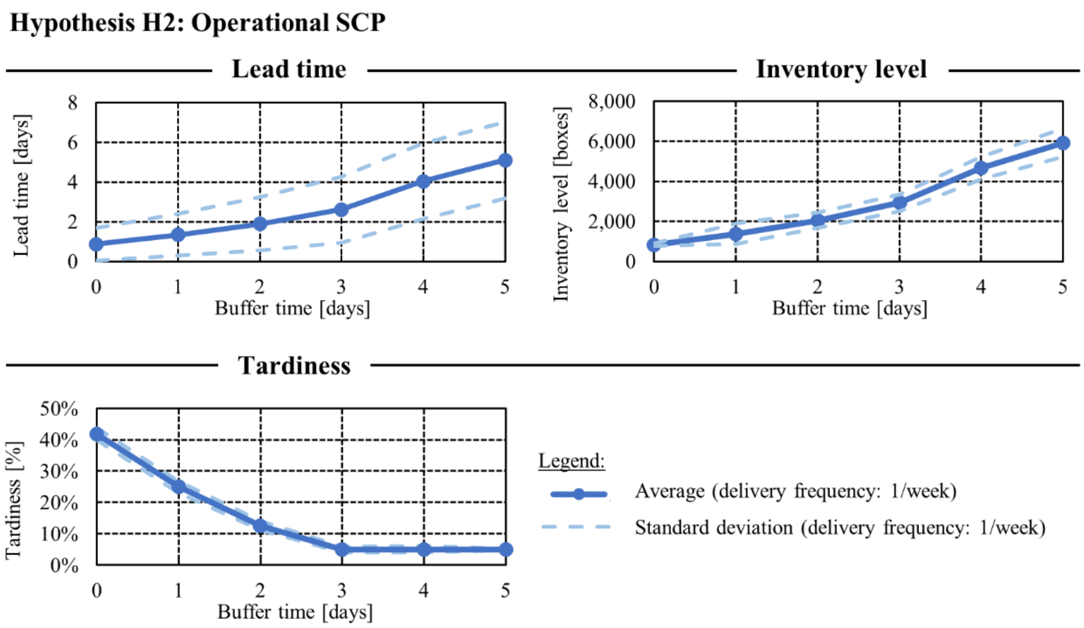

Figure 9: Hypothesis H2 – Operational SCP

The average lead time and inventory level decrease when the buffer time is reduced. While the effect is almost linear at the beginning, it weakens for buffer times of less than three days. The standard deviation of lead time and the inventory level also decreases. Tardiness remains unaffected by a buffer time reduction from five to three days but rises sharply when it falls below this threshold and hits forty percent when the buffer time is zero days.

The outbound air freight costs display a similar curve and rise ten million euros when the buffer time is reduced from three to zero days. The related costs for outbound container shipping, on the other hand, decrease just three million euros. Although the capital lock-up and the corresponding costs diminish, they are, however, the lowest of the cost elements. A buffer time reduction from five to zero also halves the overhead costs.

Inbound and labor costs remain unaffected by this measure. The total costs graph shows that a buffer time reduction from five to three days results in a ten percent decrease, whereas a further reduction increases total costs and peaks at a twenty percent increase.

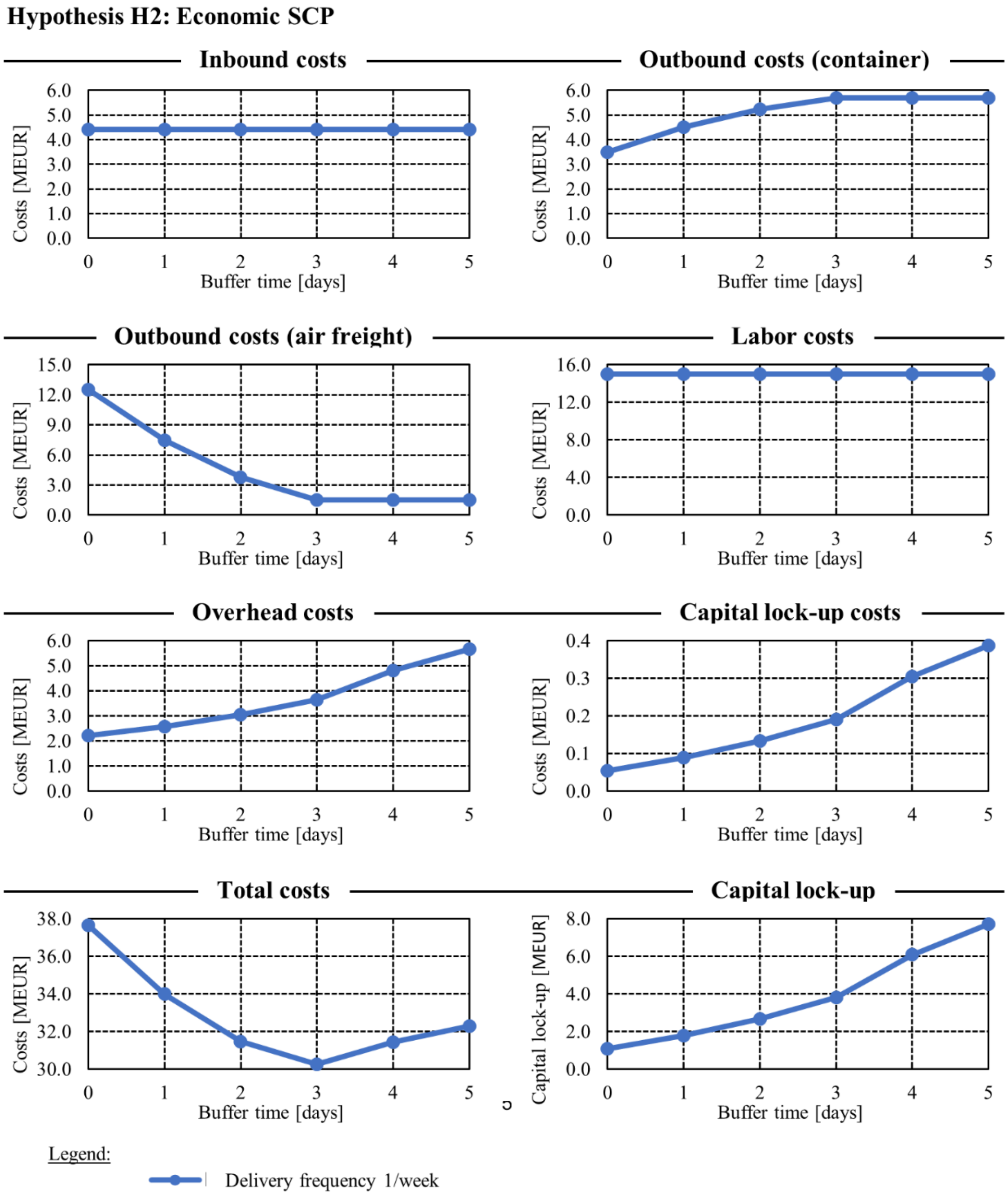

Figure 10: Hypothesis H2 – Economic SCP

As regards hypothesis H2, a buffer time reduction reduces the average and standard deviation of lead time, the inventory level and the total costs. All SCP metrics are improved and hypothesis H2 is confirmed. In the event that the buffer time drops below the threshold, however, tardiness and the air freight costs soar.

4.3 Hypothesis H3: Combined Delivery Frequency Increase and Buffer Time Reduction in PBP SCs

The third hypothesis H3 addresses combined application of the improvement levers, delivery frequency increase and buffer time reduction. Figures 11 and 12 present the results of the simulation study.

A buffer time reduction causes a steady decline in the average lead time, which is almost linear for delivery frequencies of five deliveries per week and higher. The standard deviation of lead time can be reduced substantially too. This effect is primarily attributable to the delivery frequency increase, though. The inventory level drops steadily when the buffer time is reduced and for delivery frequencies of two deliveries per week and higher almost converge toward zero. The graphs of tardiness reveal the major difference between applying improvement measures singly or in combination. All graphs for buffer times of five to three days coincide with each other. The turning point that induces a surge in tardiness, however, moves from a three day buffer time when deliveries are weekly to a one-day buffer time when deliveries are daily. Even higher delivery frequencies have no additional impact, though.

These effects can be transferred to the economic SCP. The turning point that causes the sharp rise of outbound air freight costs moves from a three day to a one-day buffer time when the delivery frequency is increased from one to five deliveries per week. The opposing container outbound costs start falling accordingly. Inbound costs rise as

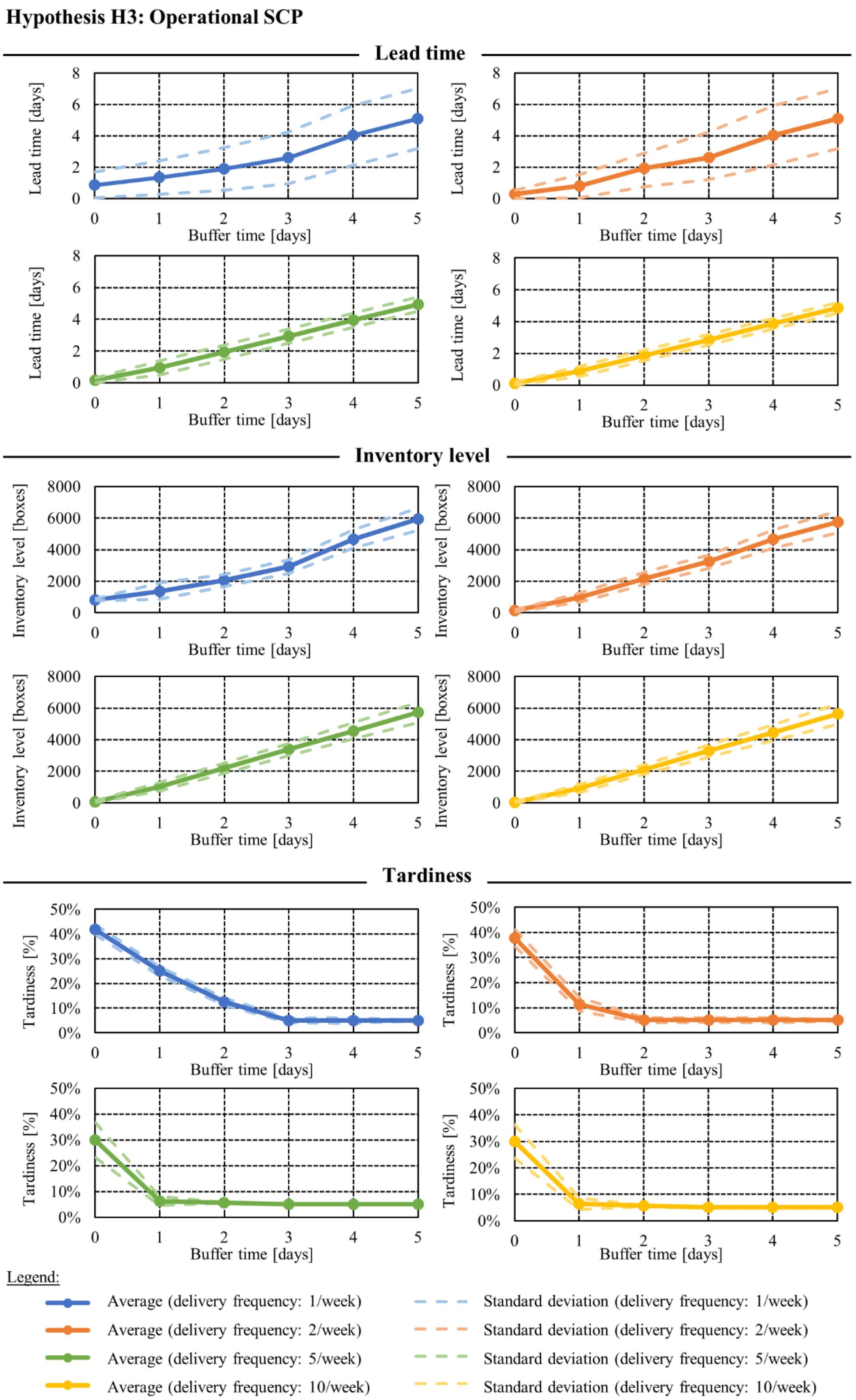

Figure 11: Hypothesis H3 – Operational SCP

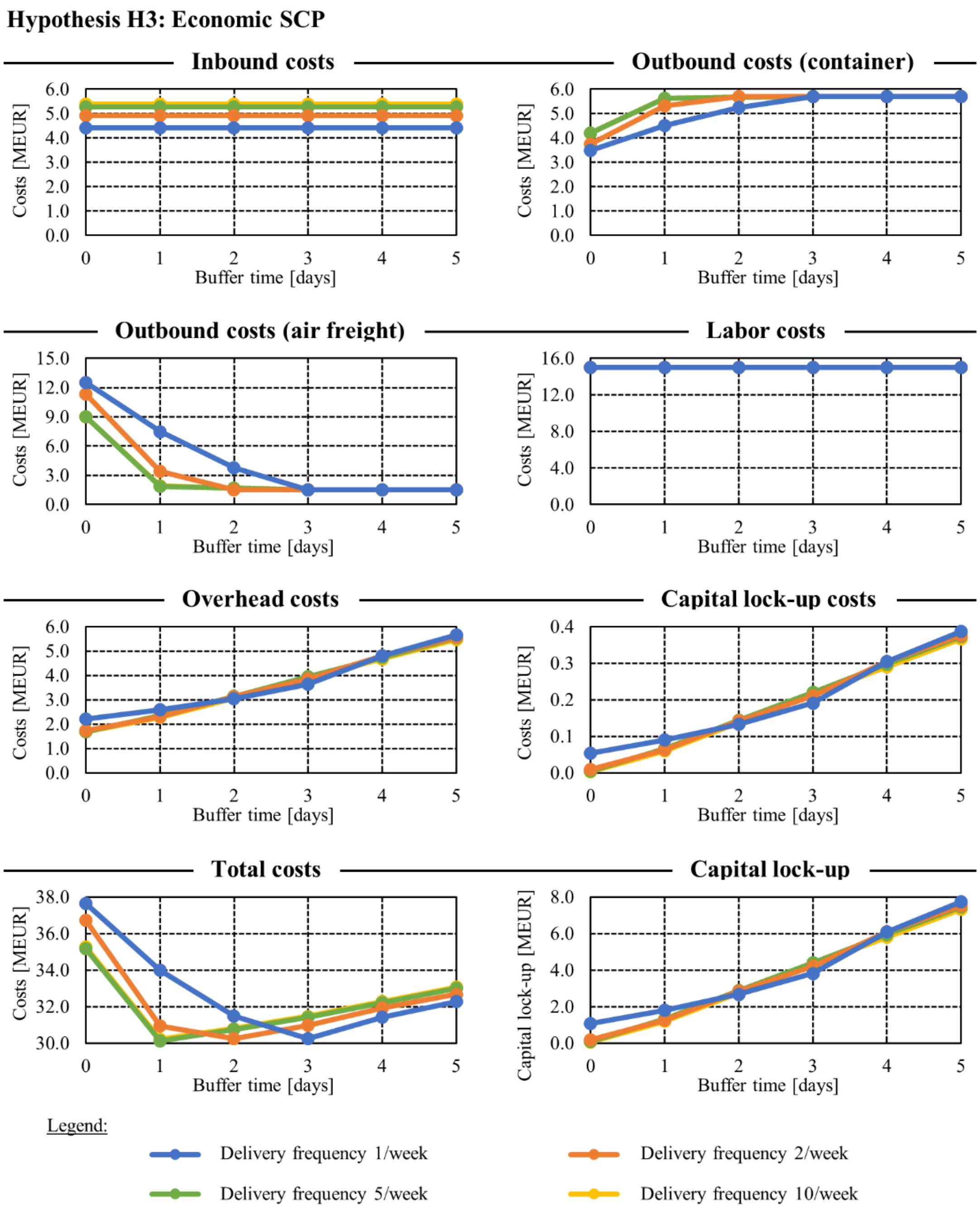

Figure 12: Hypothesis H3 – Economic SCP

delivery frequency increases. The graphs of overhead and capital lock-up costs barely vary for different delivery frequencies. Three dips become apparent when the total costs are examined. The setting with the lowest total costs in all of the experiments features a combination of five deliveries per week and a one-day buffer time. The minimum buffer time moves from three days to one day when the delivery frequency is increased to five deliveries per week.

The analysis consequently confirms hypothesis H3. Combined application of the improvement measures improves all SCP metrics. A delivery frequency of five deliveries per week and a one-day buffer time specifically yields the highest overall SCP. The lead time and the inventory level are reduced by eighty percent. As regards delivery reliability, tardiness remains at the same low level, whereas the standard deviation of lead time drops considerably. Total costs are also lowest for this combination, which cuts costs ten percent and reduces capital lock-up eighty percent.

4.4 Hypothesis H4: Combined Delivery Frequency Increase and Buffer Time Reduction in Kitting XKD SCs

Hypothesis H4 compares the SCP of PBP and kitting xKD SCs achievable by applying the improvement levers in combination. We have already presented the results for PBP SC in Section 4.3 and present the results for kitting xKD SCs in Figures 13 and 14.

A buffer time reduction from ten to six days steadily reduces the average lead time until it stagnates at around five days for further buffer time reductions, regardless of the delivery frequencies. A delivery frequency increase substantially reduces the standard deviation of lead time for buffer times of more than six days. When buffer times are lower, the standard deviation of lead time returns to the level of weekly deliveries. The inventory level similarly decreases when then buffer time is reduced from ten to six days and then stagnates. Tardiness, however, rises sharply when the buffer time falls below six days and peaks at 100 percent when the buffer time is zero days. Since the colored graphs coincide, a delivery frequency increase has no effect.

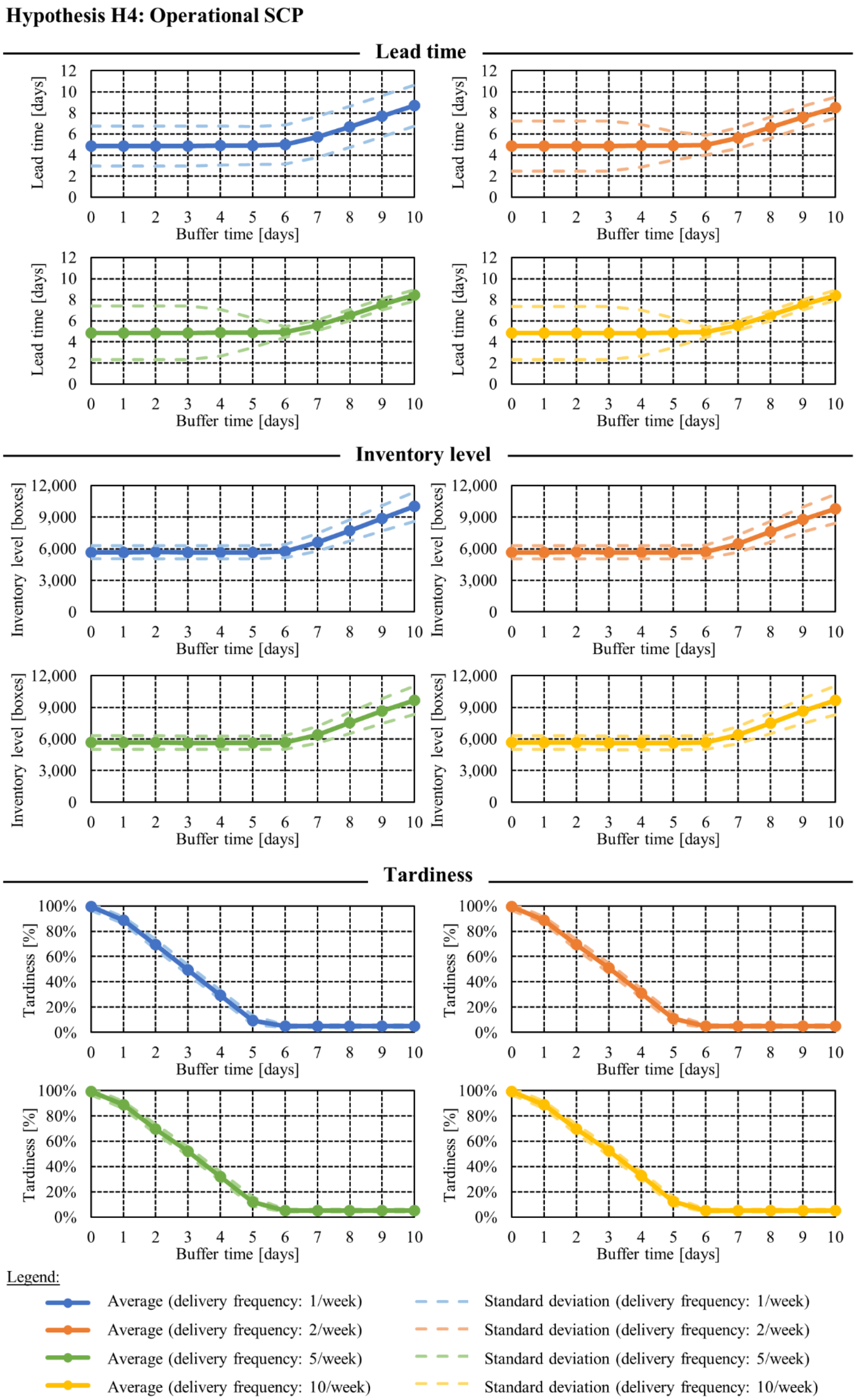

Figure 13: Hypothesis H4 – Operational SCP

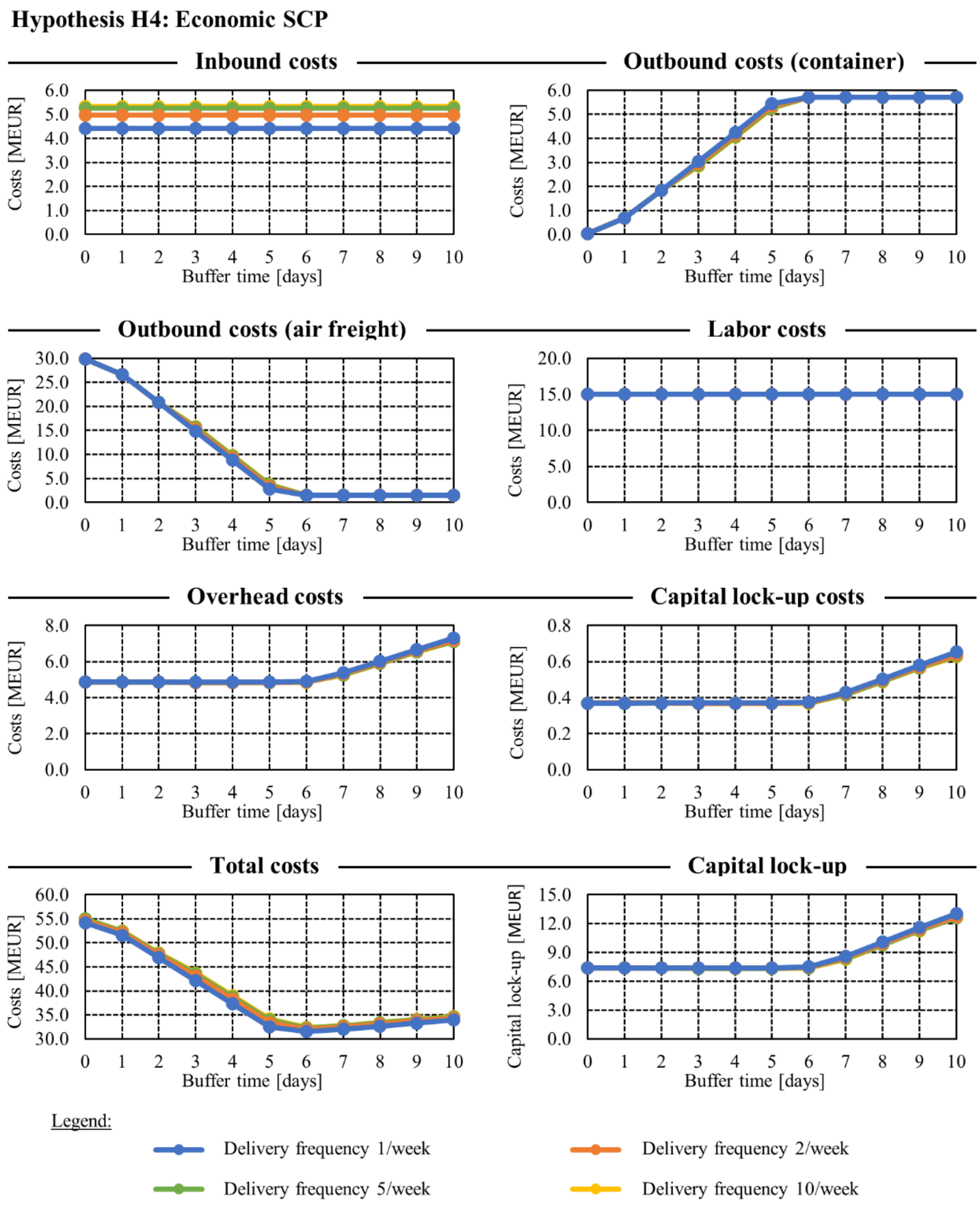

Figure 14: Hypothesis H4 – Economic SCP

A delivery frequency increase, indicated by the colored graphs, chiefly affects inbound costs. Inbound costs rise decressively when the delivery frequency is increased from one to ten deliveries per week. The graphs of all other cost elements virtually coincide and hardly vary. A weekly delivery frequency therefore yields the lowest total costs of the sample. The second improvement lever of buffer time reduction has a twofold effect. Reducing the buffer time from ten to six days lowers overhead costs and capital lockup but has no impact on any other cost elements. Consequently, total costs decline, saving two million euros. A further reduction of the buffer time to less than six days causes soaring outbound air freight costs, exceeding the falling outbound containerized shipping costs for, and total costs to rise sharply.

In comparison to PBP SCs, the SCP of kitting xKD SCs can be improved too, but not as much. Kitting xKD SCP is highest when only the buffer time is reduced to six days and a weekly delivery frequency is retained. A combination of a one-day buffer time and daily deliveries delivered the highest SCP of PBP SCs. Of these two configurations, PBP SCs have significantly lower lead times, inventory levels, standard deviations of lead time and total costs . The simulation results consequently confirm hypothesis H4.

5. Discussion

5.1 SCP of xKD SCs and Global Manufacturing Networks

Global manufacturing networks have evolved over the past decades, changing the pertinent requirements for the underlying xKD SCs. Whereas PBP SCs supply fully equipped plants while aiming for efficiency, kitting xKD SCs enable developing plants to handle complexity by simplifying. Unsurprisingly, the case study revealed that the PBP SCs have higher SCP than kitting xKD SCs (Erfurth and Bendul, 2018). It exposed lots of potential for improvement too, though.

The simulation study of PBP SCs revealed that the lead time and inventory level at the xKD center can be decreased by eighty percent. It also demonstrated that the delivery reliability can be improved substantially in terms of the standard deviation of lead time, something that enhances prediction accuracy. Total costs can be decreased by ten percent and the capital lockup by an impressive eighty percent. The simulation study therefore demonstrated that the SCP of PBP SCs can be improved significantly. The potential lead time and inventory level at the xKD center is comparable to cross-docks familiar in continental shipping. The improvement levers analyzed thus help PBP SCs meet the high SCP requirements of fully equipped overseas plants. The simulation study corroborates Song's (2009) and Erfurth and Bendul's (2018) conclusion that SCP of PBP SCs can be improved and reveals the full SCP improvement potential.

Although the simulation study was based on European OEMs, it reveals potential for improvement in Japanese OEMs too. Japanese OEMs have contrarily implemented an additional process step to ensure high delivery frequencies and low inventory levels at their xKD centers by storing all parts in warehouses prior to their delivery to the xKD center (Itoh and Guerrero, 2020). The total lead time at this warehouse and the subsequent xKD center is equivalent to the lead time of the xKD center in our simulation study and clearly exceeds one day (Itoh and Guerrero, 2020). The simulation study revealed that a one-day buffer time or lead time can be achieved without this additional warehousing and transport step. This enables both European and Japanese OEMs to improve their PBP SCs. It is particularly surprising that even Japanese OEMs, known for their high level of lean management integration, can improve their SCP.

Despite the fact that kitting xKD SCs aim for simplification rather than efficiency, the simulation results show that they can be improved too, albeit within certain limits. The kitting process substantially increases the complexity since every part is assigned a dedicated spot in the kit. This produces additional requirements to streamline the kitting process and to avoid repacking and searching. OEMs therefore only start packing kits when all required parts are at the xKD center to ensure processes are reliable. The simulation indicates that a minimum inventory level of 5,000 boxes is required. Given that a car consists of 4,000 to 6,000 individual parts and usually one xKD center packs kits for multiple car models, the minimum inventory level appears plausible (Fehse, 2016). A further reduction of the lead time and inventory level results in severe complications.

5.2 Lean Management in xKD SCs

Lean management in global SCs proposes four improvement levers. Two of them have already been integrated in xKD SCs. The remaining two are increased supplier delivery frequency and reduced buffer time at the xKD center.

Reducing buffer time for the better influences directly the SCP of PBP SCs directly. It reaches its limits, however, when the buffer time drops below a threshold that ensures a reliable supply. This is where increased delivery frequency comes in. Increased delivery frequency allows suppliers to deliver parts more accurately in terms of quantity and time, thus enabling the xKD center to reduce its inventory level and lead time even more. The simulation study reveals the highest SCP when delivery frequency is increased to daily and buffer time is reduced to one day. This can also be understood as JIT delivery (Shah and Ward, 2007). This study demonstrated that applying the four improvement levers in combination yields the highest SCP and that implementing just one improvement measure does not necessarily lead to success (Krueger, 2004; Cheng, 2011).

We have outlined the potential SCP improvements above. They also generate some benefits in addition to the obvious effects. A buffer time reduction to one day renders traditional warehousing in xKD centers obsolete. Parts can be buffered next to the packaging area, thus eliminating warehouse storage and release operations. Investments in racks and labor costs, e.g. forklift drivers, can be forgone. In keeping with the general philosophy of lean management, we assume further opportunities for improvement present themselves once the inventory level drops (Ohno, 1988; Womack *et al.*, 1990). A reduced lead time and postponed delivery date at the xKD center enable an OEM to react to production scheduling changes at shorter notice and to avoid air freight shipments. All these secondary effects have not been considered in the simulation results and amplify them.

The simulation study ultimately demonstrated that lean management enhances SCP in global SCs and diminishes the negative effects of global shipping (Fawcett and Birou, 1992; Cheng, 2011; Golini *et al.*, 2016; Lorentz *et al.*, 2018).

5.3 Cost Interdependency Effects

The simulation study identifies major causal relationships related to costs. The first insight is the buffer time threshold that ensures a stable supply for a given supplier's delivery frequency. In the event the buffer time drops below the threshold, diminishing tardiness and soaring air freight costs are inevitable. The effect size, however, was surprisingly large since neither research on xKD SCs nor on lean management in global SCs address it (Krueger, 2004; Trippner, 2006; Song, 2009; Cheng, 2011; Erfurth and Bendul, 2018).

The second insight also involves buffer time reduction. Shortening the buffer time solely within the limits of the aforementioned threshold only results in cost improvements and has no negative effect on any other cost element. OEMs can thus implement this measure without reservation. We recommend a stepwise reduction of the buffer time to approach the threshold and keep from falling below it.

The third insight relates to the interplay of the two lean management measures in global SCs discussed. Delivery frequency dictates the buffer time threshold. A delivery frequency increase lowers the threshold and enables the OEM to operate reliably with an even lower buffer time. This results in a tradeoff between inbound costs, on the one hand, and overhead costs and capital lockup, on the other hand. Both the reduction of the buffer time and the increase of the supplier's delivery frequency to one day in our simulation study proved most beneficial for PBP SCs. Having conducted a literature review and case study to identify the underlying cost functions and parameters, we assume the general impact direction to be correct. The intensity of the effect depends on conditions specific to the company, such as supplier distribution and shipping tariffs (Song, 2009). OEMs should therefore analyze the cost elements prior to implementation.

6. Implications and Conclusions

This research employed a threefold research approach to investigate the implementation of lean management practices to knocked-down supply chains. In order to ensure that the simulation results are realistic, we conducted a cross-case study of European OEMs and involved experts from them and their service providers. The comparison of the simulation results with the findings from the cross-case study shows that the same parameter setup yields in similar results with regard to lead time and inventory level, which are two key SCP indicators. We discussed the simulation model and the results with experts from different OEMs as well as their service providers. The results and behavior of the simulation model as well as the chose simulation parameters were supported. It was emphasized that the results, in particular with regard to the economic SCP, dependent on the individual OEM. However, the provided formulas and transparent parameter setup, which was gained by a literature research, serve as a well-founded basis and enable researchers and practioners to derive the implications of different cost parameters. This research design adds to the validity and credibility of the simulation study (Law 2001). Another advantage of the underlying cross-case study is that the problem formulation and the parameter setup of the simulation study is based on major European OEMs and their brands. This is further supported by the recent research work of Itoh and Guerrero (2020), who analyzed Japanese OEMs. Their process description revealed that Japanese OEMs can be improved by the findings of this simulation study and thus the implementation of lean management practices in global supply chains too. As a consequence the proposed measures apply to major OEMs of the automotive industry and we can assume that the results can be generalized.

The simulation study demonstrated that the SCP of xKD SCs can be improved significantly. This is particularly relevant to OEMs that operate PBP SCs since their global manufacturing networks demand high SCP. Daily delivery frequency combined with a one-day buffer time yielded the highest PBP SCP. Based on an xKD center that handles an annual shipping volume of 300,000 m^3, we identified potential annual cost savings of two million euros and a five million euro reduction of capital lockup. OEMs, however, operate multiple xKD centers and ship up to 3,000,000 m^3 (Erfurth and Bendul, 2018). We therefore assume that OEMs can save around twenty million euros a year and reduce their capital lock-up by fifty million euros, without even considering positive secondary effects, such as dispensing with warehousing and reducing labor costs. While cost savings are intuitively beneficial, the additionally available capital is highly useful too. Acquisitions of startups and investments in electric vehicles and digitalization constitute huge challenges for OEMs, which require every available asset (Szalavetz, 2019).

The potential gains in lead time, inventory level and delivery reliability are also extremely valuable to OEMs. The advantages of these improvements have become all the more apparent in 2020 as the world suffers through the COVID-19 pandemic. A lead time reduction of four days, for instance, would have enabled OEMs to halt their supply of closed markets at shorter notice. While this effect has cumulated during the Corona crisis, adapting shipments, e.g. when the production plan is adjusted due to market changes is routine business. A lower inventory level and lead time and improved delivery reliability enable OEMs to manage their xKD SCs more efficiently.

This research revealed that the improvement levers studied can substantially help OEMs meet their operational and financial targets. It also makes a significant contribution to the streams of research on xKD SCs and lean management in global SCs.

We analyzed improvement levers that improve xKD SCP. We targeted two major research gaps by applying a complementary research approach. On the one hand, there was no quantitative investigation on the potential SCP of xKD SCs (Song, 2009; Erfurth and Bendul, 2018). On the other hand, research lacked knowledge on currently operated xKD SCs (Talavera, 2015). We distinguished between PBP and kitting xKD SCs in our research since the requirements on the performance of PBP SCs are substantially higher. The simulation study revealed that solely applying the first improvement lever of increasing supplier delivery frequency does not automatically improve the SCP of PBP SCs. This research demonstrated that the second improvement lever of buffer time reduction has a positive effect on the SCP of PBP SCs in every respect. We uncovered the existence of a buffer time threshold that significantly governs delivery reliability and air freight costs. We determined that applying the improvement levers in combination yields the highest SCP of PBP SCs, cutting lead time and inventory level by eighty percent and total costs by ten percent. Such substantially improved SCP enables PBP SCs to meet the requirements of the global manufacturing network supplied (Erfurth and Bendul, 2018). While we showed that the SCP of kitting xKD SCs can be improved as well within certain limits, reducing complexity remains the priority.

We also made significant contributions to the research field of lean management in global SCs. We compiled the lean management measures in global SCs already developed and analyzed their effect on SCP (Lorentz *et al.*, 2018). Whereas earlier research studies mainly furnished qualitative findings and called for quantitative studies, we quantified the effect of the improvement measures as exemplified by xKD SCs

(Cheng, 2011; Cherrafi *et al.*, 2016; Stanczyk *et al.*, 2016). The simulation results confirmed that the combined application of improvement measures improves the performance of global SCs and lean management in global SCs thus diminishes the adverse effects of global shipping (Cheng, 2011; Golini *et al.*, 2016). We thus provide new impetus to the ongoing debate and corroborate the applicability of lean management in global SCs (Lorentz *et al.*, 2018).

This study has some limitations and makes suggestions for future research. We implemented assumptions and simplifications in our simulation model to analyze SCP of xKD SCs. We aggregated CKD, MKD and SKD SCs in kitting xKD SCs and disregarded the differences between them. Future research could investigate the differences between them. We conducted a cross-case study and generalized the simulation model parameter setup based on it. The conditions impinging upon xKD SCs are company-specific, however. Future research could investigate the effects of different parameter setups. In our research, we focused on the section of the xKD SC covering the suppliers to container dispatch at the xKD center. Researchers could investigate other sections of xKD SCs in the future. Since we studied the application of lean management in global SCs in the automotive industry, other researchers could focus on other industries in the future.

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5 Discussion and Conclusion

This Thesis intends to investigate how xKD supply chains and GMNs can be integrated, how individual transport legs affect the overall transportation time and transport time reliability of intermodal transport chains and how the SCP of xKD supply chains can be improved by applying measures from lean management in global supply chains. The results of the three research questions are addressed in detail.

5.1 Theoretical Contribution

This section presents and discusses the theoretical contributions of this research work to the three research objectives as well as to the individual research streams.

1. Integrate xKD supply chains and the GMN and analyze the fit of currently operated xKD supply chains and the respective GMNs.

In Chapter 2, we explore the integration of xKD supply chains and GMNs. Based on the understanding that xKD supply chains hold the coordination role for GMNs and the fact that GMN phenotypes have developed over time and thus require different supply chain services, we strive for a medium for connecting xKD supply chains and GMNs (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Meyer and Jacob 2008). Among the existing frameworks in the research on GMNs, Meyer and Jacob´s (2008) is the only one that addresses the coordination requirements of supply chains. However, there has not been an approach that links different supply chain types to GMN phenotypes. We build on the framework from Meyer and Jacob (2008) and transfer the concept of xKD supply chains in order to develop an integrated framework. This framework fills an important void in research for two main reasons. On the one hand, it enables the identification of the most suitable xKD supply chain type depending on the prevailing GMN phenotype and, on the other hand, it enables the derivation of the corresponding coordination requirements (Pontrandolfo and Okogbaa 1999; Stremme 2000). As a consequence, the integrated framework enables researchers and practitioners to evaluate the fit of xKD supply chains whereas former xKD supply chain evaluations did not consider the requirements of the overarching GMN even though it represented the basis (Trippner 2006; Song 2009).

The TCE plays a key role in this research. Based on a review of theories that potentially assign supply chain structures to GMNs, the TCE is the only theory taking the process perspective which offers two main advantages. Firstly, the TCE can express both – the coordination requirements of GMNs and the performance of xKD supply chains – in terms of transaction costs and hence establishes a common basis (Williamson 1975). This enables us to integrate GMNs and xKD supply chains into one and the same framework. Secondly, the incorporated transactional dimensions of the TCE provide the opportunity to analyze the actual transaction costs of xKD supply chains and thus to pinpoint potential improvement levers that adjust the transaction costs depending on the requirements of the GMN (Williamson 1975; Mohammady 2012). We discover that the transactional dimensions are positively affected if the xKD supply chain´s SCP is increased with respect to costs, inventory level, lead time and lead time reliability. In case a GMN phenotype encompasses coordination requirements that ask for lower transaction costs, the performance of the xKD supply chains needs to be improved. As a result, the TCE not only makes it possible to align xKD supply chains with the GMN, but also to improve transaction costs and the SCP if necessary. In turn, this research makes some contributions to the TCE, too. We show that the TCE can be applied to the GMN und xKD supply chains and thus can be used as a medium in order to integrate them. This research operationalizes the transactional dimensions and hence defines the determinants that significantly affect the transactional dimensions. We even analyze the determinants by conducting a cross-case study and compare the transaction costs of the individual cases relatively. To the best of our knowledge, this research has been the first that operationalizes the transactional dimensions and further accordingly applies the determinants (Grover and Malhotra 2003; Mohammady 2012).

Based on the integrated framework of GMN and xKD supply chains that has been developed, we conduct a cross-case study of six globally-producing OEMs in order to analyze currently operated GMNs and xKD supply chains. We discover that all OEMs of our sample operate the most suitable xKD supply chain type for their GMN phenotype. As the link between xKD supply chains and the GMN has not existed before, this finding is surprising, but also confirms the integrated framework that has been developed. We further explore the fact that GMNs and xKD supply chains follow a mutual developmental path over time. This enables OEMs to plan their next developmental step with regard to both GMN and xKD supply chains. These findings significantly contribute to both research streams and imply that xKD supply chains evolve alongside GMNs and draw the conclusion that their development is closely-related (Shi and Gregory 1998; Pontrandolfo and Okogbaa 1999; Meyer and Jacob 2008). The integrated framework further reveals that the SCP requirements of web structure GMNs exceed the SCP requirements of the other GMN phenotypes substantially. The cross-case study, however, shows that the SCP of the corresponding PBP supply chains is just marginally higher than the SCP of the other xKD supply chain types. The PBP supply chains of the OEMs investigated in this cross-case study incorporate insufficiently-high transaction costs and do not meet the SCP requirements of web structure GMNs. Whereas existing research works assume that there is a need to improve the SCP of generally all xKD supply chain types, we reach the conclusion that there is a need for PBP supply chains only (Trippner 2006; Song 2009). SKD, MKD and CKD supply chains are designed to simplify processes and to ensure a stable supply in order to facilitate car production in countries with developing overseas plants (Schulze and Hesse 2009; Klug 2010). PBP supply chains, though, manage the material flow of well-developed plants that aim for efficiency and high SCP in order to increase their competiveness. As a consequence, this research significantly contributes to xKD supply chain research since it assigns the SCP requirements to xKD supply chains depending on the prevailing GMN phenotype and hence narrows down the need for high SCP requirements to PBP supply chains that serve web structure GMNs. In contrast to previous research works that assume an insufficient SCP for generally all xKD supply chains, we show that the SCP of PBP supply chains needs to be improved explicitly and hence narrow down the research scope (Trippner 2006; Song 2009).

With respect to the research objective, we have developed an integrated framework that aligns xKD supply chains with GMNs and investigate the match of currently operated xKD supply chains and GMNs. We identify the need to improve the SCP of PBP supply chains.

2. Analyze how transport legs of an intermodal transport chain affect the transportation time and transport time reliability of the entire intermodal transport chain.

From a transportation perspective, xKD supply chains can be considered intermodal transport chains on a global scale. Intermodal transportation is a comprehensive field of research compared to the research field of xKD supply chains. Thus, we build on that knowledge in the course of Chapter 3.

We establish an understanding of the working principle of intermodal transportation and compile research works that evaluate different settings of intermodal transport chains. We discover that existing research works consider costs only as a decision-making variable and neglect other SCP indicators – first and foremost, transportation time and transport time reliability (Janic 2007; Hanssen, Mathisen and Jorgensen 2012). We thus develop an analytical model which expresses the transportation time and transport time reliability of an intermodal supply chain that consists of a pre-, long- and post-haul. This analytical model gives an overview of the individual parameters that influence transportation time and transport time reliability and enables a discussion of different parameter set-ups. Hence, this research closes a fundamental research gap by defining transportation time and transport time reliability in the context of intermodal transportation. It complements the set of performance metrics in intermodal transportation and enables the analysis of alternative transport solutions from a holistic perspective.

We develop a discrete event simulation model with the equivalent scope of the analytical model and analyze how individual transport legs affect the entire intermodal transport chain. We reveal that, in particular, pre- and long-haul have a high impact on transportation time and transport time reliability. This finding substantially contributes to research on intermodal transportation as it emphasizes the importance of these two transport legs and further enables us to accordingly prioritize measures. We further observe that measures on a dedicated transport leg, e.g. pre-haul, similarly affect the entire transport chain independently from the other transport legs. Combined with the previous finding that highlights the importance of pre- and post-haul transportation, we conclude that measures that explicitly target these two transport legs are highly effective such as the definition of delivery time windows or the deployment of freight forwarders and service providers with an improved service. These measures are favorable not only for the respective transport haul since they similarly improve the transportation time and transport time reliability of the entire intermodal transport chain. The understanding gained offers the opportunity to break down the intermodal transport chain into haulages when analyzing transportation time and transport time reliability analogously to costs (Hanssen, Mathisen and Jorgensen 2012). This finding backs previous research works that examine selected parts of intermodal transport chains, e.g. transshipment terminals or specific transport legs, and enables researchers to draw conclusions with regard to the total intermodal transport chains (Rizzoli, Fornara and Gambardella 2002; Sgouridis, Makris and Angelides 2003; Wiegmans 2010).

In summary, Chapter 3 analyzes in-depth the outlined research objective on the transportation time and transport time reliability of intermodal transport chains. We define transportation time and transport time reliability for intermodal transport chains and show that, in particular, pre- and long-haul transportation substantially affect both performance indicators. We conclude that respective improvement levers for the haulages can be examined solely and the effects can be transferred to the entire intermodal transport chain. These results lay the foundation for developing measures to improve the performance of xKD supply chains.

3. Identify and evaluate improvement levers in order to enhance the SCP of xKD supply chains by transferring measures from the lean management of global supply chains in order to align xKD supply chains with the requirements of GMNs.

In Chapter 4, we explore improvement levers for the SCP of xKD supply chains and build on the insights of the previous research works. Chapter 2 has already narrowed down the research scope to PBP supply chains as they do not meet the requirements of the supplied web structure network. Thus, we focus on PBP supply chains. We further consider the findings of Chapter 3 that highlight the importance of pre- and long-haul transportation and the opportunity to investigate the haulages separately.

We perform a systematic literature review on lean management in global supply chains – a research stream that explicitly targets performance improvements by eliminating waste. Our research is the first to our knowledge that provides a condensed overview of the improvement measures of lean management in global supply chains and transfers them holistically to one dedicated use case (Lorentz, Kumar and Srai 2018). This enables us to systematically apply and analyze them and further serves as a basis for future research. During the second step, we consult literature on the SCP and define a set of metrics suitable for investigating improvement levers on xKD supply chains. We implement the SCP metrics of lead time, lead time reliability, inventory level and costs and thus establish an evaluation basis that covers all relevant aspects (Ruiz-Benitez, Lopez and Real 2018). Costs are very sensitive for companies and thus are difficult to find out (Song 2009). We gathered all relevant cost aspects, performed intensive research on appropriate formulas as well as on realistic parameters and provide all information in an overview. This overview is particularly valuable for researchers as it enables them to draw conclusions on other parameter set-ups and gives them the opportunity to implement realistic costs in future research works. This research lays the foundation for realistically analyzing the SCP and, in particular, the costs of xKD supply chains and hence is a major contribution to research on xKD supply chains (Song 2009; Itoh and Guerrero 2020). However, this foundation is valuable for lean management in global supply chains, too as it offers the opportunity to seize the impact of the proposed improvement levers and allows researchers to analyze the improvement levers quantitatively (Staudacher and Tantardini 2009; Cheng 2011; Stanczyk et al. 2016)

Based on this, we transfer the identified measures from lean management in global supply chains to xKD supply chains and discover surprisingly that two out of four measures have already been incorporated into the design of xKD supply chains. OEMs operate xKD centers which represent consolidation centers and perform quality checks prior to long-haul transportation. They have not implemented the two measures as part of their lean management implementation strategy, though. Instead, they have introduced them in order to establish a process that ensures a stable supply of kits, that contains all parts required for manufacturing the cars and therefore bundles and checks the parts in xKD centers (Schulz and Hesse 2009; Klug 2010; Koehne 2013). This set-up, however, has led in the case of PBP supply chains to a transformation of xKD centers into consolidation centers that bundle parts in a volume-optimized way which reduces the order lot size per part and performs quality checks (Song 2009; Itoh and Guerrero 2020). Even though OEMs have been generally reluctant to introduce lean management to xKD supply chains, they have implemented two out of four lean measures by coincidence. We thus concentrate on analyzing the two remaining improvement levers – namely an increased delivery frequency of suppliers and a reduced buffer time between arrival and dispatch at xKD centers – in order to improve the SCP of PBP supply chains and match the requirements of the underlying web structure GMN. Both measures focus on pre-haul transportation. Under consideration of the insights gained in Chapter 3, we limit our investigations to pre-haul transportation.

In order to accordingly perform the analysis, we employ two complementary research methods. We develop a discrete event simulation model for experimentation and conduct a cross-case study for parameterization and for validation purposes. This way, we employ realistic data despite sparse research on current xKD supply chain configurations. We further obtain a well-grounded validation basis for the simulation model and ensure the findings can be generalized. The results of the cross-case study contribute to the research on xKD supply chains by providing first-hand information that describes the current set-up of xKD supply chains and hence establishes a foundation for future research works (Talavera 2015). We develop a discrete event simulation model which enables us to investigate the two improvement measures in case they are applied solely or in combination. In keeping with Chapter 2, we focus on PBP supply chains and utilise the opportunity to simulate either PBP or kitting supply chains.

The results of the discrete event simulation study show that a sole increase of the supplier delivery frequency does not automatically lead to an increased SCP. While the operational performance indicators, lead time and reliability as well as inventory level are improved, total costs rise due to significantly increased inbound transportation costs. Even though this finding is intuitively comprehensible, it is surprising that no previous research work addressed this relationship before (Krueger 2004; Trippner 2006; Song 2009). With regard to the second improvement measure, the simulation study reveals that a buffer time reduction between the arrival and the dispatch at the xKD center enhances the SCP in all respects. However, the simulation study also discloses the existence of a buffer time threshold which greatly determines the SCP. As soon as PBP supply chains are operated with buffer times below that threshold, the delivery reliability drops and expedited shipping costs soar. Existing research works have not addressed the corresponding risk and impact related to the buffer time threshold (Krueger 2004; Cheng 2011; Golini, Caniato and Kalchschmidt 2016). This research provides an assessment of the improvement measures on the one hand and outlines the risks that are associated with their application on the other hand. Both fundamentally contribute to the research streams.

Furthermore, we examine the fact that, by increasing the supplier delivery frequency and thus the application of the first improvement lever, the buffer time threshold can be reduced. We discover that a combined application of a buffer time reduction and a delivery frequency increase yields the highest overall SCP of PBP supply chains. The average lead time and inventory level at the xKD center are substantially reduced from five days to one day which can be understood as JIT deliveries (Shah and Ward 2007). With regard to delivery reliability, tardiness remains on a similarly low level and the standard deviation of the lead time decreases eighty percent. An application of the two measures in combination also leads to a ten percent cost cut. In summary, the simulation results show that the SCP of PBP supply chains can be improved significantly. This enables a more efficient material flow and enhances the fit of PBP supply chains and the corresponding web structure GMN. This research is the first that defines and applies measures to improve the SCP of PBP supply chains and analytically investigates their impact (Song 2009; Talavera 2015). It makes substantial contributions to research on xKD supply chains as it reveals that the PBP supply chain´s SCP can be improved considerably and meet the coordination requirement (Song 2009; Itoh and Guerrero 2020). Whereas previous researchers argue in a qualitative manner only, we analytically investigate the processes and quantify the impact using the SCP. In this regard, we discover the existence of the buffer time threshold which abruptly limits improvement and needs to be considered when implementing the improvement measures with reasonable care.

With regard to kitting xKD supply chains, the simulation study demonstrates that the SCP can be improved, too, but not to the same level. In order to ensure stable kitting processes, a buffer time of five days turns out to be necessary. Whereas a lead time reduction at the xKD center from ten to five days is beneficial for kitting xKD supply chains, too, complexity reduction remains the priority. Delivering kits to overseas plants simplifies on-site logistics and production processes and helps developing plants to cope with car production (Schulz and Hesse 2009; Koehne 2013). The results of the discrete event simulation support, the integrated framework of xKD supply chains and GMNs developed in Chapter 2 and confirm the assumption that kitting xKD supply chains cannot accomplish a similar SCP such as PBP supply chains and have different priorities. This finding contradicts previous research works that do not distinguish between the individual xKD supply chains when targeting SCP improvements, though (Song 2009; Koehne 2013; Talavera 2015). This research adjusts the SCP requirements depending on the xKD supply chain type and GMN phenotype and makes them transparent. It further discloses the full SCP potential of PBP and kitting xKD supply chains (Song 2009).

Besides the implications on the research field of xKD supply chains and GMNs, this research makes some fundamental contributions to literature on lean management in global supply chains, too. We gather the measures that have been developed and compile them into one condensed approach (Lorentz, Kumar and Srai 2018). This research is the first to our knowledge that applies and investigates the measures of lean management in global supply chains by means of an analytical research method (Staudacher and Tantardini 2009; Cheng 2011; Stanczyk et al. 2016). Whereas previous researchers argue on a qualitative basis, we demonstrate that lean management in global supply chains improves the SCP of global supply chains, given the example of xKD supply chains, and diminishes the negative effects of global transportation (Cheng 2011; Golini, Caniato and Kalchschmidt 2016). We show that a sole application of individual measures of lean management in global supply chains does not automatically improve the SCP, but, in combination, yields significant SCP improvements (Lorentz, Kumar and Srai 2018). This research emphasizes the existence of a buffer time threshold that limits the application and SCP improvement to a certain level and needs to be considered in further investigations and implementations. We thus discover and define a fundamental element that has not been addressed before and substantially determine the success of lean management in global supply chains. The findings of this research collectively contribute to the ongoing discourse about the applicability of lean management in global supply chains and state that an elaborate application of the measures can help to diminish the negative effects associated with global transportation (Cheng 2011; Golini, Caniato and Kalchschmidt 2016).

Regarding the third research objective, Chapter 4 identifies improvement levers for xKD supply chains by transferring measures from lean management in global supply chains. A simulation study shows that the SCP, in particular, of PBP supply chains can be improved considerably and the fit to the supplied GMN can be enhanced.

Overall research question: "How can xKD supply chains be aligned with the GMN in order to increase the SCP in terms of lead time, inventory level and costs?"

With regard to the overall research question, we develop an integrated framework that enables the alignment of the xKD supply chain types with GMN phenotypes by means of the TCE. This integrated framework reveals that the PBP supply chains face substantially higher SCP requirements than kitting xKD supply chain types. We conduct a cross-case study in order to analyze the fit of xKD supply chains and GMNs while taking into consideration the integrated framework and find out that OEMs operate xKD supply chain types that are most suitable for their prevailing GMN phenotype. We show, too, that PBP supply chains feature only a slightly higher SCP than kitting xKD supply chains. We thus determine that PBP supply chains do not meet the high SCP requirements of the corresponding web structure GMNs. In a two-step approach, we first investigate how individual transport legs affect the entire intermodal transport chain in order to gain a general understanding of the overall working principle of xKD supply chains. On this basis, we explore in the second step how the SCP of PBP supply chains can be improved through the application of measures proposed by research on lean management in global supply chains. The Thesis concludes that the SCP of PBP supply chains, in terms of lead time, lead time reliability, inventory level and costs, can be improved substantially by applying the measures of lean management in global supply chains in combination. In this way, PBP supply chains can be aligned and meet the requirements of the respective GMN. This research answers the overall research question including the three research objectives and contributes significantly to the respective research streams.

5.2 Implications for Practice and Managerial Contribution

The GMN and underlying xKD supply chains represent the centerpiece of OEMs' business operations. While GMNs have developed over time, xKD supply chains are still characterized by the same working principles and comprise high buffers and costs (Trippner 2006; Song 2009). OEMs, however, have been reluctant to change the operating xKD supply chains because the relevant maritime transport leg inevitably involves high lead times and a process adaptation potentially increases the risk of air freight costs in case containers miss the dispatch deadline (Song 2009). As a consequence, xKD supply chains barely have been adapted and linked to the development of their GMNs. Chapter 2 of this research explicitly targets this misfit and develops an integrated framework which forms the basis for aligning xKD supply chains with GMNs. It further offers three main advantages for OEMs. Firstly, it enables OEMs to match the most suitable xKD supply chain type to the prevailing GMN phenotype. Secondly, it displays the GMN coordination respectively performance requirements by means of transaction costs which enables the evaluation of the fit of currently-employed xKD supply chains. And last but not least, the integrated framework provides the opportunity to plan the next developmental steps for the GMN and xKD supply chains according to their mutual developmental path. OEMs have still assumed similar coordination and performance requirements for all xKD supply chain types. The integrated framework, however, reveals substantially higher performance requirements for PBP supply chains which pinpoints the need for SCP improvements and gives OEMs an orientation for their next developmental steps. Additionally, the transaction dimensions introduced that drive transaction costs examine the SCP from a different angle and can help supply chain operators to detect weak spots and starting points for future improvements.

Our research on intermodal transportation that is presented in Chapter 3 is also of great use for shipping companies. The simulation results highlight the importance and leverage of pre- and long-haul on the transportation time and transport time reliability of intermodal transport chains. In case companies aim to improve transport time reliability, these insights help to prioritize measures and analysis accordingly. OEMs can influence the transport time reliability of the haulages, for example, by tracking and adapting the performance of freight forwarders or by procuring services with higher delivery reliability. The graphs contained in Chapter 3 depict differently-distributed transportation times and illustrate the effect size and hence make it easy to understand how different transport services for transport hauls affect the transport time reliability of the entire transport chain. These findings highlight the importance for OEMs of understanding the effect of different transport services on transport time reliability and transportation time. The second key take-away for companies is that the individual haulages can be examined solely. This simplifies investigations and enables the conducting of in-depth analysis on specific haulages and the definition of corresponding measures which, in turn, supports the first key take-away.

Chapter 4 builds on Chapters 2 and 3 and investigates improvement levers for xKD supply chains and the resulting potential SCP. Gaining impetus from literature on lean management in global supply chains, Chapter 4 compiles a condensed overview of the measures developed and proposed by previous researchers. This overview provides guidance for OEMs and other global shipping companies in case they aim to improve the SCP of their global supply chains. As OEMs already employ the first two lean management approaches in global supply chain measures in their xKD supply chains, the reduction of the order lot size per part number by consolidating shipments in xKD centers and quality checks prior to long-haul transportation, we investigate the impact of the two remaining lean management improvement levers, delivery frequency increase and buffer time reduction. We show that the SCP, in particular, of PBP supply chains, can be improved substantially by a joint application of the improvement levers. OEMs need to be aware of a buffer time threshold, though. Once the buffer time drops below that threshold, the delivery reliability declines and expedited shipping costs drastically increase. Thus, we recommend a step-wise implementation of the two improvement measures combined with a continuous monitoring of the delivery reliability. We discover that a daily delivery frequency and a one-day buffer time lead to the highest overall SCP of PBP supply chains. Compared to the status quo, the improvement measures enable OEMs that operate PBP supply chains to reduce the lead time and inventory level by eighty percent and total costs by 10 percent.

These results highly impact OEMs and offer great opportunities. From a financial perspective, an OEM that ships around three million cubic meters via its PBP supply chains can potentially save 20 million euros per year and decrease its capital lock-up by fifty million euros permanently. In times of digitalization, electro-mobility and de-carbonization, these savings can substantially contribute towards subsidizing the upcoming investments and to strengthen the market position in an increasingly difficult market environment. Whereas in the factory, lean management nowadays aims to generate savings in the range of a few cents per car, the two proposed measures from lean management in the global supply chain offer the potential to save many euros on the same scale. From an operational perspective, these insights are of great value to OEMs and their service providers, too. The importance becomes even more apparent considering the current circumstances. In 2020, the whole world suffered from the COVID-19 pandemic. The disease led to country-wide lockdowns and production stoppages. However, due to the spread of the Coronavirus, countries and continents were affected at different times. While plants in China were producing, plants in Europe or in the United States of America were shut down and vice versa. This, however, has represented a massive challenge for the underlying PBP supply chains that supply the various plants of the web structure GMN with parts from around the world. Thus, a reduced pre-haul lead time in the PBP supply chain can be essential for managing a crisis like this. OEMs can react on shorter notice to volatile market environments and ship parts earlier from suppliers that have just ramped up their production again. Mr. Diess, Chief Executive Officer of Volkswagen, stated that the Volkswagen Group lost two billion euros per week due to COVID-19 shut-downs (Lanz 2020). In such situations, one day can be of critical importance. While the given example emphasizes the importance of this particular context, similar events happen in the course of the daily business all the time. Currency exchange rates, marketing campaigns, political affairs and many other factors continuously influence the market conditions and hence the demand within a market. Production schedules change and directly affect the PBP supply chains that deliver the parts accordingly. An increased SCP in terms of a reduced lead time and inventory buffers allows OEMs to react more flexibly and on shorter notice and reduces the risk of expedited shipments.

In summary, the Thesis makes a profound contribution to OEMs and the entire automotive industry as it provides guidance for managing the difficult task of global production and supply. It enables the alignment of xKD supply chains with the requirements of GMN and presents levers that significantly enhance the SCP of xKD supply chains.

5.3 Recommendations for Implementation

The Thesis reveals that PBP supply chains offer great improvement potential with regard to the SCP. It develops and evaluates improvement measures that enhance the operational performance of PBP supply chains in terms of lead time, delivery reliability and inventory level and likewise decrease costs and capital lock-up. Considering the high shipping volumes and the prosperous material flows of the OEMs´ web structure GMNs, an implementation of the outlined improvement measures appears to be highly-promising. Particularly from a financial perspective, this approach is tempting since OEMs can generate savings of multiple euros per vehicle and thus save tens of millions of euros. On the downside, these scale effects in combination with the importance of reliable supplies for overseas plants increase the pressure and risk for OEMs and have been a reason for OEMs´ reluctance to introduce improvement measures in xKD supply chains in the past. The Thesis, though, provides value insights on implementation issues and we thus propose the following implementation approach.

1) Assess the operational SCP of PBP supply chains

The first step is to assess the operational SCP of the OEM´s PBP supply chains and to ascertain the employed delivery frequency and buffer time at the xKD centers. On this basis, the OEM can evaluate the current SCP by making a comparison to the simulation results of Chapter 4 that demonstrated the highest SCP in case that a daily delivery frequency and one-day buffer time are employed. This analysis reveals the gap in the most promising set-up of PBP supply chains and further determines whether one or both improvement measures need to be applied. For the remainder of this section, we will assume the set-up to be the same as the industry-wide status-quo discovered in the course of the cross-case study in Chapter 4 and thus a weekly delivery frequency and a five-day buffer time.

2) Analyze the cost structure of PBP supply chains

The cost structure of PBP supply chains influences the suitability and overall cost impact of the improvement measures. The most suitable PBP supply chain set-up depends on the trade-off of the decreasing overhead and capital lock-up costs on the one hand and rising inbound transportation costs on the other hand. This trade-off determines the favorable delivery frequency and hence limits the buffer time reduction due to the buffer time threshold that was identified. Thus, OEMs must assess the cost impact on inbound transportation costs when delivery frequency is increased to two or five deliveries per supplier and week and derive potential savings while taking into consideration the simulation results in Chapter 4.

3) Define the most suitable PBP supply chain set-up

Based on the first two steps, an OEM defines the most suitable PBP supply chain set-up with respect to the operational and economic SCP in step three. Since the supplier delivery frequency limits the buffer time reduction, an OEM decides first how often suppliers should deliver parts to xKD centers and then identifies the buffer time threshold which results in the highest SCP. This set-up then serves as the goal for implementation.

4) Apply the supplier delivery frequency

In step four, the OEM applies the most suitable delivery frequency and therefore adapts the supplier contracts as well as the delivery order scheduling. In case the delivery frequency is higher than one delivery per week, the OEM splits the weekly delivery order into multiple orders depending on the supplier delivery frequency and schedules them according to container due date. The result of step four is a set of prioritized delivery orders.

5) Gradually reduce the buffer time at xKD centers

The OEM gradually reduces the buffer time at the xKD centers during the fifth implementation step. In multiple iterations, the buffer time is reduced day-by-day to the buffer time threshold. This way, the OEM is aware of the buffer time threshold and avoids delivery delays and the risk of high air freight costs. In order to ensure stable PBP supply chains and to assess the impact of each buffer time reduction, we propose the monitoring of the SCP of the PBP supply chains for approximately two months prior to realizing the next buffer time reduction sub-step. The last buffer time reduction to the buffer time threshold needs to be managed with extraordinary care. All supply chain analysts and managers need to be aware of the impact of the buffer time threshold at all times.

6) Realize SCP improvements

The last implementation step concerns the realization of the SCP improvements. The OEM accomplishes some SCP improvements automatically such as a decreased lead time and inventory level and hence capital lock-up. In order to realize overhead cost reductions, the OEM, however, needs to re-arrange the layout of its xKD centers in order to increase the xKD centers' utilization. The reduced inventory level enables OEMs to expand the packaging area and thus to handle a higher shipping volume in its xKD centers which potentially results in a reduced number of xKD centers and additional bundling effects for inbound transportation. This layout adaption further offers the opportunity to improve the processes in the xKD center and thus to arrange everything in close proximity to each other and to omit the warehousing process analogous to cross-docks.

This implementation approach introduces the improvement measures step-wise. It enables OEMs to realize the highest SCP and reduces the risk of process failure and air freight costs during the implementation phase.

5.4 Limitations and Outlook

The Thesis comprises limitations and offers opportunities for future research. In the following section, we explain the limits of this research and outline future research possibilities.

As recent information on GMNs and in particular on the xKD supply chains of OEMs are rare, we employed an exploratory research approach in Chapters 2 and 4. We conducted cross-case studies investigating six globally-producing OEMs and thus just a sample of European OEMs. GMNs and xKD supply chains represent competitive advantages to the OEMs and hence it is very difficult to obtain first-hand information. Particularly obtaining information about performance and costs represent major challenges. We conducted intense secondary data research combined with several expert interviews. Performance and cost information were derived indirectly via related indicators and relied on interpretations from the researchers. As a consequence, the real SCP of the xKD supply chains may vary. However, we presented the basic assumptions and the underlying data. Future research may extend the cross-case studies presented in Chapters 2 and 4 by considering additional OEMs or by analyzing complementary characteristics and determinants.

The simulation models presented in Chapters 3 and 4 reduce the real-world problem to a set of constraints required for experimentation. Both simulation models incorporate assumptions and simplifications. The selected variables and parameters as well as the working principle of the simulation models are based on systematic literature reviews and were validated either by a comparison with an analytical model in the case of intermodal transportation or with real-world data gained from the case study and expert interviews with a focus on xKD supply chains. Thus, future research may question the chosen simulation model set-ups and incorporate additional or other assumptions. The simulation models also offer the potential for conducting further experiments while taking a different perspective. Alternatively, future simulation models might focus on other parts of the xKD supply chains that complement our research results in order to provide an even more comprehensive overview of this research topic.

This Thesis contributes most notably to research on xKD supply chains and makes contributions to the literature streams on the GMN, intermodal transportation and lean management in global supply chains, too. However, research is always evolving and the discoveries from this Thesis represent the basis for future research opportunities. The integrated framework for xKD supply chains and the GMN that has been developed may be challenged or transferred to other industries. Future research works may investigate the proposed and evaluated improvement levers from lean management in global supply chains in a different context or identify additional measures. Lastly, an implementation of the improvement levers in real-life xKD supply chains under scientific guidance may offer rare first-hand information and validation for xKD supply chains and lean management in global supply chains.

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