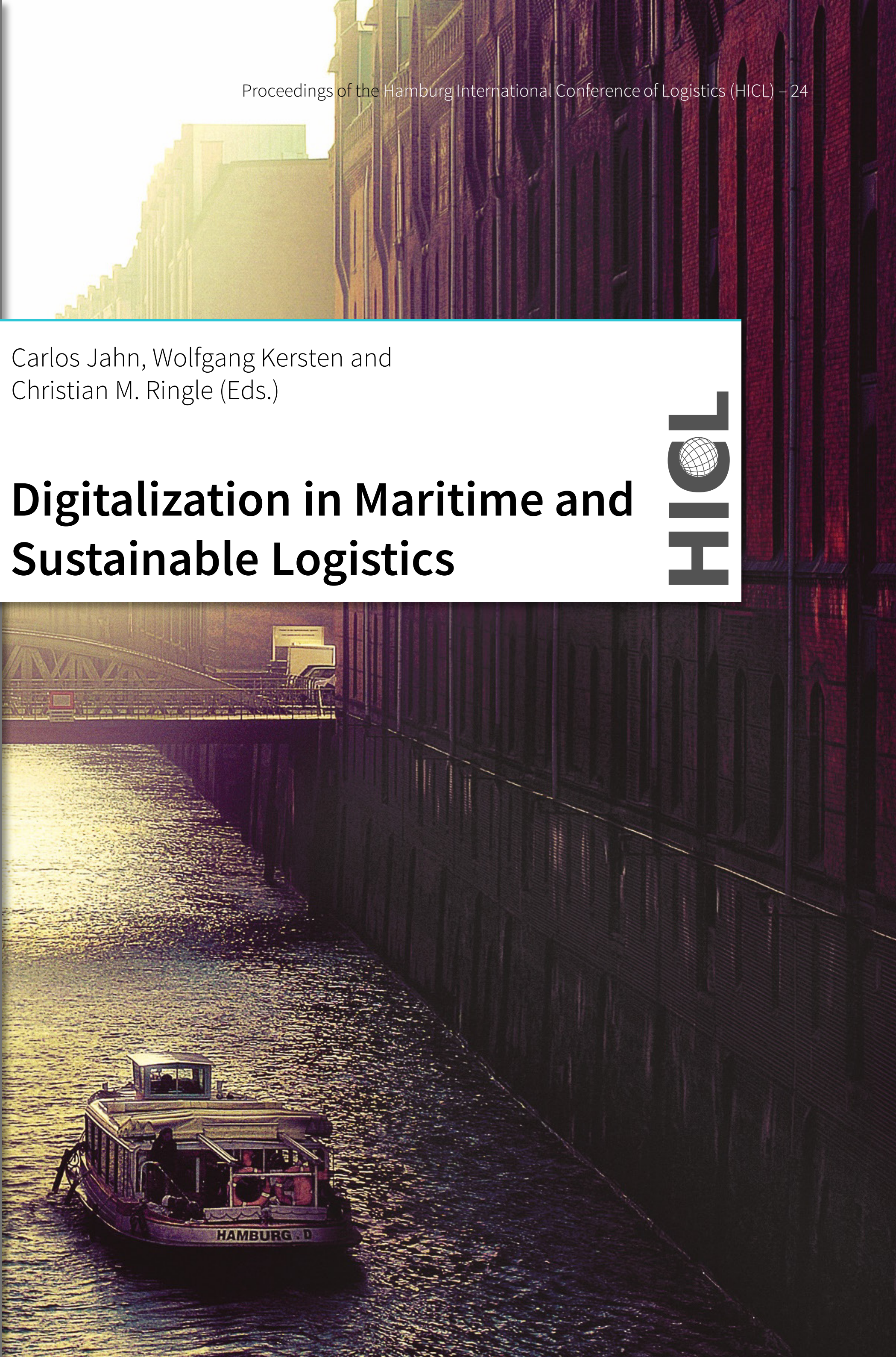

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Carlos Jahn, Wolfgang Kersten and
Christian M. Ringle (Eds.)

Digitalization in Maritime and Sustainable Logistics

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24

Digitalization in Maritime and Sustainable Logistics

City Logistics, Port Logistics and Sustainable Supply Chain Management in the Digital Age

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Contents

Preface

This year's edition of the HICL proceedings are released at a time of a profound shift: Digitalization puts existing business models to the test and questions existing business processes and logic. Companies find themselves in an increasingly volatile environment and face an ever-increasing demand for flexibility. Especially in ports and cities, these shifts put supply chain managers and logisticians on their toes – congestion in and around ports as well as emissions in cities remain a problem to be solved.

The digital shift provides the tools to address problems of logistics and supply chain management regarding sustainability as well as human factors and education. This is very necessary, because otherwise, as Charter & Clark (2008, p. 256) once noted, "never mind how big, successful and powerful a business is now, if it does not practice sustainable innovation, it will go the way of the dinosaurs.".

This book focuses on the latest discussion with regards to future supply chain solutions. It contains manuscripts by international authors discussing logistics skills as well as efficiency aspects of various European seaports and cities thus providing new insights into the field of maritime logistics and sustainable supply chain management. All manuscripts contribute to theory development and verification in their respective area of research.

We would like to thank the authors for their excellent contributions, which advance the logistics research progress. Without their support and hard work, the creation of this volume would not have been possible.

Hamburg, October 2017

Prof. Dr.-Ing. Carlos Jahn
Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle

Part I

Maritime and Port Logistics

Literature Classification on Dispatching of Container Terminal Vehicles

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Horizontal transport on container terminals represents the interface between quay and yard. Efficient transport operations are essential to improve performance and productivity. Thereby, one main decision problem is dispatching the vehicles. Despite the large amount of literature in this field, there is no classification or survey of the respective literature.

Based on an extensive survey of dispatching literature published between 2000 and 2016, a classification scheme is developed and applied to 81 scientific publications. The classification serves as a framework to propose a definition of dispatching – distinguishing it from scheduling – and to identify trends and potential for future research.

The understanding of 'dispatching' differs significantly from assigning tasks to vehicles to developing exact schedules for the vehicles. Another substantial difference is whether the dispatching problem is considered separately from other terminal operations or integrated. Influencing factors on the ranking of dispatching methods are hardly investigated.

The classification scheme provides for the first time a comprehensive background for classification of dispatching literature. It comprises a large list of criteria in three categories: problem characteristics, solution method and performance evaluation. Thereby, this paper provides a basis to derive further research activities.

Keywords: Container terminal; Horizontal transport; Literature survey and classification; Dispatching

1 Introduction

Container terminals are logistic nodes connecting sea transports of containers with the hinterland or other sea transports. For this purpose, vessels are discharged and loaded. During the discharging process of a vessel on a medium-sized to large container terminal, containers are unloaded from a vessel by quay cranes (QC), transported by vehicles to the yard area and placed in a yard block by a yard crane (YC) or straddle carrier (SC). The vessel loading process is carried out from yard to quayside respectively.

Typical equipment types for horizontal transport are terminal trucks (TT), automated guided vehicles (AGV), automated lifting vehicles (ALV) or SC. Transport equipment can be divided into active (ALV, SC) and passive (TT, AGV) equipment. Active equipment can lift a container and is able to carry out a transport tasks independently. Passive equipment has to wait for a quay or yard crane to be (un)loaded and the cranes have to wait if the passive vehicle is not yet available.

Efficient transport operations are essential to allow for optimal quay crane operations and to serve vessels as fast as possible. There are three main decision problems for horizontal transport operations (Carlo et al., 2014b, p.2): (1) Choosing the type of equipment, (2) Determining the required number of equipment, and (3) Routing and dispatching the equipment. This literature survey focuses on the last issue, especially the dispatching problem. Container transport tasks and available vehicles have to be assigned to each other most efficiently to serve the quay cranes continuously and reduce the driven distances of the vehicles as the same time.

The terms dispatching and scheduling are often used synonymously. Contrariwise, some authors see a clear difference between these terms. In that case, dispatching is usually defined as a dynamic allocation of vehicles and transport tasks when certain events occur (e.g. task accomplished, vehicle available). This is a very flexible but rather myopic approach. In contrast, scheduling is defined as calculating a detailed, static long-term schedule for container transport tasks based on estimated arrival and operations times. The schedule can be optimized using mathematical methods but is very dependent on the quality of the time estimates (Grunow et al., 2006). For the purpose of this survey, the term dispatching is used to include both ideas, following the definition from (Bian et al., 2015) who differentiate between static (scheduling) and dynamic (dispatching) dispatching.

This paper follows three objectives: (1) to develop a classification scheme for approaches to optimize dispatching in horizontal transport based on an extensive literature survey, (2) to classify 81 publications to be able to (3) determine research trends and identify potential for future research.

Therefore, the paper is structured as follows: Section 2 discusses the dispatching problem and provides information on related literature surveys. Section 3 presents information on the literature search procedure and the classification scheme. In section 4, the actual classification is given together with a literature evaluation. Section 5 comprises research trends and interesting future research areas.

2 Discussion of Dispatching Problem and Related Literature Surveys

2.1 Dispatching Problem

Dispatching in horizontal transport on container terminals has been a research topic since 15-20 years. It raised interest when the first container terminals started to automate horizontal transport using AGV. Nevertheless, also manned horizontal transport received attention from researchers in this context showing potential for optimization while in practice most non-automated terminals organize horizontal transport by dedicated dispatching (see e.g. Koo, 2013, p.2).

Dedicated dispatching is the most uncomplicated way to organize horizontal transport operations. Vehicles are organized in gangs of 4-6 and each gang is assigned to one QC. Thereby, they only conduct transport tasks for this QC. Dedicated dispatching is easy to organize although very inefficient as roughly 50% of the time the vehicles drive empty.

Dispatching follows various objectives. One objective is to serve the QC continuously by delivering or picking up containers. This results from defined vessel service times that are agreed between terminal operator and shipping company. Furthermore, QC are the most expensive equipment on a container terminal and should be utilized as much as possible. Another objective refers to the horizontal transport itself. Thereby, the driven distances should be minimized to reduce empty drives, fuel consumption, emissions, and the number of required vehicles and to maximize the equipment utilization.

2.2 Existing Literature Surveys

Vis and Koster (2003) and Steenken et al. (2004) classify decision problems in general on container terminals and provide both a large overview on terminal literature especially of the 1990s. Stahlbock and Voß (2007), Carlo et al. (2014a, 2014b, 2015) extend these and add further publications. Thereby, Carlo et al. (2014a, 2014b, 2015) investigate the three terminal areas quay side, horizontal transport and yard side separately. Kim and Lee (2015) focus on decision problem trends and place a special emphasis on Terminal Operating System (TOS) functions. Gharehgozli et al. (2016) supplement the literature surveys by an overview on innovative technologies and OR trends. Angeloudis and Bell (2011) focus on simulation models investigating container terminal operations.

Vivaldini et al. (2015), Qiu et al. (2002), Desrochers et al. (1990), Egbelu and Tanchoco (1984) offer overviews on scheduling and routing of AGVs without focusing on container terminals. Stahlbock and Voß (2008) considers especially routing problems of vehicles on container terminals. Despite the large amount of dispatching literature referring to container terminals there is no literature survey and classification focusing on this topic. This publication aims to close this gap.

3 Approach and Classification scheme

3.1 Literature Search Procedure

For the extensive literature search, several scientific databases and search engines such as Google Scholar, ScienceDirect and ResearchGate were used with the search terms dispatching or scheduling and container terminal. All publications that investigated horizontal transport operations - potentially in combination with another terminal area - were initially considered relevant and evaluated in the next step whether they actually investigated the research topic. Publications only

considering deadlock avoidance, routing or the required number of equipment were excluded. Thereby, the content and not the wording was the deciding factor. Following, during the publication analysis and classification the lists of references were evaluated to identify further publications. Only English publications were included.

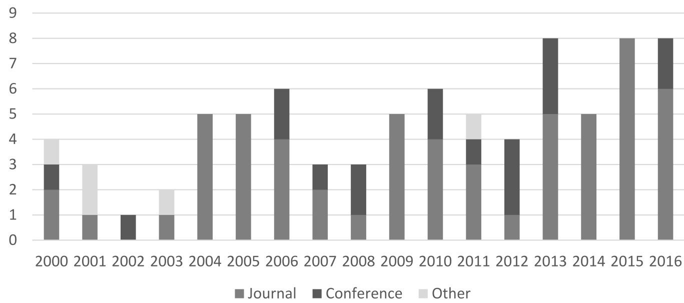

Figure 1: Relevant publications per year

The literature search produced 81 publications between 2000 and 2016 (see Figure 1). The number of papers continuously increases within that period, indicating that this is still a challenging research topic.

The 81 publications comprise 58 journal papers, 18 conference contributions and 5 other publications (research papers, dissertations). Journal paper are published in 39 different journals, most frequently OR Spectrum (8x), Transportation Research Part E: Logistics and Transportation Review (5x), and European Journal of Operational Research (4x).

3.2 Classification scheme

The classification scheme is separated in three main categories (see table 1): (1) problem characteristics, (2) solution approach, and (3) performance evaluation.

The first category problem characteristics refers to all classification parameters that describe the problem considered in the respective publication. These parameters are term, outcome, dispatching objective, system boundary and equipment. Term refers to the word that is used to describe the problem. Outcome considers the issue that the terms are defined differently and describes what is produced by the chosen dispatching method. Dispatching objective refers to the terminal performance measure that is supposed to be optimized. System boundary describes the terminal area(s) that is/are optimized in the respective publication. Equipment includes the type and capacity of the dispatched equipment.

The second category solution approach refers to all classification parameters that describe the approach that is used to solve the dispatching problem considered in the publication. These parameters are planning horizon, mathematical problem formulation, exact algorithm, dispatching method(s), and method development and / or comparison. The planning horizon describes the time perspective when a dispatching decision is taken. The planning horizon varies between real-time and a long-term dispatching plan for several hours. The parameter mathematical problem formulation describes whether the publication presents an explicit problem formulation containing objective function and side conditions. Accordingly, exact algorithm refers to the question whether the formulated problem is solved using an exact algorithm finding the best solution. Dispatching methods considers the methods investigated in the respective publication such as dedicated dispatching, priority rules or heuristics. Lastly, method development and / or comparison describes whether the authors develop an own dispatching method, compare the method with others or whether they collect typical methods and compare them.

The third category performance evaluation refers to all classification parameters that describe the implementation and testing of the solution approach. The category includes the parameters evaluation method, specific terminal, and sensitivity analysis. The first parameter evaluation method refers to the investigation approach. Specific terminal describes whether a real container terminal is investigated (usually a simplified version) or whether hypothetical numbers are used. Lastly, the sensitivity analysis parameter describes which terminal parameters are varied in the sensitivity analysis.

In the following, the classification scheme is applied to 81 publications. Thereby, the subsections are organized according to the three classification categories problem characteristics, solution approach, and performance evaluation.

Table 1: Classification scheme

Problem characteristics	Solution approach	Performance evaluation
Term	Planning horizon	Evaluation method
Outcome	Math. problem formulation	Specific terminal
Dispatching objective	Exact algorithm	Sensitivity analysis
System boundary	Dispatching method(s)	
Equipment	Method development and/or comparison	

4 Literature Classification

4.1 Problem characteristics

The first parameter in this classification category is the term that is used to describe the problem. Thereby, the most prominent appearance is significant for the classification. For example, if dispatching is used in the publication title and scheduling later on in the text, the publication is classified to the parameter value dispatching. Possible values are dispatching, scheduling and other (e.g. assigning, routing, deploying). In total, 32 publications use the term dispatching, 38 publications use the term scheduling and 11 publications use another term. As figure 2 shows, the use of the term dispatching stays relatively constant while the term scheduling increases lately.

The second classification parameter is the outcome of decision problem which can be an allocation, a sequence or a schedule. In total, 29 publications produce a dynamic allocation of tasks and equipment, 21 create a task sequence and 31 produce a detailed schedule for the equipment.

Table 2 shows the interrelation between the term that is used in the respective publication and the outcome of the dispatching process. There is a cluster of publications using the term dispatching leading to the outcome allocation or sequence. There is also a cluster of publications using the term scheduling aiming to the outcome schedule. Publications using other terms such as assigning, routing, deploying show the outcome allocation of sequence. Nevertheless, there are 11 publications that do not fit into these clusters.

The third parameter in the first category is the dispatching objective, i.e. the terminal parameter that is supposed to be optimized. 57 publications focus on one dispatching objective, accordingly 24 publications focus on more than one objective. The dispatching objective usually refers to a specific object as vessel, QC, vehicle or task. Vessel-related objectives are e.g. to minimize the makespan or the departure delay. QC-related objective are e.g. to maximize productivity or to minimize QC wait time. Vehicle-related objectives are e.g. to maximize productivity or to minimize wait time, travel distance or fleet size. Task-related objectives are usually to minimize wait time or delay. Other objectives that fit to these categories are to minimize the wait time of customers trucks, to make best use of space or to maximize the YC throughput. Most publications focus on vessel-related (38x) or vehicle-related (29x) objectives.

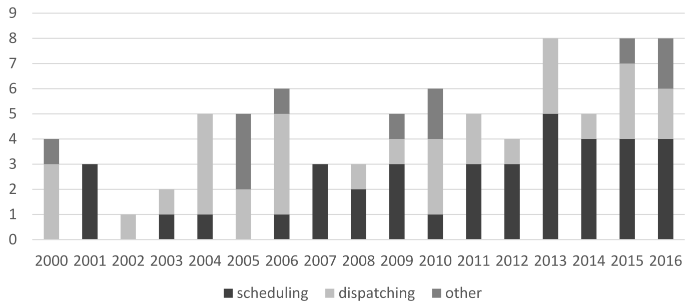

Figure 2: Number of publications per year using the respective term

Table 2: Correlation between name of term and outcome

	Allocation	Sequence	Schedule
Dispatching	20	10	2
Scheduling	2	7	29
other	7	4	0

The fourth parameter refers to the system boundaries of the respective publication. The closest boundary is to focus on horizontal transportation (HT) separately (44 publications). In contrast, the broadest boundary is to integrate horizontal transport, quayside and yard operations (HT+Q+Y; 12 publications). In between are partly integrated investigations setting the system boundaries to horizontal transport plus either quay side (HT+Q; 4 publications) or yard side (HT+Y; 21 publications).

Figure 3 shows that a separate boundary is applied continuously during the 17 years. The number of papers applying the integrated perspective increases lately, especially the publications taking the partly integrated perspective with the quay side.

Table 3 shows the number of publications that use the respective term (dispatching, scheduling, other) and define the respective system boundary (HT, HT+Q+Y, HT+Q, HT+Y). Publications using the term dispatching focus in most cases on HT separately. In contrast, in publications using the term scheduling all system boundaries are represented.

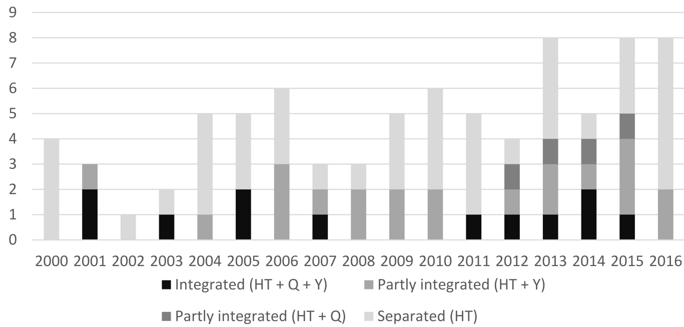

Figure 3: Number of publications per year defining the respective system boundary

Table 3: Correlation between term and system boundary

	HT	HT+Q+Y	HT+Q	HT+Y
Dispatching	28	1	1	2
Scheduling	9	9	3	17
Other	7	2	0	2

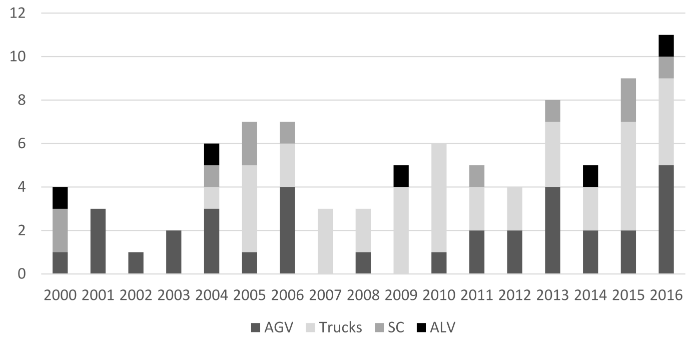

Figure 4: Number of publications per year evaluating the respective equipment

The fifth parameter describes the equipment type and capacity that is considered in the respective publication. AGV are represented in 34 publications, TT in 39 publications, SC in 11 publications and ALV in 5 publications. Only 6 publications consider dual or multiple load equipment.

Figure 4 shows the equipment distribution over time. Between 2000 and 2005/2006 the focus is on AGV, in the following years TT gained interest. Since 2011, the distribution of equipment is relatively balanced.

Figure 5 presents the classification overview for the first category.

Table 4: Abbreviations used in figure 5

A - Allocation	O - other	SQ - Sequence
AG - AGV	Q - Quay crane	T - Task
D - Dispatching	QY - Quay/Yard	TT - Terminal Truck
DM - Dual/multiple load	S - Schedule/-ing	V - Vessel
HT - Horizontal transport	SL - SC or ALV	VH - Vehicle

Publication	Term			Outcome			Dispatching Objective					Boundary		Equipment			
	D	S	O	A	SQ	S	V	Q	VH	T	O	HT	QY	SC	TT	AG	DM
(Ahn et al., 2007)		■				■		■					■		■		
(Angeloudis and Bell, 2010)			■		■			■				■				■	
(Bae and Kim, 2000)	■			■			■		■			■				■	
(Behera et al., 2000)			■	■							■	■		■			
(Bian et al., 2014)	■			■					■			■		■			
(Bian et al., 2015)	■			■							■	■				■	
(Bish et al., 2001)		■		■			■						■			■	
(Bish, 2003)		■		■			■						■			■	
(Bish et al., 2005)	■				■		■					■				■	
(Böse et al., 2000)	■				■			■	■			■		■			
(Briskorn et al., 2006)	■			■				■				■				■	
(Briskorn and Hartmann, 2006)	■			■				■				■				■	
(Cao et al., 2008)		■				■	■						■		■		
(Cao et al., 2010)		■			■		■						■		■		
(Pan et al.)	■				■				■			■			■		
(Chen et al., 2007)		■				■	■						■		■		
(Chen et al., 2013)		■				■	■						■		■		
(Chen et al., 2016)	■			■			■		■			■			■		
(Cheng et al., 2005)	■			■					■			■				■	
(Choe et al., 2012)		■				■		■			■		■		■		
(Choe et al., 2016)	■			■				■			■	■				■	
(Cordeau et al., 2015)			■		■				■				■	■	■		■
(Corman et al., 2016)		■				■	■					■				■	
(Dulebenets, 2016)			■	■					■			■		■	■	■	
(Garro et al., 2015)	■				■				■			■		■			
(Grunow et al., 2004)	■				■		■					■				■	■
(Grunow et al., 2006)	■				■		■					■				■	■
(Hartmann, 2004)		■				■				■			■	■		■	
(He et al., 2015)		■				■	■				■		■		■		
(Homayouni et al., 2012)		■			■			■	■				■			■	
(Homayouni and Tang, 2013)		■				■		■	■				■			■	
(Homayouni et al., 2014)		■				■		■	■				■			■	
(Kaveshgar and Huynh, 2015)		■			■		■						■		■		
(Kim and Bae, 2004)	■			■				■				■				■	
(Kim et al., 2013)	■			■				■	■		■	■				■	
(Klerides and Hadjiconstantinou, 2011)	■			■						■		■				■	■
(Koo, 2013)	■			■			■					■				■	
(Koster et al., 2004)	■			■						■		■		■			

Figure 5: Classification table (Problem category), continued on next page

Publication	Term			Outcome			Dispatching Objective					Boundary		Equipment			
	D	S	O	A	SQ	S	V	Q	VH	T	O	HT	QY	SC	TT	AG	DM
(Kozan and Preston, 2006)		■				■	■						■		■	■	
(Lee et al., 2008)		■				■			■				■		■		
(Lee et al., 2009b)		■				■			■				■		■		
(Lee et al., 2009a)		■				■			■	■			■		■		
(Lee et al., 2010)	■				■		■						■		■		
(Li and Vairaktarakis, 2004)	■			■			■					■			■		
(Li et al., 2015)		■				■	■						■		■		
(Liu and Ioannou, 2002)	■			■				■	■		■	■				■	
(Lu and Jeng, 2006)	■					■	■						■		■		
(Luo and Wu, 2015)		■				■	■						■			■	
(Luo et al., 2016)		■				■	■						■			■	
(Meer, op. 2000)	■			■						■		■		■			
(Meersmans and Wagelmans, 2001b)		■				■	■						■			■	
(Meersmans and Wagelmans, 2001a)		■				■	■						■			■	
(Moussi et al., 2011)		■				■			■			■		■			
(Murty et al., 2005a)			■	■			■		■		■		■	■	■		
(Murty et al., 2005b)			■	■			■		■		■		■	■	■		
(Ng et al., 2007)		■				■	■					■			■		
(Nguyen and Kim, 2009)	■					■		■	■			■		■			
(Niu et al., 2016)		■				■	■			■		■	■		■		
(Nishimura et al., 2005)			■		■				■			■			■		■
(Park et al., 2009)			■	■			■					■			■		
(Petering, 2010)			■	■				■				■			■		■
(Rashidi and Tsang, 2011)		■				■			■	■		■				■	
(Skinner et al., 2013)		■				■			■			■		■			
(Song et al., 2008)	■			■					■			■				■	
(Song and Huang, 2013)	■			■						■		■				■	
(Soriguera and Espinet, 2006)			■	■						■			■	■			
(Tang et al., 2014)		■			■		■						■		■		
(Tao and Qiu, 2015)	■			■			■		■			■			■		
(Tsai et al., 2016)		■				■					■	■			■		
(Wang, 2011)	■				■		■						■		■		
(Wang et al., 2013)		■				■			■				■		■		
(Wang et al., 2014)		■				■			■				■		■		
(Xin et al., 2014)		■			■		■				■		■			■	
(Xing et al., 2012)	■				■			■					■			■	
(Xue et al., 2013)		■				■	■		■				■		■		
(Yu et al., 2010)	■			■			■					■			■		
(Zaghdoud et al., 2016)			■		■		■					■				■	
(Zeng et al., 2009)		■			■		■					■			■		
(Zeng et al., 2011)		■				■	■					■			■		
(Zhang et al., 2005)	■				■			■				■			■		
(Zheng et al., 2012)		■			■						■	■	■		■		

Classification table (Problem category), continuation

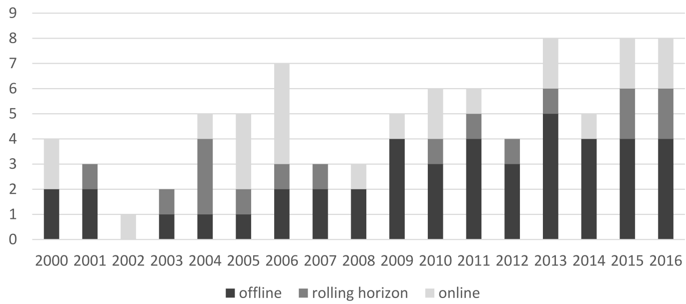

Figure 5: Number of publications per year using the respective planning horizon

4.2 Solution approach

The first parameter in this category is the planning horizon with the parameters online, rolling horizon, and offline. It refers to the period of time between the moment when the decision is taken und the moment when the last task of the planning period is executed. Therefore, online means that the task is executed right after the dispatching decision is taken. Offline implies that the planning horizon comprises several hours. Rolling horizon is a hybrid form. It refers to a planning period that is refreshed frequently but includes several hours. 23 publications investigate online planning, 44 publications investigate offline planning and 16 publications investigate the hybrid rolling horizon. Figure 5 shows the number of publications per year that investigate the respective planning horizon. While online and rolling horizon are represented in a relatively constant number of publications per year, offline planning seems to gain more and more interest.

The second and third parameter in this category are mathematical problem formulation and exact algorithm. An explicit problem formulation containing objective function and side conditions is presented by 61 publications. 31 publications solve the problem using an exact algorithm. However, this is very time consuming and congruently it is explained that this solution approach is not applicable to real container terminals.

As fourth parameter, there are various dispatching methods represented with a diverging complexity. The in practice easiest method dedicated dispatching is used in 14 publications, usually to show the potential for improvement when other methods are used. The next group of method called priority rule are often greedy methods which aim to prioritize the task assignment based on time or distance parameters. Examples are e.g. nearest vehicle, FCFS, longest wait time. 37 publications apply priority rules. The third group of dispatching methods includes optimization techniques such as genetic algorithms or local search heuristics. 61 publications apply these methods, of which 28 test genetic algorithms as largest sub-group. Only 3 publications do not apply any of these methods. They formulate a mathematical model and solve it using CPLEX. All methods are used continuously during the years.

The fifth parameter in this category is method development and/or comparison. 58 publications develop an own dispatching method, 50 publications compare either their developed method with other methods (29x) or collect several methods to compare them (21x).

Figure 6 presents the classification overview for the second category.

Table 5: Abbrevations used in figure 6

C - Comparison	OFF - Offline	PR - Priority Rule
DD - Dedicated Disp.	OM - Own method	R - Ranking
E - Exact Algorithm	ON - Online	RH - Rolling Horizon
H - Heuristic	PF - Problem Formulation	

Publication	Planning Horizon			Problem formulation and method					Development / comparison		
	ON	RH	OFF	PF	E	DD	PR	H	OM	C	R
(Ahn et al., 2007)		X					X	X	X	X	
(Angeloudis and Bell, 2010)		X		X			X	X	X	X	
(Bae and Kim, 2000)			X	X	X	X		X	X		
(Behera et al., 2000)	X						X				X
(Bian et al., 2014)	X			X	X			X			X
(Bian et al., 2015)	X			X				X			X
(Bish et al., 2001)			X	X			X	X	X	X	
(Bish, 2003)			X	X				X	X		
(Bish et al., 2005)	X						X				X
(Böse et al., 2000)			X	X		X	X	X			X
(Briskorn et al., 2006)	X			X	X		X	X			X
(Briskorn and Hartmann, 2006)	X			X				X	X		
(Cao et al., 2008)			X	X	X			X			X
(Cao et al., 2010)			X	X				X			X
(Pan et al.)			X	X				X	X		
(Chen et al., 2007)			X	X	X			X	X		
(Chen et al., 2013)			X	X	X			X	X		
(Chen et al., 2016)		X		X				X	X	X	
(Cheng et al., 2005)		X		X	X		X		X		
(Choe et al., 2012)		X		X			X	X	X	X	
(Choe et al., 2016)	X							X	X	X	
(Cordeau et al., 2015)		X		X				X	X	X	
(Corman et al., 2016)		X		X	X		X	X			X
(Dulebenets, 2016)	X						X				X
(Garro et al., 2015)		X		X		X	X		X	X	
(Grunow et al., 2004)		X		X	X		X		X		
(Grunow et al., 2006)	X	X					X		X	X	
(Hartmann, 2004)		X		X			X	X			X
(He et al., 2015)			X	X	X	X		X	X	X	
(Homayouni et al., 2012)			X	X	X		X		X	X	
(Homayouni and Tang, 2013)			X	X	X		X		X		
(Homayouni et al., 2014)			X	X	X			X			X
(Kaveshgar and Huynh, 2015)			X	X	X			X	X		
(Kim and Bae, 2004)		X		X			X	X	X	X	
(Kim et al., 2013)	X			X			X	X	X	X	
(Klerides and Hadjiconstantinou, 2011)		X		X	X						
(Koo, 2013)	X					X	X				X
(Koster et al., 2004)	X						X				X
(Kozan and Preston, 2006)			X	X				X			X
(Lee et al., 2008)			X	X			X	X	X	X	
(Lee et al., 2009b)			X	X			X	X	X	X	
(Lee et al., 2009a)			X	X	X			X	X		
(Lee et al., 2010)			X	X	X			X			X

Figure 6: Classification table (Solution approach), continued on next page

Publication	Planning Horizon			Problem formulation and method					Development / comparison		
	ON	RH	OFF	PF	E	DD	PR	H	OM	C	R
(Li and Vairaktarakis, 2004)			X	X			X	X	X	X	
(Li et al., 2015)			X	X				X	X		
(Liu and Ioannou, 2002)	X						X				X
(Lu and Jeng, 2006)			X	X		X		X	X	X	
(Luo and Wu, 2015)			X	X	X			X	X		
(Luo et al., 2016)			X	X	X			X	X		
(Meer, op. 2000)	X						X	X			X
(Meersmans and Wagelmans, 2001b)		X				X	X	X	X	X	
(Meersmans and Wagelmans, 2001a)			X		X			X	X		
(Moussi et al., 2011)			X	X				X			X
(Murty et al., 2005a)	X					X		X	X		
(Murty et al., 2005b)	X					X		X	X		
(Ng et al., 2007)			X	X	X			X	X		
(Nguyen and Kim, 2009)			X	X	X			X	X		
(Niu et al., 2016)			X	X				X	X	X	
(Nishimura et al., 2005)		X		X	X	X		X	X		
(Park et al., 2009)	X					X	X				X
(Petering, 2010)	X					X		X	X	X	
(Rashidi and Tsang, 2011)			X	X	X		X		X		
(Skinner et al., 2013)			X	X			X	X	X	X	
(Song et al., 2008)	X							X	X	X	
(Song and Huang, 2013)		X		X			X	X	X	X	
(Soriguera and Espinet, 2006)	X			X			X		X		
(Tang et al., 2014)			X	X	X			X	X	X	
(Tao and Qiu, 2015)	X						X		X	X	
(Tsai et al., 2016)			X	X							
(Wang, 2011)	X		X	X	X		X	X	X		X
(Wang et al., 2013)			X	X	X			X	X		
(Wang et al., 2014)			X	X	X			X	X		
(Xin et al., 2014)			X	X	X						
(Xing et al., 2012)			X	X	X			X	X	X	
(Xue et al., 2013)			X	X	X		X	X	X		
(Yu et al., 2010)	X							X	X		
(Zaghdoud et al., 2016)			X	X				X	X	X	
(Zeng et al., 2009)			X	X		X	X	X	X	X	
(Zeng et al., 2011)			X					X	X		
(Zhang et al., 2005)			X	X			X		X		
(Zheng et al., 2012)			X	X		X		X	X	X	

Classification table (Solution approach), continuation

4.3 Implementation and evaluation

The first parameter in this category is the evaluation method which can be simulation or numerical experiments. 24 publications evaluate using a simulation model, 55 publications conduct numerical experiments and 2 publications implement both methods.

Next parameter is specific terminal which describes whether the evaluation study is conducted for a real terminal or tested with hypothetical numbers. 33 publications refer to a specific terminal. Figure 6 shows that most of these terminals are located in Europe (16 publications) and Asia (14 publications). European terminals are located in Hamburg, Rotterdam, Gioia Tauro, Le Havre, and Barcelona. Asian terminals are amongst others located in Shanghai, Busan, Hong Kong, Singapore.

The third parameter in this category considers the sensitivity analysis of the respective publication. A lot of publications vary the equipment number in the sensitivity analysis, mostly the number of vehicles, but also the number of QC and YC (see figure 7) which usually correlates with a variation of the terminal size. The second most varied parameter is the number of tasks considered in the evaluation. Planning parameters being varied are e.g. the frequency of rescheduling (in case of a rolling horizon approach) or the configuration of a genetic algorithm. Other problem features are e.g. the time between jobs, time between vessels, container position on the vessel, QC load/discharge combination, number of consecutive QC jobs of the same type. Layout-related parameters in the sensitivity analysis are e.g. distance between quay and yard side, the number of blocks, stacking height in the yard. Stochasticity refers to the degree of stochasticity of vehicle travel time or QC operation time. This is rarely investigated similar to the vehicle capacity or speed.

Figure 8 presents the classification overview for the third category.

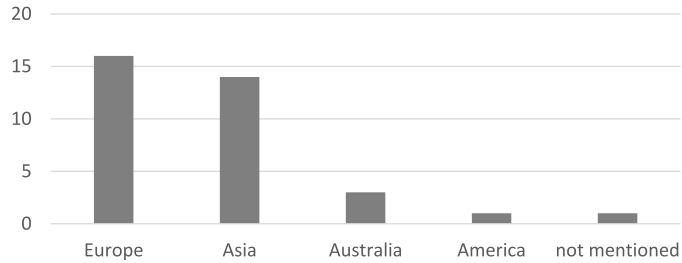

Figure 6: Number of publications referring to a terminal on the respective continent

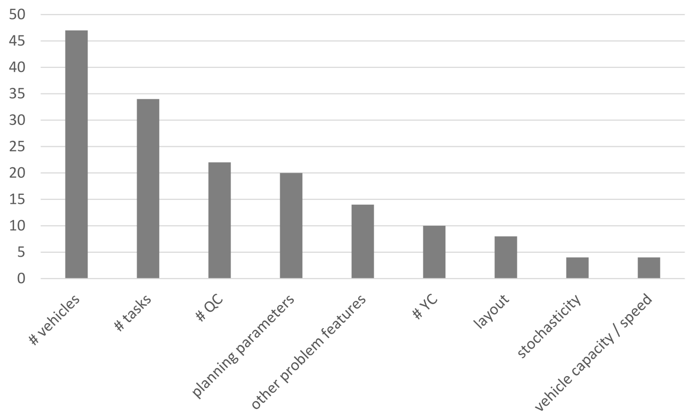

Figure 7: Number of publications varying the respective terminal parameter in the sensitivity analysis

Table 6: Abbrevations used in figure 8

L - Layout	SI - Simulation	VH - No. of vehicles
NE - Num. experiments	SP - Specific terminal	Y - No. of YC
OP - Other problem feat.	ST - Stoachsticity	
PP - Planning parameter	T - No. of tasks	
Q - No. of QC	VC - Vehicle capacity	

Publication	Evaluation method			Sensitivity analysis								
	SI	NE	SP	VH	Q	Y	T	OP	PP	L	ST	VC
(Ahn et al., 2007)	X								X			
(Angeloudis and Bell, 2010)		X	X	X								
(Bae and Kim, 2000)		X		X	X							
(Behera et al., 2000)	X		X	X				X				X
(Bian et al., 2014)		X					X					
(Bian et al., 2015)		X					X					
(Bish et al., 2001)		X		X			X					
(Bish, 2003)		X		X			X			X	X	
(Bish et al., 2005)		X										
(Böse et al., 2000)		X	X					X		X		
(Briskorn et al., 2006)	X		X					X	X			
(Briskorn and Hartmann, 2006)	X		X	X				X				
(Cao et al., 2008)		X					X					
(Cao et al., 2010)		X	X	X		X	X					
(Pan et al.)		X	X									
(Chen et al., 2007)		X	X	X	X	X	X					
(Chen et al., 2013)		X	X	X	X	X	X					
(Chen et al., 2016)		X		X	X	X		X				
(Cheng et al., 2005)	X		X	X				X				
(Choe et al., 2012)	X								X			
(Choe et al., 2016)	X			X				X				
(Cordeau et al., 2015)		X	X	X								
(Corman et al., 2016)		X		X			X					
(Dulebenets, 2016)	X				X			X				
(Garro et al., 2015)	X		X	X	X		X	X	X			
(Grunow et al., 2004)	X	X	X	X	X		X			X		
(Grunow et al., 2006)	X		X	X	X		X			X	X	X
(Hartmann, 2004)		X	X						X			
(He et al., 2015)		X		X	X	X	X					
(Homayouni et al., 2012)		X		X	X		X		X			
(Homayouni and Tang, 2013)		X		X	X		X		X			
(Homayouni et al., 2014)		X		X	X		X		X			
(Kaveshgar and Huynh, 2015)		X		X	X		X		X			
(Kim and Bae, 2004)	X			X					X		X	
(Kim et al., 2013)	X			X								
(Klerides and Hadjiconstantinou, 2011)		X		X	X		X		X			X
(Koo, 2013)		X		X								
(Koster et al., 2004)	X		X	X					X			
(Kozan and Preston, 2006)		X	X	X						X		
(Lee et al., 2008)		X					X					
(Lee et al., 2009b)		X						X				
(Lee et al., 2009a)		X						X				
(Lee et al., 2010)		X		X		X	X					

Figure 8: Classification table (Implementation and evaluation), continued on next page

Publication	Evaluation method			Sensitivity analysis								
	SI	NE	SP	VH	Q	Y	T	OP	PP	L	ST	VC
(Li and Vairaktarakis, 2004)		■	■	■			■					
(Li et al., 2015)		■										
(Liu and Ioannou, 2002)	■			■								
(Lu and Jeng, 2006)		■	■	■								
(Luo and Wu, 2015)		■		■	■	■	■		■			
(Luo et al., 2016)		■		■	■	■	■		■			
(Meer, op. 2000)	■		■									
(Meersmans and Wagelmans, 2001b)	■		■						■		■	
(Meersmans and Wagelmans, 2001a)	■		■	■	■	■	■					
(Moussi et al., 2011)		■	■				■		■			
(Murty et al., 2005a)		■	■	■								
(Murty et al., 2005b)		■	■	■								
(Ng et al., 2007)		■		■			■		■			
(Nguyen and Kim, 2009)		■		■	■		■			■		
(Niu et al., 2016)		■										
(Nishimura et al., 2005)		■	■		■			■		■		■
(Park et al., 2009)	■		■									
(Petering, 2010)	■			■		■				■		
(Rashidi and Tsang, 2011)	■						■					
(Skinner et al., 2013)	■		■				■					
(Song et al., 2008)		■	■									
(Song and Huang, 2013)	■			■					■			
(Soriguera and Espinet, 2006)	■		■									
(Tang et al., 2014)		■		■	■		■					
(Tao and Qiu, 2015)	■		■	■				■				
(Tsai et al., 2016)		■		■								
(Wang, 2011)	■	■										
(Wang et al., 2013)		■							■			
(Wang et al., 2014)		■	■									
(Xin et al., 2014)		■	■					■				
(Xing et al., 2012)		■					■					
(Xue et al., 2013)		■		■	■		■		■			
(Yu et al., 2010)		■										
(Zaghdoud et al., 2016)		■		■			■					
(Zeng et al., 2009)		■		■	■		■					
(Zeng et al., 2011)		■										
(Zhang et al., 2005)		■										
(Zheng et al., 2012)		■										

Classification table (Implementation and evaluation), continuation

5 Conclusion and Future Research

This paper develops a classification scheme for vehicle dispatching on container terminals and applies it to 81 papers. Based on the classification, developments in the research area are identified. There are two main approaches. On the one hand, there is the dispatching approach that aims at a vehicle-task allocation or sequence, focuses on the system boundary horizontal transport separately, and applies a dynamic online solution method. On the other hand, there is the scheduling approach that aims at a detailed schedule for the vehicles, potentially extends the system boundary by quay and / or yard side, and applies a static offline solution method. Of course, there are a lot of hybrid approaches in between.

A lot of publications develop an own dispatching method or compare a few methods for a specific container terminal. A couple of authors vary several terminal parameters within the sensitivity analysis. Zeng et al. (2009) and Liu and Ioannou (2002) show that the number of available vehicles affects the ranking of dispatching methods. Until today, there is no publication analyzing the interdependency between terminal parameters and method performance systematically. Furthermore, dispatching methods perform differently if they are evaluated based on different objectives (see e.g. Dulebenets, 2016). For example, one method is more appropriate to minimize a vessels makespan while another method is more appropriate to reduce the energy consumption. This is an interesting research topic for the future.

References

Ahn, E. Y., K. Park, B. Kang, and K. R. Ryu (2007). "Real Time Scheduling by Coordination for Optimizing Operations of Equipments in a Container Terminal". In: *19th IEEE International Conference on Tools with Artificial Intelligence, 2007*. Los Alamitos, Calif.: IEEE Computer Soc, pp. 44–48.

Angeloudis, P. and M. G. Bell (2010). "An uncertainty-aware AGV assignment algorithm for automated container terminals". In: *Transportation Research Part E: Logistics and Transportation Review* 46.3, pp. 354–366.

Angeloudis, P. and M. G. Bell (2011). "A review of container terminal simulation models". In: *Maritime Policy & Management* 38.5, pp. 523–540.

Le-Anh, T. and R. de Koster (2006). "A review of design and control of automated guided vehicle systems". In: *European Journal of Operational Research* 171.1, pp. 1–23.

Bae, J. W. and K. H. Kim (2000). "A pooled dispatching strategy for automated guided vehicles in port container terminals". In: *International Journal of Management Science* 6.2, pp. 47–67.

Behera, J. M., N. T. Diamond, C. J. Bhuta, and G. R. Thorpe (2000). "The impact of job assignment rules for straddle carriers on the throughput of container terminals". In: *Journal of Advanced Transportation* 34.3, pp. 415–444.

Bian, Z., W. Mi, X. Yang, N. Zhao, and C. Mi (2014). "Modified Hungarian Algorithm for Real-Time ALV Dispatching Problem in Huge Container Terminals". In: *Journal of Networks* 9.1.

Bian, Z., Y. Yang, W. Mi, and C. Mi (2015). "Dispatching Electric AGVs in Automated Container Terminals with Long Travelling Distance". In: *Journal of Coastal Research* 73, pp. 75–81.

Bish, E. K. (2003). "A multiple-crane-constrained scheduling problem in a container terminal". In: *European Journal of Operational Research* 144, pp. 83–107.

Bish, E. K., F. Y. Chen, Y. T. Leong, B. L. Nelson, J. W. C. Ng, and D. Simchi-Levi (2005). "Dispatching vehicles in a mega container terminal". In: *OR Spectrum* 27.4, pp. 491–506.

Bish, E. K., Y. T. Leong, C.-L. Li, J. W. C. Ng, and D. Simchi-Levi (2001). "Analysis of a new vehicle scheduling and location problem". In: *Naval Research Logistics* 48, pp. 363–385.

Böse, J., T. Reiners, D. Steenken, and S. Voß (2000). "Vehicle Dispatching at Seaport Container Terminals Using Evolutionary Algorithms". In: *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*. Ed. by R. H. Sprague. Los Alamitos, Calif.: IEEE Computer Society Press.

Briskorn, D., A. Drexl, and S. Hartmann (2006). "Inventory-based dispatching of automated guided vehicles on container terminals". In: *OR Spectrum* 28.4, pp. 611–630.

Briskorn, D. and S. Hartmann (2006). "Simulating Dispatching Strategies for Automated Container Terminals". In: *Operations research proceedings 2005*. Ed. by H.-D. Haasis, H. Kopfer, and J. Schönberger. Vol. 2005. Operations Research Proceedings. Berlin: Springer-Verlag, pp. 97–102.

Cao, J., D.-H. Lee, J. H. Chen, and Q. Shi (2010). "The integrated yard truck and yard crane scheduling problem: Benders' decomposition-based methods". In: *Transportation Research Part E: Logistics and Transportation Review* 46.3, pp. 344–353.

Cao, J., Q. Shi, and D.-H. Lee (2008). "A decision support method for truck scheduling and storage allocation problem at container". In: *Tsinghua Science and Technology* 13.S1, pp. 211–216.

Carlo, H. J., I. F. A. Vis, and K. J. Roodbergen (2015). "Seaside operations in container terminals: Literature overview, trends, and research directions". In: *Flexible Services and Manufacturing Journal* 27.2-3, pp. 224–262.

Carlo, H. J., I. F. Vis, and K. J. Roodbergen (2014a). "Storage yard operations in container terminals: Literature overview, trends, and research directions". In: *European Journal of Operational Research* 235.2, pp. 412–430.

Carlo, H. J., I. F. Vis, and K. J. Roodbergen (2014b). "Transport operations in container terminals: Literature overview, trends, research directions and classification scheme". In: *European Journal of Operational Research* 236.1, pp. 1–13.

Chen, J., R. Bai, H. Dong, R. Qu, and G. Kendall (2016). "A dynamic truck dispatching problem in marine container terminal". In: *IEEE SSCI 2016*.

Chen, L., N. Bostel, P. Dejax, J. Cai, and L. Xi (2007). "A tabu search algorithm for the integrated scheduling problem of container handling systems in a maritime terminal". In: *European Journal of Operational Research* 181.1, pp. 40–58.

Chen, L., A. Langevin, and Z. Lu (2013). "Integrated scheduling of crane handling and truck transportation in a maritime container terminal". In: *European Journal of Operational Research* 225.1, pp. 142–152.

Cheng, Y.-L., H.-C. Sen, K. Natarajan, C.-P. Teo, and K. C. Tan (2005). "Dispatching Automated Guided Vehicles in a Container Terminal". In: *Supply chain optimization*. Ed. by J. Geunes. Vol. 98. Applied Optimization. New York [u.a.]: Springer, pp. 355–389.

Choe, R., H. Cho, T. Park, and K. R. Ryu (2012). "Queue-based local scheduling and global coordination for real-time operation control in a container terminal". In: *Journal of Intelligent Manufacturing* 23.6, pp. 2179–2192.

Choe, R., J. Kim, and K. R. Ryu (2016). "Online preference learning for adaptive dispatching of AGVs in an automated container terminal". In: *Applied Soft Computing* 38, pp. 647–660.

Co, C. G. and J. Tanchoco (1991). "A review of research on AGVS vehicle management". In: *Engineering Costs and Production Economics* 21, pp. 35–42.

Cordeau, J.-F., P. Legato, R. M. Mazza, and R. Trunfio (2015). "Simulation-based optimization for housekeeping in a container transshipment terminal". In: *Computers & Operations Research* 53, pp. 81–95.

Corman, F., J. Xin, R. R. Negenborn, A. D'Ariano, M. Samà, A. Toli, and G. Lodewijks (2016). "Optimal Scheduling and Routing of Free-range AGVs at Large Scale Automated Container Terminals". In: *Periodica Polytechnica Transportation Engineering* 44.3, pp. 145–154.

Desrochers, M., J. K. Lenstra, and M. Savelsbergh (1990). "A classification scheme for vehicle routing and scheduling problems". In: *European Journal of Operational Research* 46, pp. 322–332.

Duinkerken, M. B. and G. Lodewijks (2015). "Routing of AGVs on Automated Container Terminals". In: *Proceedings of the 2015 IEEE 19th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. Ed. by G. Fortino, W. Shen, J.-P. Barthès, J. Luo, W. Li, S. Ochoa, M.-H. Abel, A. Guerrieri, and M. Ramos. Piscataway, NJ: IEEE.

Dulebenets, M. (2016). "A New Simulation Model for a Comprehensive Evaluation of Yard Truck Deployment Strategies at Marine Container Terminals". In: *Open Science Journal* 1.3, pp. 1–28.

Durrant-Whyte, H. F. (1996). "An autonomous guided vehicle for cargo handling applications". In: *The International Journal of Robotics Research* 15.5, pp. 407–440.

Egbelu, P. J. and J. Tanchoco (1984). "Characterization of automatic guided vehicle dispatching rules". In: *International Journal of Production Research* 22.3, pp. 359–374.

Evers, J. J. and S. A. Koppers (1996). "Automated guided vehicle traffic control at a container terminal". In: *Transportation Research Part A: Policy and Practice* 30.1, pp. 21–34.

Fleuren, H., D. d. Hertog, and P. Kort, eds. (2004). *Operations Research Proceedings 2004*. Springer Berlin Heidelberg.

Fortino, G., W. Shen, J.-P. Barthès, J. Luo, W. Li, S. Ochoa, M.-H. Abel, A. Guerrieri, and M. Ramos, eds. (2015). *Proceedings of the 2015 IEEE 19th International Conference on Computer Supported Cooperative Work in Design (CSCWD): May 6-8, 2015, Calabria, Italy*. Piscataway, NJ: IEEE.

Garro, A., M. F. Monaco, W. Russo, M. Sammarra, and G. Sorrentino (2015). "Agent-based simulation for the evaluation of a new dispatching model for the straddle carrier pooling problem". In: *SIMULATION* 91.2, pp. 181–202.

Geunes, J., ed. (2005). *Supply chain optimization*. Vol. 98. Applied Optimization. New York [u.a.]: Springer.

Gharehgozli, A. H., D. Roy, and R. de Koster (2016). "Sea container terminals: New technologies and OR models". In: *Maritime Economics & Logistics* 18.2, pp. 103–140.

Glover, F. and M. Laguna (2013). "Tabu Search". In: *Handbook of combinatorial optimization*. Ed. by P. M. Pardalos, D.-Z. Du, and R. L. Graham. SpringerReference. New York, NY: Springer New York, pp. 3261–3362.

Goldberg, D. E. (1989). *Genetic algorithms in search, optimization, and machine learning*. Reading, Mass.: Addison-Wesley Publishing Company.

Golden, B., S. Raghavan, and E. Wasil, eds. (2008). *The Vehicle Routing Problem: Latest Advances and New Challenges*. Vol. 43. Boston, MA: Springer US.

Grunow, M., H.-O. Günther, and M. Lehmann (2004). “Dispatching multi-load AGVs in highly automated seaport container terminals”. In: *OR Spectrum* 26.2, pp. 211–235.

Grunow, M., H.-O. Günther, and M. Lehmann (2006). “Strategies for dispatching AGVs at automated seaport container terminals”. In: *OR Spectrum* 28.4, pp. 587–610.

Haasis, H.-D., H. Kopfer, and J. Sch?nberger, eds. (2006). *Operations Research Proceedings 2005*. Operations Research Proceedings. Springer Berlin Heidelberg.

Haasis, H.-D., H. Kopfer, and J. Schönberger, eds. (2006). *Operations research proceedings 2005: Selected papers of the annual International Conference of the German Operations Research Society (GOR), Bremen, September 7-9, 2005*. Vol. 2005. Operations Research Proceedings. Berlin: Springer-Verlag.

Hadjiconstantinou, E. and N. L. Ma (2009). “Evaluating straddle carrier deployment policies: A simulation study for the Piraeus container terminal”. In: *Maritime Policy & Management* 36.4, pp. 353–366.

Hartmann, S. (2004). “A general framework for scheduling equipment and manpower at container terminals”. In: *OR Spectrum* 26.1, pp. 51–74.

He, J., Y. Huang, W. Yan, and S. Wang (2015). “Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption”. In: *Expert Systems with Applications* 42.5, pp. 2464–2487.

Heilig, L. and S. Voß (2017). “Inter-terminal transportation: An annotated bibliography and research agenda”. In: *Flexible Services and Manufacturing Journal* 29.1, pp. 35–63.

Henesey, L. E. (2006). *Multi-agent systems for container terminal management*. Vol. no. 2006:08. Blekinge Institute of Technology doctoral dissertation series. Karlskrona: Blekinge Institute of Technology.

Homayouni, S. M. and S. H. Tang (2013). “Multi Objective Optimization of Coordinated Scheduling of Cranes and Vehicles at Container Terminals”. In: *Mathematical Problems in Engineering* 2013.27, pp. 1–9.

Homayouni, S. M., S. H. Tang, and O. Motlagh (2014). “A genetic algorithm for optimization of integrated scheduling of cranes, vehicles, and storage platforms at automated container terminals”. In: *Journal of Computational and Applied Mathematics* 270, pp. 545–556.

Homayouni, S. M., M. R. Vasili, S. M. Kazemi, and S. H. Tang (2012). “Integrated scheduling of Sp-AS/RS and handling equipment in automated container terminals”. In: *CIE Proceedings*, pp. 207-1 –207-12.

Hu, W., ed. (2010). *2010 International Conference on Logistics Engineering and Intelligent Transportation Systems (LEITS)*. Piscataway, NJ: IEEE.

Kang, S., J. C. Medina, and Y. Ouyang (2008). “Optimal operations of transportation fleet for unloading activities at container ports”. In: *Transportation Research Part B* 42, pp. 970–984.

Karam, A., A. B. Eltawil, and N. A. Harraz (2016). “Simultaneous assignment of quay cranes and internal trucks in container terminals”. In: *International Journal of Industrial and Systems Engineering* 24.1, p. 107.

Kaveshgar, N. and N. Huynh (2015). “Integrated quay crane and yard truck scheduling for unloading inbound containers”. In: *International Journal of Production Economics* 159, pp. 168–177.

Khatib, O. and J. K. Salisbury, eds. (1996). *Experimental robotics IV: The 4th international symposium, Stanford, California, June 30-July 2, 1995*. Vol. 223. Lecture Notes in Control and Information Sciences. London and New York: Springer-Verlag.

Kim, J., R. Choe, and K. R. Ryu (2013). “Multi-Objective Optimization of Dispatching Strategies for Situation-Adaptive AGV Operation in an Automated Container Terminal”. In: *Research in Adaptive and Convergent Systems*.

Kim, K. H. (2005). “Models and Methods for Operations in Port Container Terminals”. In: *Logistics Systems: Design and Optimization*. Ed. by A. Langevin and D. Riopel. New York: Springer-Verlag, pp. 213–243.

Kim, K. H. and J. W. Bae (2004). “A Look-Ahead Dispatching Method for Automated Guided Vehicles in Automated Port Container Terminals”. In: *Transportation Science* 38.2, pp. 224–234.

Kim, K. H. and H.-O. Günther, eds. (2007a). *Container Terminals and Cargo Systems*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Kim, K. H. and H.-O. Günther (2007b). “Container terminals and terminal operations”. In: *Container Terminals and Cargo Systems*. Ed. by K. H. Kim and H.-O. Günther. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 3–12.

Kim, K. H., S. M. Jeong, and K. R. Ryu (2006). “Deadlock prevention for automated guided vehicles in automated container terminals”. In: *OR Spectrum* 28, pp. 659–679.

Kim, K. H., J. S. Kang, and K. R. Ryu (2004). “A beam search algorithm for the load sequencing of outbound containers in port container terminals”. In: *OR Spectrum* 26, pp. 93–116.

Kim, K. H. and H. Lee (2015). “Container Terminal Operation: Current Trends and Future Challenges”. In: *Handbook of Ocean Container Transport Logistics*. Ed. by C.-Y. Lee and Q. Meng. Vol. 220. International Series in Operations Research & Management Science. Cham: Springer International Publishing, pp. 43–73.

Kim, K. Y. and K. H. Kim (1999). “A routing algorithm for a single straddle carrier to load export containers onto a containership”. In: *International Journal of Production Economics* 59, pp. 425–433.

Klerides, E. and E. Hadjiconstantinou (2011). “Modelling and solution approaches to the multi-load AGV dispatching problem in container terminals”. In: *Maritime Economics & Logistics* 13.4, pp. 371–386.

Koo, P.-H. (2013). “Dispatching Transport Vehicles in Maritime Container Terminals”. In: *International Journal of Business Tourism and Applied Sciences* 1, pp. 90–97.

Koster, R. de, T. Le-Anh, and J. R. van der Meer (2004). “Testing and classifying vehicle dispatching rules in three real-world settings”. In: *Journal of Operations Management* 22.4, pp. 369–386.

Kozan, E. and P. Preston (2006). “Mathematical modelling of container transfers and storage locations at seaport terminals”. In: *OR Spectrum* 28.4, pp. 519–537.

Langevin, A. and D. Riopel, eds. (2005). *Logistics Systems: Design and Optimization*. New York: Springer-Verlag.

Lee, C.-Y. and Q. Meng, eds. (2015). *Handbook of Ocean Container Transport Logistics*. International Series in Operations Research & Management Science. Cham: Springer International Publishing.

Lee, D.-H., J. X. Cao, and Q. X. Shi (2009). “Synchronization of yard truck scheduling and storage allocation in container terminals”. In: *Engineering Optimization* 41.7, pp. 659–672.

Lee, D.-H., J. Cao, and Q. Shi (2008). “Integrated Model for Truck Scheduling and Storage Allocation Problem at Container Terminals”. In: *TRB 87th Annual Meeting*. Washington: Transportation Research Board Business Office.

Lee, D.-H., J. Cao, Q. Shi, and J. H. Chen (2009). “A heuristic algorithm for yard truck scheduling and storage allocation problems”. In: *Transportation Research Part E: Logistics and Transportation Review* 45.5, pp. 810–820.

Lee, L. H., E. P. Chew, K. C. Tan, and Y. Wang (2010). “Vehicle dispatching algorithms for container transshipment hubs”. In: *OR Spectrum* 32.3, pp. 663–685.

Legato, P., R. M. Mazza, and R. Trunfio (2010). “Simulation-based optimization for discharge/loading operations at a maritime container terminal”. In: *OR Spectrum* 32.3, pp. 543–567.

Lehmann, M. (2006). “Einsatzplanung von Fahrerlosen Transportsystemen in Seehafen-Containerterminals”. Dissertation. Berlin: Technische Universität Berlin.

Lehmann, M., M. Grunow, and H.-O. Günther (2006). “Deadlock handling for real-time control of AGVs at automated container terminals”. In: *OR Spectrum* 28.4, pp. 631–657.

Lehnfeld, J. and S. Knust (2014). “Loading, unloading and premarshalling of stacks in storage areas: Survey and classification”. In: *European Journal of Operational Research* 239.2, pp. 297–312.

Li, C., Z. Lu, X. Han, Y. Zhang, and L. Wang (2015). “Integrated scheduling of a container handling system with simultaneous loading and discharging operations”. In: *Engineering Optimization* 48.3, pp. 397–414.

Li, C.-L. and G. L. Vairaktarakis (2004). “Loading and unloading operations in container terminals”. In: *IIE Transactions* 36.4, pp. 287–297.

Li, Q., A. C. Adriaansen, J. T. Udding, and A. Y. Pogromsky (2011). “Design and Control of Automated Guided Vehicle Systems: A Case Study”. In: *IFAC Proceedings Volumes* 44.1, pp. 13852–13857.

Li, W., Y. Wu, and M. Goh (2015a). “Maritime Terminal Operational Problems”. In: *Planning and Scheduling for Maritime Container Yards*. Ed. by W. Li, Y. Wu, and M. Goh. Cham: Springer International Publishing, pp. 5–29.

Li, W., Y. Wu, and M. Goh, eds. (2015b). *Planning and Scheduling for Maritime Container Yards*. Cham: Springer International Publishing.

Liu, C.-I. and P. Ioannou (2002). “A comparison of different AGV dispatching rules in an automated container terminal”. In: *IEEE 5th International Conference on Intelligent Transportation Systems*, pp. 880–885.

Liu, C.-I., H. Jula, Vukadinovic, and P. Ioannou (2004). “Automated guided vehicle system for two container yard layouts”. In: *Transportation Research Part C* 12, pp. 349–368.

Lu, H.-A. and J.-Y. Jeng (2006). “Modeling and Solution for Yard Truck Dispatch Planning at Container Terminal”. In: *Operations Research Proceedings 2005*. Ed. by H.-D. Haasis, H. Kopfer, and J. Sch?nberger. Vol. 2005. Operations Research Proceedings. Springer Berlin Heidelberg, pp. 117–122.

Luo, J. and Y. Wu (2015). “Modelling of dual-cycle strategy for container storage and vehicle scheduling problems at automated container terminals”. In: *Transportation Research Part E: Logistics and Transportation Review* 79, pp. 49–64.

Luo, J., Y. Wu, and A. B. Mendes (2016). “Modelling of integrated vehicle scheduling and container storage problems in unloading process at an automated container terminal”. In: *Computers & Industrial Engineering* 94, pp. 32–44.

Meer, J. R. van der (op. 2000). *Operational control of internal transport*. Vol. 1. ERIM Ph. D. series research in management. [Rotterdam]: [ERIM].

Meersmans, P. J. and R. Dekker (2001). *Operations Research supports container handling*.

Meersmans, P. J. and A. P. Wagelmans (2001a). *Dynamic Scheduling of Handling Equipment at Automated Container Terminals*. Rotterdam.

Meersmans, P. J. and A. P. Wagelmans (2001b). *Effective Algorithms for Integrated Scheduling of Handling Equipment at Automated Container Terminals*. Rotterdam.

Möhring, R. H., E. Köhler, E. Gawrilow, and B. Stenzel (2004). "Conflict-free Real-time AGV Routing". In: *Operations Research Proceedings 2004*. Ed. by H. Fleuren, D. d. Hertog, and P. Kort. Springer Berlin Heidelberg, pp. 18–24.

Moreira, A. P., A. Matos, and G. Veiga, eds. (2015). *CONTROLO'2014 – Proceedings of the 11th Portuguese Conference on Automatic Control*. Lecture Notes in Electrical Engineering. Cham: Springer International Publishing.

Moussi, R., A. Yassine, A. Kansou, and T. Galinho (2011). "Scheduling of lifting vehicles with time windows in an automated port container terminal". In: *2011 4th International Conference on Logistics*. [Piscataway, N.J.]: IEEE, pp. 55–61.

Murty, K. G., J. Liu, Y.-w. Wan, and R. Linn (2005). "A decision support system for operations in a container terminal". In: *Decision Support Systems* 39, pp. 309–332.

Murty, K. G., Y.-w. Wan, J. Liu, M. M. Tseng, E. Leung, K.-K. Lai, and H. W. C. Chiu (2005). "Hongkong International Terminals Gains Elastic Capacity Using a Data-Intensive Decision-Support System". In: *Interfaces* 35.1, pp. 61–75.

Naso, D. and B. Turchiano (2005). "Multicriteria Meta-Heuristics for AGV Dispatching Control Based on Computational Intelligence". In: *IEEE Transactions on Systems, Man and Cybernetics, Part B (Cybernetics)* 35.2, pp. 208–226.

Ng, J. W. C., K. L. Mak, and Y. X. Zhang (2007). "Scheduling trucks in container terminals using a genetic algorithm". In: *Engineering Optimization* 39.1, pp. 33–47.

Nguyen, V. D. and K. H. Kim (2009). "A dispatching method for automated lifting vehicles in automated port container terminals". In: *Computers & Industrial Engineering* 56, pp. 1002–1020.

Nishimura, E., A. Imai, and Papadimitriou (2005). "Yard trailer routing at a maritime container terminal". In: *Transportation Research Part E: Logistics and Transportation Review* 41, pp. 53–76.

Niu, B., T. Xie, L. Tan, Y. Bi, and Z. Wang (2016). "Swarm intelligence algorithms for Yard Truck Scheduling and Storage Allocation Problems". In: *Neurocomputing* 188, pp. 284–293.

Pan, C., H. Fan, and Z. Zhai (n.d.). "Research on Horizontal Transport Optimization System of Container Terminal". In: *2010 3rd International Conference on Knowledge Discovery and Data Mining (WKDD 2010)*, pp. 16–19.

Pardalos, P. M., D.-Z. Du, and R. L. Graham, eds. (2013). *Handbook of combinatorial optimization*. 2. ed., [elektronische Ressource]. SpringerReference. New York, NY: Springer New York.

Park, N. K., Branislav Dragovic, and J. Y. Kim (2009). "Dynamic equipment deployment at a container terminal: transfer system based on real-time positioning". In: *Journal of Mechanical Engineering* 55.2, pp. 83–94.

Petering, M. E. H. (2010). "Development and simulation analysis of real-time, dual-load yard truck control systems for seaport container transshipment terminals". In: *OR Spectrum* 32, pp. 633–661.

Petering, M. E. H. (2011). "Decision support for yard capacity, fleet composition, truck substitutability, and scalability issues at seaport container terminals". In: *Transportation Research Part E: Logistics and Transportation Review* 47, pp. 85–103.

Qiu, L., W.-J. Hsu, S. Y. Huang, and H. Wang (2002). "Scheduling and routing algorithms for AGVs: A survey". In: *International Journal of Production Research* 40.3, pp. 745–760.

Rabe, M., S. Spieckermann, and S. Wenzel (2008). *Verifikation und Validierung für die Simulation in Produktion und Logistik: Vorgehensmodelle und Techniken*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Rashidi, H. and E. P. K. Tsang (2011). "A complete and an incomplete algorithm for automated guided vehicle scheduling in container terminals". In: *Computers and Mathematics with Applications* 61, pp. 630–641.

Sargent, R. G. (2013). "Verification and validation of simulation models". In: *Journal of Simulation* 7.1, pp. 12–24.

Siebertz, K., D. van Bebber, and T. Hochkirchen (2010). *Statistische Versuchsplanung: Design of Experiments (DoE)*. [Place of publication not identified]: Springer.

Skinner, B., S. Yuan, S. Huang, D. Liu, B. Cai, G. Dissanayake, H. Lau, A. Bott, and D. Pagac (2013). "Optimisation for job scheduling at automated container terminals using genetic algorithm". In: *Computers & Industrial Engineering* 64, pp. 511–523.

Song, L. Q. and S. Y. Huang (2013). "A hybrid metaheuristic method for dispatching automated guided vehicles in container terminals". In: *2013 IEEE Symposium on Computational Intelligence in Scheduling (SCIS)*. Piscataway, NJ: IEEE, pp. 52–59.

Song, X., H. C. Cho, J. W. Lee, and K. S. Lee (2008). "New dispatching rule of LMTT shuttle cars using fuzzy inference and ant colony algorithm". In: *2008 Chinese Control and Decision Conference (CCDC)*, pp. 5279–5282.

Soriguera, F. and D. Espinet (2006). "A simulation model for straddle carrier operational assessment in a marine container terminal". In: *Journal of Maritime Research* 3.2, pp. 19–34.

Soriguera, F., D. Espinet, and F. Robusté (2007). "Optimization of Internal Transport Cycle in a Marine Container Terminal Managed by Straddle Carriers". In: *Transportation Research Record: Journal of the Transportation Research Board* 2033, pp. 21–30.

Soriguera, F., F. Robusté, R. Juanola, and A. Lopez-Pita (2006). "Optimization of Handling Equipment in the Container Terminal of the Port of Barcelona, Spain". In: *Transportation Research Record: Journal of the Transportation Research Board* 1963, pp. 44–51.

Stahlbock, R. and S. Voß (2007). "Operations research at container terminals: A literature update". In: *OR Spectrum* 30.1, pp. 1–52.

Stahlbock, R. and S. Voß (2008). "Vehicle Routing Problems and Container Terminal Operations – An Update of Research". In: *The Vehicle Routing Problem: Latest Advances and New Challenges*. Ed. by B. Golden, S. Raghavan, and E. Wasil. Vol. 43. Boston, MA: Springer US, pp. 551–589.

Steenken, D. (1992). "Fahrwegoptimierung am Containerterminal unter Echtzeitbedingungen". In: *OR Spektrum* 14.3, pp. 161–168.

Steenken, D., A. Henning, S. Freigang, and S. Voß (1993). "Routing of straddle carriers at a container terminal with the special aspect of internal moves". In: *OR Spektrum* 15.3, pp. 167–172.

Steenken, D., S. Voß, and R. Stahlbock (2004). "Container terminal operation and operations research - a classification and literature review". In: *OR Spectrum* 26.1, pp. 3–49.

Tang, L., J. Zhao, and J. Liu (2014). "Modeling and solution of the joint quay crane and truck scheduling problem". In: *European Journal of Operational Research* 236.3, pp. 978–990.

Tao, J. and Y. Qiu (2015). "A simulation optimization method for vehicles dispatching among multiple container terminals". In: *Expert Systems with Applications* 42.7, pp. 3742–3750.

Tsai, F.-M., C.-C. Lu, and Y.-M. Chang (2016). "A network model for solving the yard truck routing and scheduling problem". In: *The International Journal of Logistics Management* 27.2, pp. 353–370.

Vis, I. F. A., R. de Koster, K. J. Roodbergen, and L. W. P. Peeters (2001). "Determination of the number of automated guided vehicles required at a semi-automated container terminal". In: *Journal of the Operational Research Society* 52.4, pp. 409–417.

Vis, I. F. A. and K. J. Roodbergen (2009). "Scheduling of Container Storage and Retrieval". In: *Operations Research* 57.2, pp. 456–467.

Vis, I. F. (2006). “Survey of research in the design and control of automated guided vehicle systems”. In: *European Journal of Operational Research* 170.3, pp. 677–709.

Vis, I. F. and R. de Koster (2003). “Transshipment of containers at a container terminal: An overview”. In: *European Journal of Operational Research* 147, pp. 1–16.

Vivaldini, K. C. T., L. F. Rocha, M. Becker, and A. P. Moreira (2015). “Comprehensive Review of the Dispatching, Scheduling and Routing of AGVs”. In: *CONTROLO’2014 – Proceedings of the 11th Portuguese Conference on Automatic Control*. Ed. by A. P. Moreira, A. Matos, and G. Veiga. Vol. 321. Lecture Notes in Electrical Engineering. Cham: Springer International Publishing, pp. 505–514.

Wang, Y. (2011). “Integrated vehicle dispatching for container terminal”. Dissertation. Singapore: National University of Singapore.

Wang, Z. X., F. T. S. Chan, and S. H. Chung (2013). “Storage Allocation and Yard Trucks Scheduling in Container Terminals Using a Genetic Algorithm Approach”. In: *3rd International Conference on Intelligent Computational Systems*.

Wang, Z. X., F. T. S. Chan, S. H. Chung, and B. Niu (2014). “A decision support method for internal truck employment”. In: *Industrial Management & Data Systems* 114.9, pp. 1378–1395.

Xin, J. and G. Lodewijks (2015). *Control and coordination for automated container terminals*. Vol. T2015/13. TRAIL thesis series. Delft: TRAIL Research School.

Xin, J., R. R. Negenborn, F. Corman, and G. Lodewijks (2015). “Control of interacting machines in automated container terminals using a sequential planning approach for collision avoidance”. In: *Transportation Research Part C: Emerging Technologies* 60, pp. 377–396.

Xin, J., R. R. Negenborn, and G. Lodewijks (2014). “Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control”. In: *Transportation Research Part C: Emerging Technologies* 44, pp. 214–230.

Xing, Y., K. Yin, L. Quadrifoglio, and B. Wang (2012). “Dispatch Problem of Automated Guided Vehicles for Serving Tandem Lift Quay Crane”. In: *Transportation Research Record: Journal of the Transportation Research Board* 2273, pp. 79–86.

Xue, Z., C. Zhang, L. Miao, and W.-H. Lin (2013). “An ant colony algorithm for yard truck scheduling and yard location assignment problems with precedence constraints”. In: *Journal of Systems Science and Systems Engineering* 22.1, pp. 21–37.

Yin, X. F., L. P. Khoo, and C.-H. Chen (2011). “A distributed agent system for port planning and scheduling”. In: *Advanced Engineering Informatics* 25.3, pp. 403–412.

Yu, H., Y.-E. Ge, J. Chen, L. Luo, C. Tan, and D. Liu (2017). “CO 2 emission evaluation of yard tractors during loading at container terminals”. In: *Transportation Research Part D: Transport and Environment* 53, pp. 17–36.

Yu, M., S. Wang, and Y. Cai (2010). “A Dispatching Method for Trucks at Container Terminal by Using Fuzzy-CNP Concept”. In: *2010 International Conference on Logistics Engineering and Intelligent Transportation Systems (LEITS)*. Ed. by W. Hu. Piscataway, NJ: IEEE.

Zaghdoud, R., K. Mesghouni, S. C. Dutilleul, K. Zidi, and K. Ghedira (2016). “A Hybrid Method for Assigning Containers to AGVs in Container Terminal”. In: *IFAC-PapersOnLine* 49.3, pp. 96–103.

Zeng, Q., Z. Yang, and X. Hu (2011). “A method integrating simulation and reinforcement learning for operation scheduling in container terminals”. In: *Transport* 26.4, pp. 383–393.

Zeng, Q., Z. Yang, and L. Lai (2009). “Models and algorithms for multi-crane oriented scheduling method in container terminals”. In: *Transport Policy* 16.5, pp. 271–278.

Zhang, L.-W., R. Ye, S. Y. Huang, and W.-J. Hsu (2005). “Mixed integer programming models for dispatching vehicles at a container terminal”. In: *Journal of Applied Mathematics and Computing* 17.1-2, pp. 145–170.

Zhen, L., S. Yu, S. Wang, and Z. Sun (2016). "Scheduling quay cranes and yard trucks for unloading operations in container ports". In: *Annals of Operations Research* 122.1–4, p. 21.

Zheng, X., F. Shu, and W. Mi (2012). "Research on genetic algorithm-based simulation of dynamic container truck scheduling". In: *2012 IEEE International Conference on Computer Science and Automation Engineering (CSAE)*, pp. 131–135.

Reducing Truck Congestion at Ports – Classification and Trends

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Truck drayage in container ports faces several challenges. Due to the ongoing growth of container ship sizes, there are increasingly high peak situations in land-side container handling at logistic nodes in the port, e.g. container terminals, empty depots, freight stations. In combination with rising demands to improve the port's ecological footprint this requires the port and its companies to adapt to the situation in order to reduce congestion. To identify important methods, key parameters, past developments and future trends a classification scheme based on an extensive literature survey on waiting times at terminals and drayage operations is conducted and applied to 71 publications. The analyzed methods to reduce congestion in the port range from optimizing the infrastructure to controlling truck arrival times. While this problem is mainly analyzed from a container terminal perspective, its impacts also affect other stakeholders in the port as trucking companies, empty depots or freight stations. Past literature surveys mainly focus on either one method or one stakeholder. This led to limited assessments for the whole drayage networks in ports. Therefore, the developed classification scheme is a basis to identify promising further research areas while enabling a more holistic approach.

Keywords: drayage; port logistics; congestion; classification scheme

1 Introduction

Seaports are the main interface connecting main carriage and hinterland transportation in maritime supply chains. The amount of world seaborne trade increased more than 2% in millions of tons loaded in 2015 compared to 2014 (UNCTAD, 2016). Combined with rising ship dimensions, especially for container ships, seaports face severe challenges to achieve the productivities demanded by their clients. Furthermore, other stakeholders as the government, environmental organizations and local residents impose demands on port companies regarding environmental and social aspects. The ongoing growth of container ship sizes leads to high peak situations in landside container handling and thereby to a high traffic load on the port street network. In combination with rising demands to improve the port's ecological footprint, this leads to the necessity to reduce truck congestion at container terminals and in the port. Furthermore, port drayage is an important part of maritime supply chains, which often accounts for a high percentage of the overall transportation cost and for a large proportion of truck arrivals at container terminals (Harrison et al., 2007; Shiri and Huynh, 2016). Therefore, main focus of this paper will be on terminal gate, related yard operations and drayage transportation. Seaside (berth, quay, related yard areas and horizontal transportation) and train operations are not considered in this paper. For an extensive overview on operations of container terminals and possible improvement strategies, please consider e.g. Vis and De Koster (2003), Stahlbock and Voß (2007) and Carlo, Vis and Roodbergen (2014a; 2014b).

The first aim of this paper is to present a classification scheme for approaches to reduce truck congestion at logistics nodes in the port, especially at container terminals. It bases on an extensive review of literature during the last 20 years on waiting times in the port and drayage operations. The second aim is to apply the developed classification scheme to 71 publications to identify important methods, key parameters, past developments and future trends. The methods applied in studies to reduce truck waiting times at container terminals range from optimizing the infrastructure to controlling truck arrival times. While this challenge is mainly analyzed from a container terminal perspective, it also affects other stakeholders in the port as empty depots or freight stations. The paper is organized as follows: Section 2 provides information about truck transportation and handling, especially of drayage trucks, in a port, current industry trends and main research done concerning this topic. In section 3 the approach for developing the classification scheme and necessary definitions are given. The classification scheme for approaches to reduce truck congestion at logistic nodes

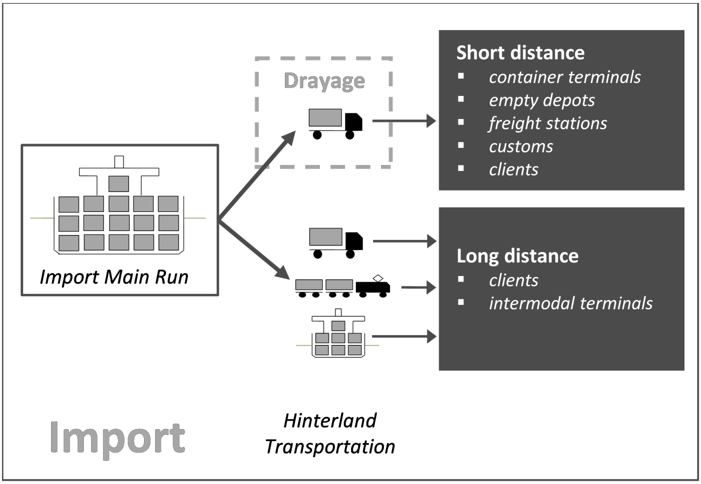

Figure 1: Drayage as a part of the import transport chain

in the port is presented in section 4 and an in depth overview of the reviewed publications based on the classification scheme is given. Finally, in section 5 future trends and promising research areas are presented.

2 Developments and Challenges in Port Related Truck Transportation and Handling

Port drayage is defined as "truck pickup from or delivery to a seaport, with the trip origin and destination in the same urban area" (Hartmann, 2004; Huynh et al., 2011). Figure 1 illustrates exemplarily the different possibilities for transporting an import container from a seaport. Furthermore, the scope of the term drayage in contrast to long distance transportation is shown.

Import containers, either full or empty, are brought to a port on the main carriage mainly by ocean carriers. Depending on their destination and the required specifics of transport, there are several possible options for further transportation. If the container is a transhipment container, it will either be loaded on another ship at the terminal of arrival or be transported to another terminal in the port to be loaded there. Another option is the transport of the container to the hinterland either via short sea vessel, train or truck. Some trucking containers are only transported a short distance, because the recipient, e.g. client, empty depot, is located in the port area.

Export containers can be brought to the port by different means of transport. These mirror the transport options of the import supply chain. The means of transportation can either be ocean carriers with a transhipment container for another vessel or short sea vessels, trains or trucks. Following the given definition, all short distance truck transports of containers to or from the port - no matter if import, export or transhipment container - are considered port drayage.

2.1 Description of Current Situation

The increase in vessel sizes and the relating strain imposed on the landside operation of container terminals due to peaks in truck arrivals for delivering or picking up a container lead to a rising interest in improvement strategies in both industry and research. Based on the high fluctuation in truck traffic load the capacity at the terminal gates and in the yard are mainly either too high or too low, leading to high labor costs for the terminal or to long waiting times for the trucks and as a consequence to congestion at the gates. This phenomenon also affects public streets and the performance of other companies in the port, e.g. freight stations, empty container depots or customs. As the truck engines are running most of the time while queuing or waiting in a traffic jam, the situation leads to higher emissions in the port area. The port drayage sector is highly impacted by these developments due to its focus on transport in the port area and the dependency on the container terminals as main sources and drains of drayage transports. Furthermore, the drayage truck drivers, which are mainly owner operators and get paid per successful trip, are dependent on a certain amount of trips per day to pay their expenses. Extensive waiting times lead to a low number of trips per day for the drivers and therefore to financial challenges.

2.2 Current Industry Trends and Main Research Areas

Several different approaches to reduce waiting times at logistics nodes in the port and in drayage are developed, analyzed and in some cases implemented. Many of the studies focus on container terminals and aim at smoothing the peaks in truck arrivals. Analyzed approaches are among others: controlling the gate lanes (Gracia, González-Ramírez, Mar-Ortiz, 2016), offering incentives for using night or off-peak shifts (Bentolila et al., 2016), installing webcams at the gate to inform truckers about the queues (Huynh et al., 2011) and introducing and optimizing a truck arrival management (inter alia Guan and Liu, 2009; Huynh and Walton, 2011).

Another starting point is to improve drayage operations to reduce congestion and increase the profit for the drayage companies. Therefore, studies with drayage truck drivers are conducted and different scheduling and routing algorithms are developed (Jula, Dessouky, Ioannou and Chassiakos, 2005; Namboothiri and Erera, 2008). Cooperations between truck drivers and other companies are explored (Caballini, Sacone and Saeednia, 2016). Furthermore, more general approaches as implementing a new traffic control system (Rajamanickam and Ramadurai, 2015), introducing supply chain management instruments (Ascencio, González-Ramírez, Bearzotti, Smith and Camacho-Vallejo, 2014) or introducing dry docks while using new concepts like an chassis exchange system (Dekker et al., 2013) are analyzed.

In industry, the introduction of the first what is now called Truck Appointment System (TAS) in the ports of Los Angeles and Long Beach in 2002 in response to California Assembly Bill (AB) 2650 posed a starting point for a development which is still ongoing. The idea was to use a vehicle booking system to control the number of trucks arriving at the terminal at different times of the day. The success of the program has been controversial due to its voluntary nature and the fact that all terminals in the port implemented a different system. This led to high barriers for the truck drivers and therefore to a low participation (Giuliano and O'Brien, 2007). This happened at a time with rising challenges at the terminal gates due to high numbers of arriving trucks with increasing fluctuations. Therefore, the TAS as well as other approaches have been studied increasingly. Today, several successful TAS are running in different parts of the world, e.g. Vancouver, Sydney and Southampton, but the development goes on to improve these systems or to find better alternatives (inter alia Davies and Kieran, 2015; Huynh, Smith and Harder, 2016).

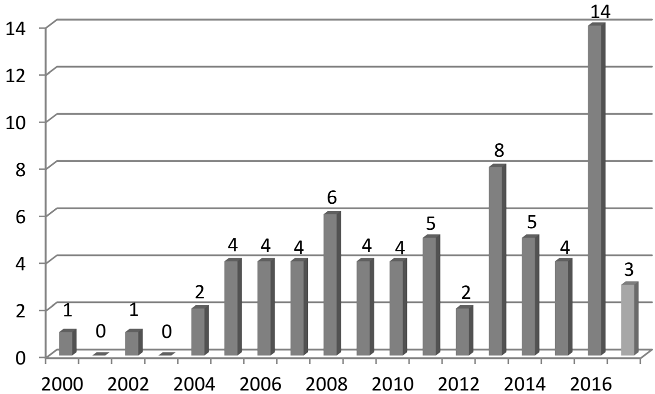

Figure 2: Publications per year 2000 – 2017 (preliminary)

3 Approach and Definition of Research Focus

In an extensive research in scientific databases, e.g. Google Scholar, ResearchGate, ScienceDirect, a broad basis for the literature review was extracted. The keywords used for the search were truck appointment system, gate congestion and drayage. The search was completed by checking the cited work for each paper and adding them to the list, if they met the mentioned focus of this study. 71 papers are considered relevant, published between 2000 and 2017. Because the necessity to reduce gate congestion occurred around 2000 for the first time, no prior papers are considered. Figure 2 shows the number of publications per year considered in this review. It demonstrates that the interest in this topic has increased constantly since 2000. The year with the most publication so far has been 2016. Since the challenge is still growing, an increasing number of publications can be expected.

Figure 3 shows how many publications apply their findings to existing ports on each continent. To illustrate the changes of focus over the time, two diagrams with different time spans, 2000 to 2008 and 2009 to 2017, are given.

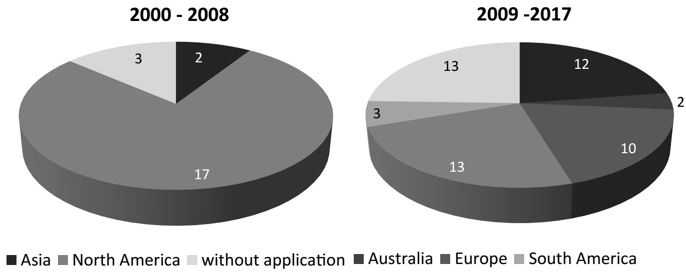

Figure 3: Publications' application focus per continent

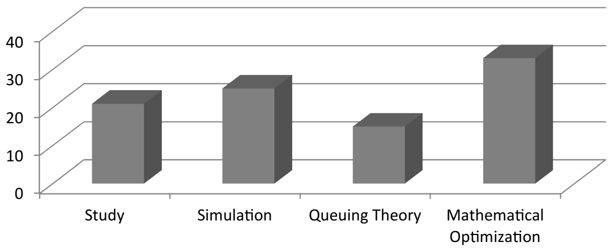

Figure 4: Used methods in relevant publications

It can be seen that the research started at first in North America. After around 8 years more publications focused on ports on other continents. The level of publications about Asian and European ports is similar. Still a very small number considers ports in developing or emerging countries. A growing number of publications is purely theoretical and doesn't include any applications on real live terminals. Figure 4 presents an overview of the applied methods in the publications. Studies and simulation models focus mainly on analyzing or improving existing terminals with or without TAS. Queueing theory models and mathematical optimization models either concentrate on working with existing terminals or develop a solution for a theoretical problem in this research field.

4 Classification Scheme for Approaches to Reduce Congestion of Drayage Trucks

The proposed classification scheme is illustrated in table 1. It consists of five main criteria which can be divided in total into 29 specifications. The specifications can either take the value 0 or 1, meaning no or yes. For every specification either a short description or some examples are given in table 1 to facilitate the understanding. The application of the 71 publications to the proposed classification scheme is presented in figure 5 at the end of this section.

As there are many different approaches how to reduce congestion for drayage trucks at logistic nodes and in the port street network, it is reasonable to first classify the publications by their aim. The aims of the examined publications can roughly be grouped by their focus: the whole transportation network (reduce system costs, reduce congestion in the port, reduce emissions in the port), the trucking companies (increase drayage productivity, reduce truck turn time) and the container terminals/logistic nodes (reduce queue/queueing time, increase node productivity). As these aims can be reached by many different ways, the second criterion in the classification scheme is the used mean to handle the challenge. The rough division applied for the aims is also applicable here: the whole transportation network (improve traffic control, improve cooperation in the port), the trucking companies (improve truck scheduling, improve route finding) and the logistics nodes (influence truck arrival, improve TAS, improve yard management). Some other means have been studied occasionally. These are collected in the specification other.

The third criterion is the recipient of the improvement. The recipient is the stakeholder, which benefits most of the proposed improvement. This can differ from the focus described above, because even if the aim or mean focus on one party, e.g. the whole transport network, another party can have a bigger benefit, e.g. the container terminal. Based on the observed 71 publications, the following specifications have been developed: trucking company, container terminal, both (trucking company and container terminal) and other. The fourth criterion is the method used in the publications. As mentioned above, four main methods have been identified: study, simulation, queueing theory and mathematical optimization. Queueing theory could also be counted in the area of mathematical optimization, but due to its importance in this research field it seemed reasonable to treat it separately.

The last criterion is the continent of the port, to which the approach of the publication was applied. Only the continents mentioned in the relevant publications have been considered further. Therefore, the specifications are Asia, Australia, Europe, North America and South America. As some publications don't apply their approach to an existing port, the specification no application was added.

In the following subsections a detailed overview of literature focusing on the different aims is given, along with the classification of the 71 analyzed publications between 2000 and 2017. If a publication focuses on more than one aim, it is presented in the subsection of the first aim mentioned.

4.1 Reduce System Costs

In this subsection six papers are presented, which focus on reducing the system costs. System costs are mainly understood as the combined costs of trucking companies and container terminals for one transport. Therefore, the recipients of the benefits in most papers are trucking companies as well as container terminals. Furthermore, most publications use several methods, mainly a study part, queueing theory and mathematical optimization combined. Only one of the studies uses simulation. The approaches developed in the papers are applied to North America in three cases, to Asia and South America each in one case and one paper has no application to an existing port.

Ascencio et al. (2014) develop a collaborative logistics framework for the transport chain in the port. With this framework the different stakeholders in the port and the port processes are integrated to improve their performance. Several papers analyze the impact of influencing truck arrivals on gate congestion. Guan and Liu (2009a,b) apply queueing theory to model the congestion of inbound trucks at container terminal gates to quantify waiting costs and to find possible ways to optimize the gate processes. Ioannou et al. (2006) present an algorithm to generate cooperative time windows and study their effects by using a container terminal simulation model. Chen, Govindan and Yang (2013) implement vessel dependent time windows for arriving trucks to flatten the peaks and thereby reducing truck congestion at the terminal gates. Kim and Kim (2002) present a cost model which is used to identify the optimal amount of storage space and transfer cranes for import containers considering the costs for space costs and costs for cranes and trucks.

Table 1: Proposed classification scheme for reducing port congestion

	Specification	Description/Example
Aim		
1	reduce system costs	overall cost of all stakeholders
2	reduce congestion in the port	on public streets
3	reduce emissions in the port	by trucks or handling equipment
4	increase drayage productivity	of trucking companies
5	reduce truck turn time	on the terminal or in the port
6	reduce queue/queuing time	at/on logistics nodes
7	increase node productivity	e.g. of container terminals
Means		
1	improve traffic control	port authority point of view
2	improve cooperation in the port	between different stakeholders
3	improve truck scheduling	e.g. job sequence, organization
4	improve route finding	use of algorithms
5	influence truck arrivals	e.g. opening hours, incentives
6	improve TAS	e.g. slot length, booking, rules
7	improve yard management	e.g. space allocation, equipment
8	other	e.g. decision support systems
Recipient		
1	trucking company	focus on trucking company
2	container terminal	focus on terminal operator
3	both	trucking company and terminal
4	other	e.g. freight stations, empty depots
Method		
1	study	e.g. interviews, regression analysis
2	simulation	e.g. agent based, discrete-event
3	queuing theory	e.g. non-stationary queuing models
4	mathematical optimization	e.g. genetic algorithm, tabu search
Application		
1	Asia	e.g. Hong Kong, Shenzhen, Tianjin
2	Australia	e.g. Sydney
3	Europe	e.g. Genoa, Marseille, Rotterdam
4	North America	e.g. Long Beach/LA, NY, Vancouver
5	South America	e.g. San Antonia, Santiago de Chile
6	no application	no reference to existing port

4.2 Reduce Congestion in the Port

The eight papers presented in this subsection concentrate exclusively on reducing the congestion in the port. Only half of the papers specifically consider congestion at terminal gates and none considers TAS. As a consequence, the main recipients of the benefits in these papers are the trucking companies. Two papers focus on other stakeholders and one on container terminals. Both trucking companies as well as container terminals are not considered. The methods used in the papers are studies or simulation. Five of the papers apply their work to Asian ports, two to North American and one has no application to an existing port.

Bentolila et al. (2016), Ozbay, Yanmaz-Tuzel and Holguin-Veras (2006), Regan and Golob (2000), Yang, Chen and Moodie (2010) and Zhang et al. (2012) study the effect of existing programs to reduce congestion in ports in different parts of the world. The ”Good Night” program in Israel, the Time-of-day Pricing Initiative in New York/New Jersey, the trucking industry in California and the situation in China are evaluated. Nabais et al. (2013), Rajamanickam and Ramadurai (2015) and Yu et al. (2014) use simulation to evaluate ways to reduce congestion in the port. Rajamanickam and Ramadurai (2015) aim to find the causes for congestion in a port city. Yu et al. (2014) present the interactive factors which have an impact on the land transportation in a port city. Nabais et al. (2013) analyze the effects of a multi-agent system to guarantee cooperation among terminals within a seaport.

4.3 Reduce Emissions

Four of the eight papers presented in this subsection focus on another aim besides reducing the emissions in ports. Influencing the truck arrivals and optimizing existing TAS are the most employed means. All but one paper focus at least partially on container terminals. One focusses only on trucking companies and two on both trucking companies as well as container terminals. The methods used are nearly evenly distributed. More than 50% of the papers apply their work to North American ports.

Morais and Lord (2006), Giuliano and O’Brien (2007; 2008) and Giuliano et al. (2008) focus on the congestion in the ports of Los Angeles and Long Beach. They analyze the first implemented TAS and its effects on congestion and emissions in the port. They point out that the right setting and implementation of a TAS is important for it to work properly. Chen, Govindan and Golias (2013) examine the relationship between influencing truck arrivals and reducing emissions at container terminals. The impact of an off-dock terminal with chassis exchange system to reduce loading and unloading times at marine container terminals is investigated by Dekker et al. (2013). Do et al. (2016) present a system with individual time slots per truck, which don't have to be booked in advance. Schulte, González and Voß (2015) analyze ways to reduce empty truck trips by implementing collaboration among truckers working in a port with a TAS.

4.4 Increase Drayage Productivity

Two thirds of the papers presented in this subsection concentrate exclusively on increasing the drayage productivity. The means used to reach this goal vary over nearly all possibilities. All of the papers focus on trucking companies. Only one paper also considers container terminals and another one other stakeholders. Mathematical optimization clearly dominates the used methods in these papers. In one third of the papers the results are not applied to existing terminals.

Harrison et al. (2007) and Monaco and Grobar (2004) study the characteristics of drayage operations in Houston and in Los Angeles/Long Beach and give recommendations for further improvement. Hill and Böse (2016) present a decision support system for improved resource planning and truck routing at logistic nodes. Huynh, Smith and Harder (2016), Chen and Yang (2010), Phan and Kim (2015) and Shiri and Huynh (2016) present solutions to influence the truck arrival times to avoid congestions and to improve existing TAS inter alia by introducing a negotiation system between terminal operator and trucking companies. Namboothiri (2006), Namboothiri and Erera (2008) and Wasesa, Stam and van Heck (2017) develop scheduling and routing solutions for drayage companies to improve their productivity. Caballini, Sacone and Saeednia (2016) examine a possible cooperation between trucking companies in a port and its impact.

4.5 Reduce Truck Turn Time

The focus of twelve of the eighteen papers in this subsection is exclusively on reducing the truck turn time. This is mainly done by controlling the arrival time of the trucks or by optimizing the TAS. Either trucking companies or container terminals benefit in these papers, but only once both of them and no other stakeholders are considered. The methods used are evenly distributed over all papers. A high percentage of the papers apply their results to North American ports.

Lam Park and Pruitt (2007) collect detailed data on truck arrival and waiting times at the port of Los Angeles/Long Beach and analyze their impact for the terminal. Azab and Eltawil (2016), Chen, Zhou and List (2011), Davies (2009; 2013), Huynh (2005) and Schepler et al. (2017) aim to reduce the truck turn time by influencing the truck arrivals patterns. Huynh (2009), Huynh and Walton (2008; 2011), Zhang, Zeng and Chen (2013) and Zouhaier and Ben Said (2016; 2017) improve existing TAS to help to reduce the truck turn time. Amongst other different booking strategies, slot capacities and penalties for late deliveries or know shows are analyzed. Jula et al. (2005) examine algorithms for improved scheduling and routing in the port. Huynh and Walton (2007) present a simulation model to analyze the required amount of yard cranes to reduce the waiting to an acceptable level. In Huynh and Hutson (2008) sources of delay for drayage transport are investigated and recommendations for future mitigation are given.

4.6 Reduce Queue / Queuing Time

Twelve of the sixteen papers presented in this subsection aim exclusively at reducing the queueing time of trucks. Many different means are used in these papers, but influencing the truck arrival times and improving existing TAS dominate this group. Improving the yard management and optimizing dispatching and routing of trucking companies are often studied as well. Many of the papers apply their results to North American and European ports or use no real live data. None of the papers consider other stakeholders besides trucking companies and container terminals and only four focus on both.

Davies and Kieran (2015) analyze congestion and drayage with a study and an additional simulation model. Goodchild and Mohan (2008), Phan and Kim (2016) and Sharif, Huynh and Vidal (2011) present solutions to influence truck arrival times. Ambrosino and Peirano (2016), Chen et al. (2013), Chen and Jiang (2016) and Gracia, González-Ramírez and Mar-Ortiz (2016) improve existing TAS to reduce the queue at the terminals gate or on the yard. Zehendner and Feillet (2014) also aim to improve the service quality of trains, barges and larger vessels. Chen and Yang (2014) and Huynh et al. (2011) develop methods to estimate the queue length in front of the gate and the caused delays either by a queuing theory model or by implementing camera technology at the gate. Huynh, Walton and Davis (2004) and Veloqui (2014) present ways to reduce the queuing time by improving the yard management at container terminals. This is mainly done by reducing the service time in the yard, e.g. by adding more handling equipment.

4.7 Increase Node Productivity

In this subsection fourteen papers are presented. Five of them focus on one other goal as well. The means analyzed in these papers are to either optimize the TAS or the yard management. All but one paper focus on container terminals and the main method used is mathematical optimization. Most papers are either applied to North American ports or have no application to an existing port at all.

Van Asperen, Borgman and Dekker (2013) and Zhao and Goodchild (2010a; 2010b) present solutions to increase the node productivity by influencing truck arrivals. On the one hand the truck arrival information are used to shorten the handling times and on the other hand the amount of reshuffles in the container block are minimized by intelligent stacking orders. Furthermore, possibilities to coordinate terminal and truck drayage operations through sharing information, e.g. TAS or GPS on trucks, are investigated. Li, Chen, Govindan and Jin (2016) and Zhao and Goodchild (2013) improve the terminal performance by analyzing the impact of different TAS characteristics and evaluating disturbances in truck arrivals. Ku and Arthanari (2016) and Le-Griffin, Mai and Griffin (2011) analyze the impact of an improved yard management on the node productivity. They evaluate the impact of improved stacking algorithms and optimized route finding of terminal trucks based on known truck arrival times. Murty et al. (2005a) and Murty et al. (2005b) develop a decision support system for improving the terminal productivity. A part of this decision support system is the yard management as well as the truck arrival control.

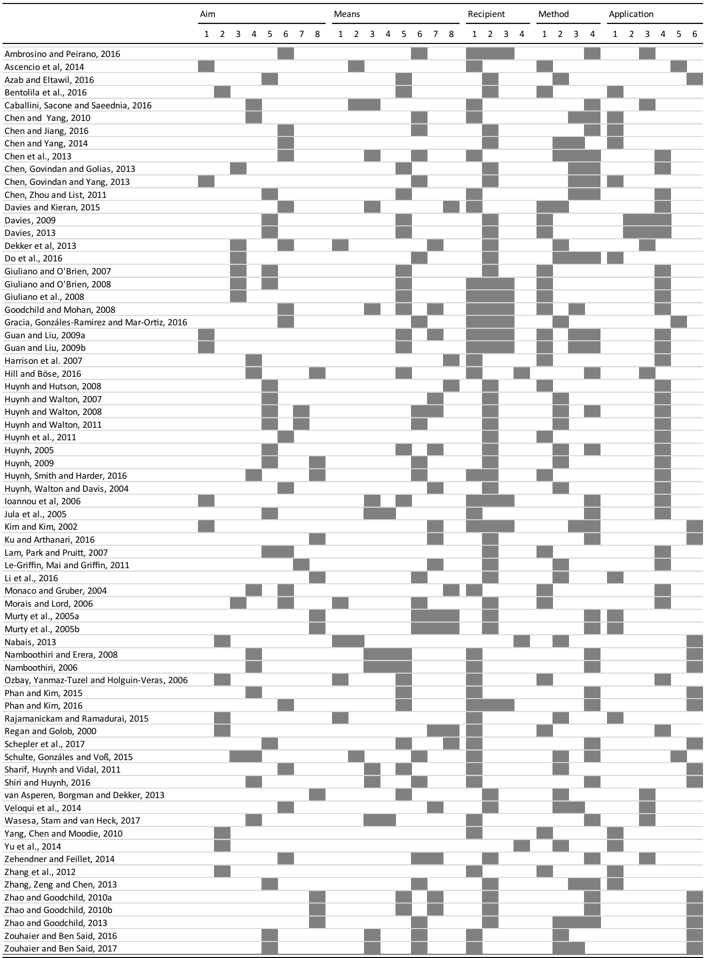

Figure 5: Classification of relevant publications

5 Present and future research areas and conclusions

Based on the information gathered in the previous sections, the characteristics of the present research are derived. Furthermore, gaps in this state of research are identified and promising future research areas are pointed out.

Reducing congestion in ports is a very diverse research field. Various approaches are analyzed with several different aims, which have only been combined in some few later papers. In future it is important to strengthen the interfaces between these approaches and to use the results from existing research.

Main focus points of relevant papers are container terminals. Less frequent, but still extensively studied are trucking companies. Other stakeholders are examined rarely. Furthermore, most of the time just one stakeholder is considered. Exceptions are some papers where trucking companies are studied as well as container terminals. This is not sufficient to completely analyze the impacts of methods to reduce congestion, especially TAS, on the port network and on drayage. This is pointed out in the conclusions of many papers but never executed. In future research it is important to close this gap to get realistic results.

Furthermore, most of the time an author focusses on the same port in all papers, probably because of existing data. Due to that only some ports have been analyzed so far. Some of the world's biggest ports haven't been considered and ports in developing or emerging countries have nearly not been studied at all. These ports might present challenges to existing research solutions due to different organizational structures, technology levels and objectives. Therefore it is important to expand the research focus on these ports.

Many authors point out that it is hard to get sufficient data for their explorations. Existing data is mainly generated by cooperation with terminal operators or interviews with trucking companies. Complete data about all operations in a port is challenging to get. Still, in future a more extensive data basis is recommended to produce more conclusive results. Due to the ongoing digitalization in the logistics sectors in general and especially in ports, it seems reasonable to assume, that more complete data sets will soon be available.

In the beginning, there were many different designs of TAS. But over time and due to many assessments, all proposed TAS share some criteria, e.g. their obligatory nature, the length of time windows and the use of penalties for trucking companies as well as for container terminals. It is necessary to use these findings in future research but also to not to be limited to this design. Some promising papers show promising out of the box thinking, e.g. the implementation of dry docks or a more extensive supply chain collaboration, which will help this research area to develop further.

In this paper methods for reducing the congestion in ports and at container terminals, especially for drayage trucks, are discussed and the current research and future trends are presented.

The current situation of truck transportation in the ports and the specifics of drayage are described. Due to the fact that severe challenges are arising for this sector, the implementation of new operational practices is important. These are presented combined with an overview about recent research solution in this area. To have a basis to analyze promising future research fields a classification scheme for approaches to reduce truck congestion is developed. Its criteria are the aim of the paper, the mean to achieve this aim, the recipient of the improvement, the used method and the continent of port, to which the results are applied to. This classification scheme is applied to 71 relevant publications and their characteristics are presented in detail.

In conclusion, the research done in this field, even though it is extensive, only covers some parts of the overall topic. Interfaces between different aims, means or focus points are limited. Furthermore, the research is only applied to some specific use cases. In future it is important to strengthen these interfaces and connect the separate research foci.

References

Ambrosino, D. and L. Peirano (2016). “Truck Arrival Management at Maritime Container Terminals”. In: *30th European Conference on Modelling and Simulation (ECMS 2016)*. Ed. by T. Claus, F. Herrmann, M. Manitz, and O. Rose. Red Hook, NY: Curran Associates, Inc.

Ascencio, L. M., R. G. González-Ramírez, L. A. Bearzotti, N. R. Smith, and J. F. Camacho-Vallejo (2014). “A Collaborative Supply Chain Management System for a Maritime Port Logistics Chain”. In: *Journal of Applied Research and Technology* 12.3, pp. 444–458.

Azab, A. E. and A. B. Eltawil (2016). “A Simulation Based Study Of The Effect Of Truck Arrival Patterns On Truck Turn Time In Container Terminals”. In: *30th Conference on Modelling and Simulation*, pp. 80–86.

Bentolila, D. J., R. K. Ziedenveber, Y. Hayuth, and T. Notteboom (2016). “Off-peak truck deliveries at container terminals: the ?Good Night? program in Israel”. In: *Maritime Business Review* 1.1, pp. 2–20.

Caballini, C., S. Sacone, and M. Saeednia (2016). "Cooperation among truck carriers in seaport containerized transportation". In: *Transportation Research Part E: Logistics and Transportation Review* 93, pp. 38–56.

Carlo, H. J., I. F. A. Vis, and K. J. Roodbergen (2014a). "Storage yard operations in container terminals: Literature overview, trends, and research directions". In: *European Journal of Operational Research* 235.2, pp. 412–430.

Carlo, H. J., I. F. A. Vis, and K. J. Roodbergen (2014b). "Transport operations in container terminals: Literature overview, trends, research directions and classification scheme". In: *European Journal of Operational Research* 236.1, pp. 1–13.

Chen, G., K. Govindan, and M. M. Golias (2013). "Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern". In: *Transportation Research Part E: Logistics and Transportation Review* 55, pp. 3–22.

Chen, G., K. Govindan, and Z. Yang (2013). "Managing truck arrivals with time windows to alleviate gate congestion at container terminals". In: *International Journal of Production Economics* 141.1, pp. 179–188.

Chen, G., K. Govindan, Z.-Z. Yang, T.-M. Choi, and L. Jiang (2013). "Terminal appointment system design by non-stationary M(t)/Ek/c(t) queueing model and genetic algorithm". In: *International Journal of Production Economics* 146.2, pp. 694–703.

Chen, G. and L. Jiang (2016). "Managing customer arrivals with time windows: a case of truck arrivals at a congested container terminal". In: *Annals of Operations Research*.

Chen, G. and Z.-Z. Yang (2014). "Methods for estimating vehicle queues at a marine terminal: A computational comparison". In: *International Journal of Applied Mathematics and Computer Science* 24.3.

Chen, G. and Z. Yang (2010). "Optimizing time windows for managing export container arrivals at Chinese container terminals". In: *Maritime Economics & Logistics* 12.1, pp. 111–126.

Chen, X., X. Zhou, and G. F. List (2011). "Using time-varying tolls to optimize truck arrivals at ports". In: *Transportation Research Part E: Logistics and Transportation Review* 47.6, pp. 965–982.

Davies, P. (2009). *Container Terminal Reservation Systems: Paper presented at the 3rd Annual METRANS National Urban Freight Conference*. Long Beach, USA.

Davies, P. (2013). *Container Terminal Reservation Systems Design and Performance: Paper presented at the METRANS International Urban Freight Conference*. Long Beach, USA.

Davies, P. and M. E. Kieran (2015). *Port Congestion and Drayage Efficiency: Paper presented at the METRANS International Urban Freight Conference*. Long Beach, USA.

Dekker, R., S. van der Heide, E. van Asperen, and P. Ypsilantis (2013). "A chassis exchange terminal to reduce truck congestion at container terminals". In: *Flexible Services and Manufacturing Journal* 25.4, pp. 528–542.

Do, N. A. D., I. E. Nielsen, G. Chen, and P. Nielsen (2016). "A simulation-based genetic algorithm approach for reducing emissions from import container pick-up operation at container terminal". In: *Annals of Operations Research* 242.2, pp. 285–301.

Giuliano, G., S. Hayden, P. Dell'aquila, and T. O'Brien (2008). *Evaluation of the Terminal Gate Appointment System at the Los Angeles/Long Beach Ports: Final report METRANS Project 04-06*.

Giuliano, G. and T. O'Brien (2007). "Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach". In: *Transportation Research Part D: Transport and Environment* 12.7, pp. 460–473.

Giuliano, G. and T. O'Brien (2008). *Responding to Increasing Port-related Freight Volumes: Lessons from Los Angeles / Long Beach and Other US Ports and Hinterlands*. Vol. no. 2008/12. OECD/ITF Joint Transport Research Centre Discussion Papers. Paris: OECD Publishing.

Goodchild, A. and K. Mohan (2008). "The Clean Trucks Program: Evaluation of Policy Impacts on Marine Terminal Operations". In: *Maritime Economics & Logistics* 10.4, pp. 393–408.

Gracia, M. D., R. G. González-Ramírez, and J. Mar-Ortiz (2016). "The impact of lanes segmentation and booking levels on a container terminal gate congestion". In: *Flexible Services and Manufacturing Journal* 244.3, p. 675.

Le-Griffin, H. D., L. Mai, and M. Griffin (2011). "Impact of container chassis management practices in the United States on terminal operational efficiency: An operations and mitigation policy analysis". In: *Research in Transportation Economics* 32.1, pp. 90–99.

Guan, C. and R. Liu (2009a). "Modeling Gate Congestion of Marine Container Terminals, Truck Waiting Cost, and Optimization". In: *Transportation Research Record: Journal of the Transportation Research Board* 2100, pp. 58–67.

Guan, C. and R. Liu (2009b). "Container terminal gate appointment system optimization". In: *Maritime Economics & Logistics* 11.4, pp. 378–398.

Harrison, R., N. Hutson, J. West, and J. Wilke (2007). "Characteristics of Drayage Operations at the Port of Houston, Texas". In: *Transportation Research Record: Journal of the Transportation Research Board* 2033, pp. 31–37.

Hartmann, S. (2004). "Generating scenarios for simulation and optimization of container terminal logistics". In: *OR Spectrum* 26.2, pp. 171–192.

Hill, A. and J. W. Böse (2016). "A decision support system for improved resource planning and truck routing at logistic nodes". In: *Information Technology and Management* 22.2–3, p. 109.

Huynh, N. (2005). "Methodologies for Reducing Truck Turn Time at Marine Container Terminals". Dissertationsschrift. Austin, USA: The University of Texas.

Huynh, N. (2009). "Reducing Truck Turn Times at Marine Terminals with Appointment Scheduling". In: *Transportation Research Record: Journal of the Transportation Research Board* 2100, pp. 47–57.

Huynh, N., F. Harder, D. Smith, O. Sharif, and Q. Pham (2011). "Truck Delays at Seaports". In: *Transportation Research Record: Journal of the Transportation Research Board* 2222, pp. 54–62.

Huynh, N. and N. Hutson (2008). "Mining the Sources of Delay for Dray Trucks at Container Terminals". In: *Transportation Research Record: Journal of the Transportation Research Board* 2066, pp. 41–49.

Huynh, N., D. Smith, and F. Harder (2016). "Truck Appointment Systems". In: *Transportation Research Record: Journal of the Transportation Research Board* 2548, pp. 1–9.

Huynh, N. and C. M. Walton (2007). "Evaluating truck turn time in grounded operations using simulation". In: *World Review of Intermodal Transportation Research* 1.4, p. 357.

Huynh, N. and C. M. Walton (2008). "Robust Scheduling of Truck Arrivals at Marine Container Terminals". In: *Journal of Transportation Engineering* 134.8, pp. 347–353.

Huynh, N. and C. M. Walton (2011). "Improving Efficiency of Drayage Operations at Seaport Container Terminals Through the Use of an Appointment System". In: *Handbook of Terminal Planning*. Ed. by J. W. Böse. Vol. 49. Operations Research/Computer Science Interfaces Series. New York, NY: Springer New York, pp. 323–344.

Huynh, N., C. Walton, and J. Davis (2004). "Finding the Number of Yard Cranes Needed to Achieve Desired Truck Turn Time at Marine Container Terminals". In: *Transportation Research Record: Journal of the Transportation Research Board* 1873, pp. 99–108.

Ioannou, P., A. Chassiakos, H. Jula, and G. Valencia (2006). *Cooperative Time Window Generation for Cargo Delivery/Pick up with Application to Container Terminals: Final Report METRANS Project 03-18*. Ed. by Metrans Transportation Center.

Jula, H., M. Dessouky, P. Ioannou, and A. Chassiakos (2005). “Container movement by trucks in metropolitan networks: Modeling and optimization”. In: *Transportation Research Part E: Logistics and Transportation Review* 41.3, pp. 235–259.

Kim, K. H. and H. B. Kim (2002). “The optimal sizing of the storage space and handling facilities for import containers”. In: *Transportation Research Part B: Methodological* 36.9, pp. 821–835.

Ku, D. and T. S. Arthanari (2016). “Container relocation problem with time windows for container departure”. In: *European Journal of Operational Research* 252.3, pp. 1031–1039.

Lam, S. F., J. Park, and C. Pruitt (2007). *An accurate monitoring of truck waiting and flow times at a terminal in the Los Angeles/Long Beach ports*. [Los Angeles, Calif.]: [METRANS].

Li, N., G. Chen, K. Govindan, and Z. Jin (2016). “Disruption management for truck appointment system at a container terminal: A green initiative”. In: *Transportation Research Part D: Transport and Environment*.

Monaco, K. and L. Grobar (2004). *A Study of Drayage at the Ports of Los Angeles and Long Beach*. Ed. by Metrans Transportation Center.

Morais, P. and E. Lord (2006). *Terminal Appointment System Study*.

Murty, K. G., J. Liu, Y.-w. Wan, and R. Linn (2005). “A decision support system for operations in a container terminal”. In: *Decision Support Systems* 39.3, pp. 309–332.

Murty, K. G., Y.-w. Wan, J. Liu, M. M. Tseng, E. Leung, K.-K. Lai, and H. W. C. Chiu (2005). “Hongkong International Terminals Gains Elastic Capacity Using a Data-Intensive Decision-Support System”. In: *Interfaces* 35.1, pp. 61–75.

Nabais, J. L., R. R. Negenborn, Carmona Benítez, Rafael B., and M. Ayala Botto (2013). “Setting Cooperative Relations Among Terminals at Seaports Using a Multi-Agent System”. In: *16th International IEEE Conference on Intelligent Transportation Systems (ITSC), 2013*. Piscataway, NJ: IEEE, pp. 1731–1736.

Namboothiri, R. (2006). “Planning Container Drayage Operations at Congested Seaports”. Dissertationsschrift. Atlanta, USA: Georgia Institute of Technology.

Namboothiri, R. and A. L. Erera (2008). “Planning local container drayage operations given a port access appointment system”. In: *Transportation Research Part E: Logistics and Transportation Review* 44.2, pp. 185–202.

Ozbay, K., O. Yanmaz-Tuzel, and J. Holguin-Veras (2006). “The Impact of Time-of-day Pricing Initiative of NY/NJ Port Authority Facilities Car and Truck Movements”. In: *Transportation Research Board’s 85th Annual Meeting*.

Phan, M.-H. and K. H. Kim (2015). “Negotiating truck arrival times among trucking companies and a container terminal”. In: *Transportation Research Part E: Logistics and Transportation Review* 75, pp. 132–144.

Rajamanickam, G. D. and G. Ramadurai (n.d.). “Simulation of truck congestion in Chennai port”. In: *2015 Winter Simulation Conference (WSC)*, pp. 1904–1915.

Rashidi, H. and E. P. K. Tsang (2013). “Novel constraints satisfaction models for optimization problems in container terminals”. In: *Applied Mathematical Modelling* 37.6, pp. 3601–3634.

Regan, A. C. and T. F. Golob (2000). “Trucking industry perceptions of congestion problems and potential solutions in maritime intermodal operations in California”. In: *Transportation Research Part A: Policy and Practice* 34.8, pp. 587–605.

Schepler, X., S. Balev, S. Michel, and ? Sanlaville (2017). “Global planning in a multi-terminal and multi-modal maritime container port”. In: *Transportation Research Part E: Logistics and Transportation Review* 100, pp. 38–62.

Schulte, F., R. G. González, and S. Voß (2015). “Reducing Port-Related Truck Emissions: Coordinated Truck Appointments to Reduce Empty Truck Trips”. In: *Computational Logistics*. Ed. by F. Corman, S. Voß, and R. R. Negenborn. Vol. 9335. Lecture Notes in Computer Science. Cham: Springer International Publishing, pp. 495–509.

Sharif, O., N. Huynh, and J. M. Vidal (2011). “Application of El Farol model for managing marine terminal gate congestion”. In: *Research in Transportation Economics* 32.1, pp. 81–89.

Shiri, S. and N. Huynh (2016). “Optimization of drayage operations with time-window constraints”. In: *International Journal of Production Economics* 176, pp. 7–20.

Stahlbock, R. and S. Voß (2007). “Operations research at container terminals: a literature update”. In: *OR Spectrum* 30.1, pp. 1–52.

UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (2017). *REVIEW OF MARITIME TRANSPORT 2016*. [S.l.]: UNITED NATIONS.

van Asperen, E., B. Borgman, and R. Dekker (2013). “Evaluating impact of truck announcements on container stacking efficiency”. In: *Flexible Services and Manufacturing Journal* 25.4, pp. 543–556.

Veloqui, M., I. Turias, M. M. Cerbán, M. J. González, G. Buiza, and J. Beltrán (2014). “Simulating the Landside Congestion in a Container Terminal. The Experience of the Port of Naples (Italy)”. In: *Procedia - Social and Behavioral Sciences* 160, pp. 615–624.

Vis, I. F. A. and R. de Koster (2003). “Transshipment of containers at a container terminal: An overview”. In: *European Journal of Operational Research* 147.1, pp. 1–16.

Wasesa, M., A. Stam, and E. van Heck (2017). “The seaport service rate prediction system: Using drayage truck trajectory data to predict seaport service rates”. In: *Decision Support Systems* 95, pp. 37–48.

Yang, Z., G. Chen, and D. R. Moodie (2010). “Modeling Road Traffic Demand of Container Consolidation in a Chinese Port Terminal”. In: *Journal of Transportation Engineering* 136.10, pp. 881–886.

Yu, B., C. Zhang, L. Kong, H.-L. Bao, W.-S. Wang, S. Ke, and G. Ning (2014). “System dynamics modeling for the land transportation system in a port city”. In: *Simulation: Transactions of the Society for Modeling and Simulation International* 90(6), pp. 706–716.

Zehendner, E. and D. Feillet (2014). “Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal”. In: *European Journal of Operational Research* 235.2, pp. 461–469.

Zhang, J., P. Xiao, X. Zhang, and H. Lin (2012). “A Study on the Relations between Port Container Throughput and Truck Trips in Different Logistics Modes”. In: *The Twelfth COTA International Conference of Transportation Professionals*, pp. 412–421.

Zhang, X., Q. Zeng, and W. Chen (2013). “Optimization Model for Truck Appointment in Container Terminals”. In: *Procedia - Social and Behavioral Sciences* 96, pp. 1938–1947.

Zhao, W. and A. Goodchild (2010). “Impact of Truck Arrival Information on System Efficiency at Container Terminals”. In: *Transportation Research Record: Journal of the Transportation Research Board* 2162, pp. 17–24.

Zhao, W. and A. V. Goodchild (2010). “The impact of truck arrival information on container terminal rehandling”. In: *Transportation Research Part E: Logistics and Transportation Review* 46.3, pp. 327–343.

Zhao, W. and A. V. Goodchild (2013). “Using the truck appointment system to improve yard efficiency in container terminals”. In: *Maritime Economics & Logistics* 15.1, pp. 101–119.

Zouhaier, H. and L. Ben Said (n.d.). “An Application Oriented Multi-Agent Based Approach to Dynamic Truck Scheduling at Cross-Dock”. In: *2016 17th International Conference on Parallel and Distributed Computing, Applications and Technologies (PDCAT)*, pp. 233–239.

Zouhaier, H. and L. B. Said (n.d.). “Robust scheduling of truck arrivals at a cross-docking platform”. In: *the Australasian Computer Science Week Multiconference*, pp. 1–9.

Comparative Analysis of Synchromodality in Major European Seaports

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Global container throughput recorded a substantial growth over the past 25 years. The ports of Rotterdam, Hamburg and Antwerp have benefited greatly from this development. At the same time rapid increases can be observed for the dimensions of container vessels calling these ports. In 2005 the average capacity of container vessels in operation between Northern Europe and Far East amounted to 6,000 TEU. Today market actors already talk about container vessels with a capacity of 24,000 TEU. (ITF, 2015) This development provides a challenge for seaports concerning the water-side and landside accessibility. According to UVHH (2014) a rising amount of Ultra Large Container Vessels in the Port of Hamburg bears the risk of an increasing number of peaks and bottlenecks within the container terminals. These fluctuations will be continued at the interface to hinterland transport modes and to the connections to hinterland regions. By intelligently combining and switching between different transport modes the concept of synchromodality could form a solution for improving hinterland transportation and reducing bottlenecks in the seaports. (Tavasszy et al., 2015) This paper analyses the degree of implementation of synchromodality in major European container ports with special focus on the Port of Hamburg.

Keywords: Synchromodality; Maritime logistics; Hinterland transport chains; Collaborative networks

1 Introduction

Global container throughput recorded a substantial growth over the past 25 years. The ports of Rotterdam, Hamburg and Antwerp have benefited greatly from this development. The Port of Hamburg's container throughput e.g. increased by more than 451 % from just under 1.98 million Twenty-foot Equivalent Unit (TEU) in 1990 to almost 8.93 million TEU in 2016. (Statistisches Amt für Hamburg und Schleswig-Holstein, 2017) At the same time the Port of Antwerp recorded an increase in handled container volumes of almost 648 % from 1.55 million TEU in 1990 to about 10.04 million TEU in 2016. During the same period of time the Port of Rotterdam's container volumes increased by more than 338% from 3.67 million TEU to 12.39 million TEU. (Statistisches Amt für Hamburg und Schleswig-Holstein, 2017)

Similar rapid increases can be observed for the dimensions of container vessels calling these ports. In 2005 the average capacity of container vessels in operation between Northern Europe and Far East amounted to 6,000 TEU. The average capacity increased to 10,000 TEU in 2013 and is still increasing. (ITF, 2015) According to ITF (2015) shipping lines have ordered vessels with even larger nominal capacities. Already today market actors talk about container vessels with a capacity of 24,000 TEU and above. Ocean Shipping Consultants and Lloyds Register already conducted a feasibility study on such container vessels. (ITF, 2015)

The described development of the world container vessel fleet provides a challenge for seaports. On the one hand this concerns the nautical accessibility as well as the dimensions of berths. On the other hand increasing vessel dimensions and capacities are challenging container terminals and the connections to the hinterland. According to UVHH (2014) a rising amount of Ultra Large Container Vessels (ULCV) in the Port of Hamburg bears the risk of an increasing number of peaks and bottlenecks. These fluctuations will be continued at the interface to hinterland transport modes and to the connections to hinterland regions. Port and infrastructure extensions could form a solution to this. However, due to scarce space reserves an expansion of infrastructure and terminal capacities can hardly be realized in the large European seaports. Hence, Notteboom and Rodrigue (2005) refer to growing interdependencies between the seaports and terminals in the hinterland. A collaboration of seaports and inland terminals could help to overcome peaks and bottlenecks. (Notteboom and Rodrigue, 2005) The concept is further developed to an Extended Gateway Concept by Veenstra et al. (2012). Synchromodality bases upon the Extended Gateway Concept and thus, could form a solution smoothing the peaks and reducing the bottlenecks resulting from continuously growing container vessel sizes.

In this paper the degree of implementation of synchromodality in major European container ports is analyzed. For this an extensive literature review has been carried out in 2016 in order to define synchromodality in a first step. Afterwards the general definition of synchromodality is transferred to the maritime transport chain. In a third step the degree of implementation of synchromodality in major European container ports is analyzed with special focus on prerequisites of synchromodality in maritime transport chains. Finally, conclusions are drawn summarizing the results and evaluating the chances and state of synchromodality in the Port of Hamburg.

2 Synchromodality – The next generation of multimodal transportation

Generally spoken, synchromodality is a relatively young term that is not officially defined so far. The concept is part of the long-term vision of the Physical Internet until 2050 (alice, 2015). First usages can be found in the grey literature in 2010 e.g. the publication of a project report by the Dutch research institute TNO on behalf of the Dutch Ministry of Infrastructure and Environment. (Tavasszy et al., 2010) According to Tavasszy et al. (2010) synchromodality means an integrated transport solution (for a larger group of companies) where the optimal transport mode and available capacity is used at all times. One or more coordinators of complete transport chains or transport chain sections are monitoring the synchromodal transport chain. The mode choice decision is continuously checked. It will be then dynamically adjusted if there is a new ‘best transport mode’.

Since the first use of the term synchromodality in the grey literature different definitions arose. (van der Burgh, 2012) Although the term synchromodality is gaining popularity in academic publications, no final and consistent definition exists so far. (Pleszko, 2012; van der Burgh, 2012;van Riessen, 2013; Reis, 2015; Tavasszy et al., 2015) In order to define synchromodality, in a way that integrates all aspects of synchromodality discussed in the grey and scientific literature, a total of 23 publications have been analyzed. (Tavasszy et al., 2010; ECT, 2011; Tavasszy et al., 2011; van Stijn et al., 2011; van Wijk et al., 2011; Verweij, 2011; Douma et al., 2012; Pleszko, 2012; van der Burgh, 2012; Li et al., 2013; van Riessen et al., 2013a; van Riessen, 2013; van Riessen et al., 2013b; Roth, 2013; Behdani et al., 2014; DHL, 2014; Knol et al., 2014; SteadieSeifi et al., 2014; alice, 2015; Putz et al., 2015; Reis, 2015; Tavasszy et al., 2015; TKI DINALOG, no date)

In this paper synchromodality is defined by the authors in high conformity with Putz et al. (2015) as follows: 'Synchromodality is at the actual time of performance the most efficient and most appropriate transport solution in terms of transport costs, duration as well as sustainability. Within the concept of synchromodality the configuration of the transport chain is not pre-defined before the transport starts but flexible. Thus, the configuration of the transport chain (mode choice) can be adapted according to the infrastructural and capacitive conditions at the actual time of transportation. This is made possible through a collaboration of all transport modes, the required terminal facilities as well as other actors involved that exchange real-time information on capacities and schedules. Thereby the collaboration is under the governing of a central institution that monitors the interactions between the different actors as well as provides the necessary information technology infrastructure.'

The majority of the analyzed publications consider synchromodality as the latest stage of development of still developing modality concepts. (Tavasszy et al., 2011; Verweij, 2011; Pleszko, 2012; Behdani et al., 2014; Putz et al., 2015; Tavasszy et al., 2015) The differences between the different concepts are partly just marginal. (SteadieSeifi et al., 2014; Reis, 2015) As an example, according to SteadieSeifi et al. (2014) the concept of multimodality includes all other modality concepts. Thus, the authors only use the term multimodality in their research paper. Reis (2015) also mention the co-existing and overlapping definitions for the different modality concepts. For a greater clarity Reis (2015) carried out an extensive literature analysis in order to be able to clearly define and differentiate the terms multimodality, intermodality, combined transport, co-modality and synchromodality. It is not explicitly stated whether co-modality and synchromodality require the use of at least two different transport modes. Pleszko (2012) also mentions co-existing definitions and defines synchromodality as a "multimodal transport policy at a higher level of process organization […], based on combinations of co-modal transport with proper scale of individualized solutions". In this definition co-modality allows the use of one transport mode only if this is the most efficient solution.

According to Tavasszy et al. (2015) and Behdani et al. (2014) synchromodality can be differentiated from the other modality concepts due to a higher degree of process organization. Following the authors' argumentation synchromodality is characterized by a dual integration that is no attribute of the other modality

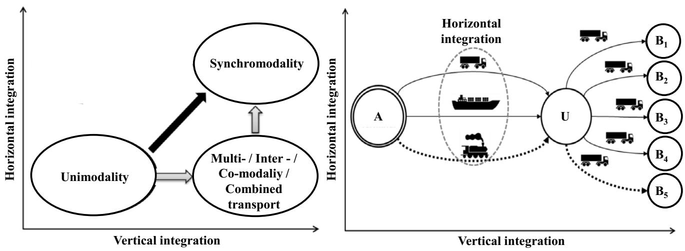

Figure 1: Dual integration as distinction criteria of synchromodal transport (authors based on Behdani et al. 2014)

concepts. This is illustrated in figure 1. According to Tavasszy et al. (2015) and Behdani et al. (2014) the vertical and at the same time horizontal integration of different transport modes leads to a coherent transport product with an improved service level for the shipper and a better use of resources concerning the different transport modes and transport sections. Tavasszy et al. (2015) describe synchromodality or synchromodal intermodality as a vision of a network of synchronized and connected transport modes that collaboratively meet the aggregated transport demand and align to the individual and current needs of the users of the transport network. As shown in figure 1 and in accordance with Tavasszy et al. (2015) and Behdani et al. (2014) this includes transport chains where the truck can be used between origin A and terminal U as well as between terminal U and destinations B1 to B5. Following this definition synchromodality does not necessitate the use of different transport modes.

In the analyzed research papers there is also no consistency concerning the scope of the definitions for synchromodality. The definitions in the analyzed research papers and publications can be divided into four groups as shown in table 1.

The chosen scope of synchromodality defines which actors are identified as relevant and which roles are assigned to these actors. This becomes clear by e.g. comparing the definitions describing synchromodality as relevant for sections of a transport chain within a clearly defined area with definitions that describe synchromodality as relevant mostly for the pre- and post-haulage of maritime transports. In the first case operators of sea terminals do not have a significant role. In the second case operators of sea terminals are key actors of synchromodal transport chains (terminal operator's haulage). (Tavasszy et al., 2015)

Table 1: Classification of definitions for synchromodality

Scope	References
Definitions that do not mention the scope of synchromodality within the transport chain.	Tavasszy et al., 2010; SteadieSeifi et al., 2014; Reis, 2015; TKI DINALOG, no date
Definitions that describe synchromodality as relevant for all sections of a transport chain between shipper A and consignee B.	ECT, 2011; Verweij, 2011; Douma et al., 2012; Li et al., 2013; Roth, 2013; DHL, 2014;
Definitions that describe synchromodality as relevant for sections of a transport chain within a clearly defined area.	van der Burgh, 2012;alice,2015
Definitions that describe synchromodality as relevant mostly for the pre- and post-haulage of maritime transports.	Tavasszy et al., 2011; Pleszko, 2012; van Riessen, 2013; van Riessen et al., 2013a, 2013b; Behdani et al., 2014; Knol et al., 2014; Putz et al., 2015; Tavasszy et al., 2015;

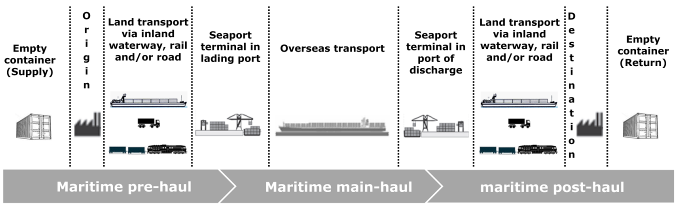

Figure 2: Sections of a maritime transport chain (authors based on Schönknecht 2009, Grig 2012 and Walter 2015)

3 The vision of the synchromodal seaport hinterland transport chain

In order to describe the vision of the synchromodal seaport hinterland transport chain the maritime transport chain is described in a first step. A transport chain can be described as a sequence of different processes and relationships of a loading unit with resources necessary for carrying out the transport. (Schönknecht, 2009) Transport chains that include waterborne transport can be summarized as maritime transport chains. The general structure of a maritime transport chain is illustrated in figure 2.

As can be taken from figure 2 the maritime transport chain consists of a maritime pre-haul (supply of empty container, loading of container as well as land transport), a maritime main-haul (handling of container at seaports and overseas transport) and a maritime post-haul (land transport, unloading of container and return of empty container). (Schönknecht, 2009; Grig, 2012; Walter, 2015)

The targets of synchromodality depend on the considered scope (within the fields of logistics). The targets of synchromodality as a concept for maritime transport chains are derived from the targets of synchromodality in general as described by ECT (2011), van Wijk et al. (2011), Verweij (2011), Douma et al. (2012), Pleszko (2012), van der Burgh (2012), Li et al. (2013), van Riessen (2013), van Riessen et al. (2013a), van Riessen et al. (2013b), Behdani et al. (2014), SteadieSeifi et al. (2014), Putz et al. (2015), Reis (2015) and Tavasszy et al. (2015). In order to make hinterland transportation more efficient the realization of synchromodality aims at achieving the following targets:

— Reduction of the total costs for transport, handling, storage, capital commitmentand charges

— Reduction of other logistics costs than transport, handling, storage, capital commitment and charges by

 … an increased resilience within the maritime pre- and post-haul;

 … an increased reliability of the maritime pre- and post-haul;

 … an increased flexibility within the maritime pre- and post-haul;

 … an increased responsiveness within the maritime pre- and post-haul;

... an improved service quality across the whole maritime transport chain;

— Increase of sustainability across the whole maritime transport chain and

— Coping the growth in transport volumes by an improved use of infrastructure

Van Riessen (2013), van Riessen et al. (2013a), van Riessen et al. (2013b) and Tavasszy et al. (2015) explicitly state that the reduction of transport and handling costs is a target of synchromodality. According to them the flexible combination of different transport modes within a clearly defined network leads to time and cost advantages. This is illustrated in figure 3.

The hexagons represent the price and duration of transport modes in unimodal transport chains. The squares T1 to T4 symbolize intermodal transport chains via the terminals 1 to 4 that are either cheaper or faster than unimodal transports. The circles T5 to T7 mean intermodal transport chains via the terminals 5 to 7 that are neither less expensive nor faster than the unimodal transport solutions. Following the argumentation of van Riessen (2013), van Riessen et al. (2013a), van Riessen et al. (2013b) and Tavasszy et al. (2015) the flexible combination of different intermodal transport chains within a synchromodal network leads to a variety of synchromodal solutions that are faster and less expensive than unimodal transport chains and that complement existing intermodal transport chains. The line represents the mentioned complementation of existing intermodal transport chains. The hatched area corresponds to the added value of synchromodal transport services compared to unimodal transport solutions.

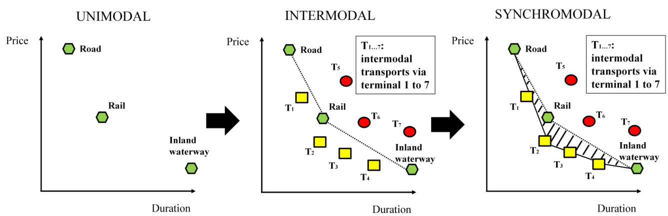

Figure 3: Temporary and/or price advantage of synchromodal networks (authors based on Tavasszy et al. 2015)

However, several aspects of maritime logistics counteract the concept of synchromodality. Examples for this are contractual regulations concerning e.g. quotas for individual transport modes. Each of the existing organization forms (e.g. merchant's haulage, carrier's haulage or terminal haulage) has its own special focus on the costs and organization of hinterland transportation. These restricted scopes – expressed within the existing tariff structures – lead to a limitation of flexibility required for synchromodal transport flows.

4 Degree of implementation of synchromodality in major European container ports

In order to achieve the objectives of synchromodality in maritime transport chains certain prerequisites need to be fulfilled. These are derived from the different definitions for synchromodality and are as diverse as these. Putz et al. (2015) classify the prerequisites for synchromodality into seven categories. As shown in table 2 these categories can be summarized to four main categories due to overlapping characteristics (based on Putz et al., 2015).

The term synchromodality is known in the Port of Hamburg but not implemented. This is the result of discussions carried out with market actors in 2016. Nevertheless, almost all actors referred to projects in Hamburg that could fit to single aspects of synchromodality. Further, actors associated synchromodality with the Ports of Rotterdam and Antwerp. Hence, the degree of implementation of synchromodality in these ports is analyzed. The question to be answered is, whether the whole concept of synchromodality or only single aspects are realized in these ports and what distinguishes these ports from the Port of Hamburg.

Answers to this question were found by carrying out an extensive literature review (especially publications by and about the Port of Hamburg, the Port of Rotterdam and the Port of Antwerp). The results are summarized in table 3.

As can be taken from The term synchromodality is known in the Port of Hamburg but not implemented. This is the result of discussions carried out with market actors in 2016. Nevertheless, almost all actors referred to projects in Hamburg that could fit to single aspects of synchromodality. Further, actors associated synchromodality with the Ports of Rotterdam and Antwerp. Hence, the degree of implementation of synchromodality in these ports is analyzed. The question to be answered is, whether the whole concept of synchromodality or only single

Table 2: Identified prerequisites for synchromodality

Title	Description
Physical network/ connections	Dense and reliable network of nodes (seaports and multimodal hinterland terminals and inland ports) and transport links (roads, railways and inland waterways) (Douma et al., 2012; Tavasszy et al., 2015)
Real-time data/(partly) automated transport planning	Consideration of "[…] uncertainty, traffic at terminals or en route, resource limitations and modal capacities" (SteadieSeifi et al., 2014, p. 14); Central information and communication platform for sharing up-to-date information (ECT, 2011; van Wijk et al., 2011; Pleszko, 2012; Behdani et al., 2014; Tavasszy et al., 2015).
Collaborative networks/trust	Cooperativeness and willingness to share real-time information; This includes the collaboration of shippers as well as logistics service providers. (Verweij, 2011; Douma et al., 2012; Pleszko, 2012; Behdani et al., 2014; Tavasszy et al., 2015) The information exchange requires trust between the involved actors. Governance mechanisms within the collaborative network can support building a solid basis of trust. (Mason et al., 2007; Pleszko, 2012; Pomponi et al., 2015) Further, synchromodality requires a different initiation of business where the organization of the transport chain is not predetermined. (van Wijk et al., 2011; Douma et al., 2012; Reis, 2015; Tavasszy et al., 2015)
Legal and political framework conditions	Horizontal collaborations need to be allowed under competitive law. (Tavasszy et al., 2015) Further, transportation regulations need to be harmonized, hampering rules and laws need to be eliminated and the legal framework needs to be revised concerning liability issues and the transfer of liability. (van Wijk et al., 2011; Pleszko, 2012; Tavasszy et al., 2015)

Table 3: Aspects of synchromodality in the major European container ports (authors based on UNICONSULT 2009a, 2009b; Eurogate and HHLA 2010; ECT 2011; van Wijk et al. 2011; Douma et al. 2012; MSC 2013; van Riessen 2013; van Riessen et al. 2013a, 2013b; Behdani et al. 2014; Port of Antwerp 2014)

Port of …	Rotterdam	Antwerp	Hamburg
Physical network/ connections	→	→	→
Real-time data/(partly) automated transport planning	↑	→	→
Collaborative networks/ trust	→	No (sufficient) information found	↓
Legal and political aspects	↑	↑	↑

↑ full compliance → partical compliance ↓ no compliance with prerequisites

aspects are realized in these ports and what distinguishes these ports from the Port of Hamburg.

Answers to this question were found by carrying out an extensive literature review (especially publications by and about the Port of Hamburg, the Port of Rotterdam and the Port of Antwerp). The results are summarized in table 3.

Table 3 none of the analyzed ports completely complies with all prerequisites. The Port of Rotterdam brands itself as a synchromodal port (ECT, no date) where the hinterland transport is organized by European Gateway Services (EGS) via the organization form terminal operator's haulage: For each trip to the hinterland region the modal choice is based upon the most efficient and sustainable solution and modes of transport can be immediately changed. (EGS, no date) Extended Gateway Terminals and adapted customs legislation allow the transport of containers directly into the Extended Gateway Terminals without customs audits procedures directly in the Port of Rotterdam. Although the Port of Rotterdam brands itself as a synchromodal port the network of Extended Gateway Terminals is still too small. The complete underlying synchromodal network comprises of in total 25 terminals in six countries. (ECT, no date) Thus, not all hinterland transports can be organized in a synchromodal way. Further, EGS, the logistics service provider offering synchromodal transports, is an ECT company. (EGS, no date) Hence, there is no real competition or collaboration of different logistics service providers, but all transports are organized by vertically integrating different logistics service providers. For the Port of Rotterdam case synchromodality is just realized within a clearly delimited geographic area and with regard to ECT only within one organizational entity (EGS as an affiliated entity of ECT). For all that, the Port of Rotterdam can be identified as one of the most open minded ports with regard to new collaboration forms. Although there is no collaboration of different logistics service providers a unique degree of collaboration between shippers respectively consignees and the transport organizing entity has been applied within a pilot study at the Port of Rotterdam. (Douma et al., 2011)

The Port of Antwerp also shows aspects of synchromodality, but the port does not brand itself as a synchromodal port. Like the Port of Rotterdam the Port of Antwerp also features a network of Extended Gateway Terminals especially in the region of Flanders. (UNICONSULT, 2009a) The Port of Antwerp as well as the Port of Rotterdam run Port Community Systems (PCS) that are used for the communication between the different actors involved in the transport chains via these ports. These PCS can be understood as a starting point for information and communication platforms for real-time information sharing as needed for synchromodal transport chains. (Port of Antwerp, 2014; UNICONSULT, 2009a) Further, the overarching goal of the advancement of the Port of Rotterdam's PCS Portbase (joint PCS of the Port of Rotterdam and the Port of Amsterdam) is a national PCS with key function in national and international port related logistical networks. This complies with the prerequisite of a central information and communication platform for sharing up-to-date information. (van Wijk et al., 2011; ECT, 2011; Pleszko, 2012; Tavasszy et al., 2015)

Compared to the Port of Rotterdam and the Port of Antwerp synchromodality is least developed in the Port of Hamburg. As shown in The term synchromodality is known in the Port of Hamburg but not implemented. This is the result of discussions carried out with market actors in 2016. Nevertheless, almost all actors referred to projects in Hamburg that could fit to single aspects of synchromodality. Further, actors associated synchromodality with the Ports of Rotterdam and Antwerp. Hence, the degree of implementation of synchromodality in these ports is analyzed. The question to be answered is, whether the whole concept of synchromodality or only single aspects are realized in these ports and what distinguishes these ports from the Port of Hamburg.

Answers to this question were found by carrying out an extensive literature review (especially publications by and about the Port of Hamburg, the Port of Rotterdam and the Port of Antwerp). The results are summarized in table 3.

Table 3, the conditions in the Port of Hamburg do not comply with the named prerequisites. As described above a dense and reliable network of nodes (seaports, multimodal terminals and inland ports) and transport links (roads, railways, inland waterways) forms a prerequisite for synchromodality. In the study 'hinterland gateway concept as relief for the Port of Hamburg' UNICONSULT (2009a) analyzed the demand for a network of hinterland terminals for the Port of Hamburg. They concluded that the hinterland gateway concept needs to be realized in the medium- and long-term in order to secure the Port of Hamburg's competitiveness. The two large container terminal operators in the Port of Hamburg Eurogate and Hamburger Hafen und Logistik AG (HHLA) even founded the Inland Port Network (IPN) in order to develop and implement an integrated strategy for maritime hinterland transports and terminals. (Schiffer and Jürgens, no date) The joint venture failed due to decreasing container volumes and therefore reduced bottlenecks in the Port of Hamburg.

Nevertheless, approaches exist in the Port of Hamburg in order to implement a central information and communication platform for sharing up-to-date information. The existing PCS forms a starting point for this. E.g. as part of the Port of Hamburg's PCS the Import Message Platform (IMP) is an intelligent electronic platform, enabling information to be exchanged between involved actors. (DAKOSY, no date) Though, it does not contain real-time traffic data in the port area. With the project smartPORT logistics the Hamburg Port Authority (HPA) aims at increasing the efficiency of the port as an important link in the supply chain by developing smart traffic and trade flow solutions. (HPA, no date) The project focusses on infrastructure, traffic and trade flows and pursues the following overriding objectives:

- "Managing and using the existing infrastructure in the Port of Hamburg in an efficient manner
- Reducing traffic-related emissions of air pollutants and greenhouse gases
- Establishing intelligent infrastructure in the Port of Hamburg
- Optimizing the flow of information to manage trade flows efficiency (HPA, no date, p. 2)"

Currently, the project is further developed to an international network of connected smart ports. (Brümmerstedt et al., 2017) As part of its smartPORT logistics initiative the HPA develops applications for better provisioning of up-to-date traffic data for truck drivers and dispatchers. This data comprises the traffic situation in the Port of Hamburg and on the highways, closure times of movable bridges and additional infrastructure information. It also includes the traffic situation at important actors like e.g. empty container depots and container terminals and information about the availability of parking lots for trucks. (HPA, no date)

However, so far only the port area and relevant connections are included in this project. Thus, port traffic within the Port of Hamburg will be improved only. For synchromodal hinterland solutions hinterland terminals and transport modes and routes outside the port area need to be included as well.

Three main framework conditions hampering the introduction of synchromodality in the Port of Hamburg can be identified:

— In contrast to the Port of Rotterdam (besides of Hapag Lloyd at the Container Terminal Altenwerder (share of 25.1%)) no dedicated terminal exists in the Port of Hamburg. Dedicated terminals form a prerequisite for vertically integrated and synchromodal transport chains organized as terminal operator's haulage.

— Customs procedures and provisions hinder the fast transport of containers to the hinterland terminals as well as the flexible reaction of hinterland transports to short-term problems.

— The willingness to cooperate lacks and trust is missing between

    … the shippers and liner shipping companies as well as ocean freight forwarders,

    … the competing liner shipping companies and ocean freight forwarders and

    … the liner shipping companies and the terminal operators in seaports.

Without removing these obstacles, synchromodality will hardly be implemented in the Port of Hamburg.

5 Conclusion

As discussed in the previous sections synchromodality seems to form a solution for improving hinterland transportation and reducing bottlenecks in seaports. But it is neither clearly defined nor completely realized in any of the analyzed ports so far. Nevertheless, the Port of Rotterdam shows the highest degree of implementation. Synchromodality has already led to improvements in the hinterland transport chains of the Port of Rotterdam. (ECT, no date) For a complete implementation of synchromodality four prerequisites need to be fulfilled:

Firstly, synchromodality requires a dense and reliable network of nodes (multimodal terminals) and transport links. (Douma et al., 2012; Tavasszy et al., 2015) Secondly, the actors and transport modes need to be connected via a central information and communication platform for sharing up-to-date information concerning traffic data, resource limitations and modal capacities. (ECT, 2011; van Wijk et al., 2011; Pleszko, 2012; Behdani et al., 2014; Tavasszy et al., 2015) Thirdly, synchromodality requires the cooperativeness and willingness of all actors to share real-time information. This includes the collaboration of shippers as well as logistics service providers. (Verweij, 2011; Douma et al., 2012; Pleszko, 2012; Behdani et al., 2014; Tavasszy et al., 2015) Finally, the legal and political framework conditions need to allow collaborations of companies which are inevitable for the concept of synchromodality. Further, transportation regulations need to be harmonized, hampering rules and laws need to be eliminated and the legal framework needs to be revised concerning liability issues and the transfer of liability. (van Wijk et al., 2011; Pleszko, 2012; Tavasszy et al., 2015)

The concept of synchromodality is a relatively new concept for the Port of Hamburg. Although synchromodality is not implemented in the Port of Hamburg, market experts indicated that parts of the concept of synchromodality would lead to a de-stressing of the Port of Hamburg's hinterland connections. These are especially an increased share of up-to-date information and a central information and communication platform, more collaboration between the actors of the transport chain as well as a dense network of hinterland terminals and the Extended Gateway Concept. The Extended Gateway Concept as well as a dense network of hinterland terminals already were about to get realized in the Port of Hamburg but efforts were discontinued due to decreasing container volumes and resulting from this reduced bottlenecks. The smartPORT logistics initiative forms a first step towards an increased sharing of up-to-date information. The project concentrates only on the Port of Hamburg and needs to include especially hinterland terminals in order to become an information and communication platform that could be used in a synchromodal context.

Putting everything in a nutshell, synchromodality could form a solution for optimizing seaport hinterland transports, reducing the dwell-times of containers in the Port of Hamburg, increasing the storage capacities of the container terminals within the Port of Hamburg and by that increasing the reactiveness to peaks in waterside container handling due to larger container vessels. However, there is still a long way to go for synchromodal hinterland transport chains in the Port of Hamburg. The Port of Rotterdam case shows, that smaller scale synchromodal concepts can be successfully implemented. Although synchromodality is part of the Physical Internet roadmap until 2050 it is unclear to what extend the concept of synchromodality will prevail in European seaports.

References

alice Alliance for Logistics Innovation through Collaboration in Europe (2015). *Corridors, Hubs and Synchromodality: Research & Innovation Roadmap*.

Antwerp Port Authority (2015). *Maritime cargo turnover - January - December 2014*.

Behdani, B., Y. Fan, B. Wiegmans, and R. Zuidwijk (2014). *Multimodal Schedule Design for Synchromodal Freight Transport Systems*.

Brümmerstedt, K., R. Fiedler, V. Flitsch, C. Jahn, H. Roreger, B. Sarpong, S. Saxe, and B. Scharfenberg (2017). *Digitalization of Seaports - Visions of the Future*. Stuttgart: Fraunhofer Verlag.

DAKOSY (2017). *IMP - Import Message Platform*.

DHL (2014). *Logistics Trend Radar: Delivering insight today. Creating value tomorrow! Version 2014*. Ed. by DHL Customer Sulutions & Innovation.

Douma, A., A. Veenstra, and K. Verwey (2012). *Een stip op de horizon synchromodal vervoer in 2020. Definitie, kansen en perspectieven*.

ECT (2011). *The future of freight transport. ECT's vision on sustainable and reliable European transport*.

ECT (2017). *Europas synchromodaler Dienstleister*.

Eurogate and HHLA (2010). *Hinterland-Terminals für die maritime Containerlogistik*.

European Gateway Services (2017). *Company Profile*.

Grig, R. (2012). *Governance-Strukturen in der maritimen Transportkette: Agentenbasierte Modellierung des Akteursverhaltens im Extended Gate*. Schriftenreihe Logistik der Technischen Universität Berlin Technische Universität Berlin. Berlin: Univ.-Verl. der Techn. Univ. Berlin.

Hamburg Port Authority [HPA] (2014). *Port of Hamburg - digital Gateway to the World*.

International Transport Forum (2015). *The Impact of Mega-Ships*.

Knol, A., B. Klievink, and Y.-h. Tan (2014). “Data Sharing Issues and Potential Solutions for Adoption of Information Infrastructures: Evidence from a Data Pipeline Project in the Global Supply Chain over Sea: Paper 40”. In: *BLED 2014 Proceedings 2014*. Ed. by Association for Information Systems AIS Electronic Library (AISeL).

Li, L., R. R. Negenborn, and B. de Schutter (2013). “A general framework for modeling inter-modal transport networks”. In: *2013 10th IEEE International Conference on Networking, Sensing and Control (ICNSC)*. [Piscataway, N.J.]: [IEEE], pp. 579–585.

Mason, R., C. Lalwani, and R. Boughton (2007). “Combining vertical and horizontal collaboration for transport optimization”. In: *Supply Chain Management: An International Journal* 12.3, pp. 187–199.

MSC (2013). *Extended Gateway: Bringing the port to your doorstep.*

Notteboom, T. and J.-P. Rodrigue (2005). “Port regionalization: Towards a new phase in port development”. In: *Maritime Policy and Manegement* 32.3, pp. 297–313.

Pleszko, J. (2012). “Multivariant configurations of supply chains in the context of synchromodal transport”. In: *LogForum Scientific Journal of Logistics* 8.4, pp. 287–295.

Pomponi, F., L. Fratocchi, and S. Rossi Tafuri (2015). “Trust development and horizontal collaboration in logistics: a theory based evolutionary framework”. In: *Supply Chain Management: An International Journal* 20.1, pp. 83–97.

Port of Antwerp (2014). *How does APCS work?*

Port of Rotterdam Authority, PIM, and CBL (2017). *Containers and TEU time series*.

Putz, L.-M., C. Haider, A. Haller, and O. Schauer (2015). “Identifying Key Enablers for Synchromodal Transport Chains in Central Europe”. In: *Proceedings of the WCTRS SIGA2 2015 Conference "The Port and Maritime Sector: Key Developments and Challenges"*.

Reis, V. (2015). “Should we keep on renaming a +35-year-old baby?” In: *Journal of Transport Geography* 46, pp. 173–179.

Roth, M. (2013). “Monitoring von Prozessinstanzen in logistischen Netzwerken”. In: *Beiträge zum 17. Interuniversitären Doktorandense-minar Wirtschaftsinformatik (IDS 2013)*. Ed. by J. Ruhland and L. Wenige, pp. 49–58.

Schiffer, E. and S. Jürgens (n.d.). *Hinterland-Terminals für die maritime Containerlogistik*.

Schönknecht, A. (2009). *Maritime Containerlogistik: Leistungsvergleich von Containerschiffen in intermodalen Transportketten*. VDI-Buch. Berlin, Heidelberg: Springer Berlin Heidelberg.

Statistisches Amt für Hamburg und Schleswig-Holstein (2017). *Schifffahrt und Außenhandel Hamburgs 1970 bis 2016: STATISTISCHE BERICHTE G III/H II - j 16 HH (Sonderbericht)*.

SteadieSeifi, M., N. P. Dellaert, W. Nuijten, T. van Woensel, and R. Raoufi (2014). “Multimodal freight transportation planning: A literature review”. In: *European Journal of Operational Research* 233, pp. 1–15.

Tavasszy, L., B. Behdani, and R. Konings (2015). *Intermodality and Synchromodality*.

Tavasszy, L., R. Janssen, L. van der Lugt, and Lorike Hagdorn (2010). *Verkenning Synchromodaal Transportsysteem - hoofdrapport: In opdracht van: Ministerie van Infrastructuur & Milieu: TNO-034-DTM-2010-04431*.

Tavasszy, L., H. J. Quak, and R. Janssen (2011). “Orchestrating innovations in lo-gistics: mind your step”. In: *EVO’s Logistics Yearbook edition 2011*. Ed. by P. J. van der Sterre. Zoetermeer, pp. 19–27.

TKI DINALOG (2017). *Synchromodal*.

UNICONSULT (2009a). *Hinterland Gateway Konzept zur Entlastung des Hamburger Hafens: Im Auftrag der Hamburg Port Authority HPA*.

UNICONSULT (2009b). *Konzeptstudie zur Verkehrsverlagerung vom LKW auf Binnenschiffe und zur Stärkung der Hinterlandverkehre: Im Auftrag der Behörde für Wirtschaft und Arbeit der Freien und Hansestadt Hamburg*.

Unternehmensverband Hafen Hamburg e.V. (2017). *Hafen Hamburg: Jahresbericht 2014*.

van der Burgh, M. (2012). *Synchromodal transport for the horticulture industry: Requirements for implementation in the Westland-Oostland greenport: Master thesis at the Erasmus University Rotterdam*.

van Riessen, B. (2013). *Planning of hinterland transportation in the EGS network: Master's thesis Transport Engineering and Logistics (TU Delft) Operations Research & Quantitative Logistics (EUR)*.

van Riessen, B., R. R. Negenborn, R. Dekker, and G. Lodewijks (2013a). "Impact and relevance of transit disturbances on planning in intermodal container networks: (No. EI 2013-18)". In: *Econometric Institute Research Papers, Erasmus University Rotterdam*, pp. 1–23.

van Riessen, B., R. R. Negenborn, R. Dekker, and G. Lodewijks (2013b). "Service network design for an intermodal container network with flexible due dates/times and the possibility of using subcontracted transport: (No. EI2013-17)". In: *Econometric Institute Research Papers, Erasmus University Rotterdam*, pp. 1–16.

van Stijn, E., D. Hesketh, Y.-h. Tan, B. Klievink, S. Overbeek, F. Heijmann, M. Pikart, and T. Butterly (2011). *The Data Pipeline: Global Trade Facilitation Conference 2011: Connecting International Trade: Single Windows and Supply Chains in the Next Decade*.

van Wijk, L., L. Hagdorn, W. Versteijnen, and M. Dierikx (2011). *Partituur naar de top Adviesrapport Topteam Logistiek: Topteam Logistiek*.

Veenstra, A., R. Zuidwijk, and E. van Asperen (2012). "The extended gate concept for container terminals: Expanding the notion of dry ports". In: *Maritime Economics & Logistics* 14, pp. 14–32.

Verweij, K. (2011). "Synchromodal transport: Thinking in Hybrid Cooperative Networks". In: *EVO's Logistics Yearbook edition 2011*. Ed. by P. J. van der Sterre. Zoetermeer, pp. 77–88.

Walter, F. (2015). *Informationsaustausch in der maritimen Transportkette: Untersuchung der Prozessleistung im Datenfluss und der Kapazitätsauslastung*. SpringerLink : Bücher. Wiesbaden: Springer Gabler.

Interactive Planning and Control for Finished Vehicle Logistics

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Logistic processes on sea and inland ports play an important role in the context of finished vehicle logistics as the vehicles are turned over for import and export here. Due to increasing dynamics and complexity, the planning and control of these processes requires high flexibility and reactivity. For example, changing dealer demands or delays of trucks, trains and ships may require a short-term replanning of the logistics processes on sea and inland ports. In this context, this paper describes the procedures and challenges within finished vehicle logistics. Furthermore, an approach for developing highly flexible and efficient logistics planning and control processes for sea and inland ports is introduced. On the one hand, this approach involves an interactive planning tool that visualizes the outcomes of different planning alternatives computed by discrete event simulation. On the other hand, a concept for a novel control system for order allocation will be presented that is based on tracking and tracing of vehicles and workers. This includes a novel method for tracking and tracing as current methods are not suitable in terms of accuracy or cost-efficiency. It is envisioned that the introduced concept will offer significant improvements in terms of reactiveness to spontaneous changes and efficiency in travel paths compared to current practices.

Keywords: maritime; port logistics; port transshipment

1 Motivation

In the context of global competition, ever increasing efficiency and flexibility are crucial factors for all industrial and services sectors. This also holds for finished vehicle logistics. Finished vehicle logistics is a part of transport logistics which deals with the transportation of finished vehicles from the site of production to the dealer or end user. Finished vehicle logistics are usually taken care of by a series of logistic service providers (LSPs) that are responsible for different parts of the route of transportation (Holweg and Miemczyk, 2002; Werthmann et al., 2016). Sea and inland ports play an important role in this context as the vehicles are turned over for import and export here. In addition, vehicles might also undergo technical services at the ports. These are value added services that are also arranged by the LSPs (Holweg & Miemczyk 2002). Due to the complexity of the logistic processes at sea and inland ports, LSPs are confronted with several challenges: The planning of the logistic processes is based on forecasts provided by the manufacturer's production department. Due to the dynamic order situation these forecasts are often not accurate enough and short-termed changes are common (Holweg and Miemczyk, 2002). Moreover, the forecasts can be further distorted by incidents of the resident technical services centers or of third parties which arrange the delivery or take-away of vehicles by truck, train or ship.

Another challenge is the constant increase of turnover rates of finished vehicles at sea and inland ports. At the vehicle compound in Bremerhaven, the turnover of vehicles increased by 13.9% in early 2017 (DVV Media Group GmbH, 2017). In order to keep pace with the increase in workload and the complexity of the dynamic processes, a planning and control system is needed that offers large flexibility and efficiency.

The present planning and control systems are usually IT supported but do not provide the needed flexibility. Usually, there is no infrastructure that supplies the IT-systems with automated real-time information from the compound. Instead, manual scanning and information transfer is in use, which is error-prone and delivers information with a time lag (Werthmann, Ruthenbeck and Scholz-Reiter, 2012; Böse, Lampe and Scholz-Reiter, 2006). In addition, the software structures have often evolved historically so that the coordination of planning and control is poor. Overall, the IT support exists in form of rather fixed and inflexible structures and as the exact situation on the compound is not known, it is impossible to generate optimally tailored planning and control solutions.

In this context, this paper presents a possible approach on how to create an integrated planning and control system to improve the flexibility and efficiency of logistics processes at sea and inland ports. The approach is based on a planning and control system that supports the processes for finished vehicle logistics based on real-time information. Furthermore, the system is supposed to be interactive so that it is possible to involve employee's expertise.

The envisioned planning and control system will be developed in a cooperation between the BIBA – Bremer Institut für Produktion und Logistik GmbH, the logistic service provider BLG AutoTerminal Bremerhaven GmbH & Co. KG and the software enterprise 28Apps Software GmbH. It will be developed in the scope of the IHATEC project "Automobillogistik im See- und Binnenhafen: Interaktive und simulationsgestützte Betriebsplanung, dynamische und kontextbasierte Steuerung der Gerät- und Ladungsbewegungen" which translates to "Automobile logistics in sea- and inland ports: interactive and simulation-based operation planning, dynamic and context-based control of device- and load movements".

2 Procedures and Challenges within Finished Vehicle Logistics

2.1 Procedures

The term finished vehicle logistics includes all logistics processes that are necessary in order to transport a finished vehicle from the site of the manufacturer

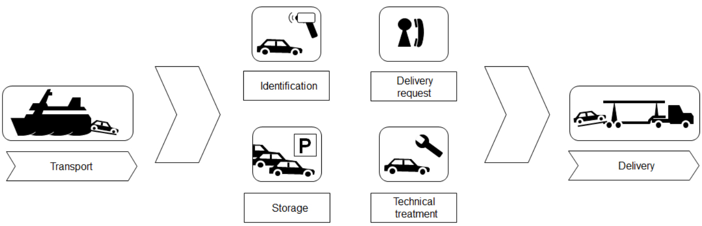

Figure 1: Throughput process of imported vehicles at a vehicle compound that offers technical services (based on Böse et al., 2008)

to the dealer or end user (Holweg and Miemczyk, 2002). These two sites may be located on different continents. Thus, all means of transportation, but mainly truck, train and ship, can be involved. Ports are responsible for the import and export of the vehicles and therefore finished vehicle logistics are especially complex here. An overview of the throughput processes of imported vehicles at a vehicle compound is given in figure 1.

The complete process can be roughly described as follows: The manufacturer engages a logistic service provider for the transportation from the production site to the compound at the port (Werthmann et al., 2016). At the compound the vehicles are unloaded, temporarily parked for checks on completeness and damages (Klug, 2010), supplied with value added services such as remodeling, washing or removal of waxing at the technical service centers (Holweg and Miemczyk, 2002; Ruthenbeck, Lappe and Lampe, 2010), stored until further transportation, temporarily parked for the process of loading and finally loaded onto a ship for export or truck or train for import (Böse, Piotrowski and Bernd Scholz-Reiter, 2008). The further transportation is carried out by LSPs. Before the vehicles of either ex- or import reach the end destination, they might be turned over at further vehicle distribution centers (VDCs) where similar logistics processes take place (Werthmann et al., 2016).

Any movement of vehicles that happens on the compound is carried out by a team of handling employees. As the area on vehicle compounds is rather wide spread, the handling employees are transported to the vehicles by shuttle services (Böse, Piotrowski and Bernd Scholz-Reiter, 2008). The shuttle services follow the handling employees when they transpose the vehicles and pick them up again in order to bring them to another lot of vehicles that needs to be transported.

2.2 Challenges

The planning of logistic processes at vehicle compounds that involve not only pure logistic processes but also quality checks and value added services is rather complex. The ways of transportation can be unique to single cars. Different batches of vehicles require different services which can vary in number. Some vehicles might not require any value added service and again while others require customer specific services.

Moreover, such vehicle compounds are rather large in size and therefore the distances between sites of unloading, storing and loading are crucial. As several shipping berths, railway platforms and truck disposition areas exist, there are several options on how to assign the different deliveries to certain sites of unloading.

In order to manage the processes at a vehicle compound, planning and control systems are used. While the planning system is responsible for generating a plan for the processing of incoming orders, the control system interferes in case of unexpected events during the processing and generates specific solutions for these cases in order to prevent further deviations from the planned scenario.

As the operator of the vehicle compound receives forecast information from the vehicle manufacturer on which deliveries to expect at what time, it is appropriate to manage the assignment of loading and unloading sites via the planning system. The vehicle movement processes can be interrupted quite easily by unexpected events. Consequently, long-term planning of these processes is not appropriate as it would involve re-planning at high frequency and thus, the managing of vehicle movements on the compound should be left to the control system. On current vehicle compounds, however, the situation is different.

2.2.1 Planning

The planning of loading and unloading sites suffers from unreliable forecasts which impede optimal planning (Holweg and Miemczyk, 2002). Moreover, due to a lack of digitalization, there is no detailed real-time map of the situation on the compound available, which, if existent, would make short-term re-planning possible (Werthmann, Ruthenbeck and Scholz-Reiter, 2012). The current IT-support can thus never generate solutions that are tailored exactly to the situation on the compound. Instead, current planning is usually largely dependent on the experience-based knowledge of the employees. If unexpected changes occur, such as delay or failure of ship or railway, time intensive manual interventions are necessary, which usually involve high administrative efforts and do not guarantee efficient solutions. The planners know about the impossibility of generating optimal solutions and therefore they tend to choose rather safe planning options. For example, rather too large parking areas are selected for storing the vehicles of a certain ship or rather more handling employees than actually needed are assigned to the unloading process. By doing so, valuable resources are wasted and make the operations on the compound less efficient.

2.2.2 Control

The control system includes the management of the vehicle movements. However, also here the same lack of a detailed real-time map of the situation on the compound states a problem. For this reason, plans for vehicle movements are generated at the beginning of each shift. The software generates plans with minimized distances. However, the plans with due vehicles movements are printed out on paper and handed to the team leader of each driving team. As they are printed on paper they cannot be updated easily (Werthmann, Ruthenbeck and Scholz-Reiter, 2012). If unexpected changes occur, there is no quick connection to the central board of control such that the planned processes are usually not re-planned but rather carried out in an inefficient manner.

Moreover, as the successful movement of vehicles is also documented manually on paper, the central board of control is not informed about the change of location in real-time and updates are thus only possible towards the end of a shift or during breaks. Moreover, the manual recording of vehicle movements involves media breaks and is thus error-prone. If a vehicle is parked in a different location than documented, time-consuming search actions are necessary.

As no reliable control system exists that could generate and distribute ad-hoc orders to the handling employees, the usage of shuttle busses is the best option for the transport of the handling employees between different tasks. An optimal solution, however, would be the development of a system in which the handling employees transport themselves from one driving job to the next by carrying out a driving job itself. By doing so, any empty runs carried out by the shuttle services could be eliminated.

2.2.3 Integration of Planning and Control

Up to date, the software for the planning and control processes is usually not integrated and also within the two parts of planning and control, often different software programs are used. Moreover, different departments and sections of the compound might use different programs. An IT-based integration of all systems usually does not exist and therefore the coordination between different departments and sections on the compound is left to personal consultation between managers, which makes the process prone to errors and negligences.

In order to stay competitive in the future, a concept needs to be developed that significantly improves the efficiency and flexibility of the current planning and control processes. The concept should include real-time information of the status of berths, platforms and truck disposition areas, i.e. whether they are engaged or not and if engaged which delivery or further transportation is currently in progress. Moreover, the location of single vehicles needs to be included such that vehicle movements can be managed via ad-hoc controlling. Overall, the system needs to offer interfaces for human-technology interaction. In the following, the authors will outline an approach towards such a concept.

3 Approach towards a Planning and Control System

The overall aim of the concept introduced in the following is to raise the efficiency and flexibility of the turnover processes at compounds within finished vehicle logistics through creating an interactive and adaptive planning and control system. The aim is to design a system that, on the one hand, supports the employees in terms of planning processes. Planning processes involve the planning of berths and tracks for incoming ships and trains, the allocation of parking spaces to incoming vehicles as well as allocation of employees to incoming tasks. On the other hand, the control processes need to be supported in a more efficient manner. Control processes mainly involve the vehicle transport on the compound. The aim is to allocate tasks to the employees in dependence on their current location and on the vehicles current locations. By doing so, the ratio of non-value added transfer of employees to the next vehicle to be transported should be reduced significantly. In both cases, it is the aim to involve the employees in the form of human-technology interaction. This, on the one hand, allows the employees to integrate their expertise that cannot be formalized in an adequate way in the implementation of the software. On the other hand, human-technology interaction allows to leave the employees with certain rights for co-decisions. These aspects are very important from a work-psychological point of view (Cotton et al., 1988).

Overall, the concept aims at a significant improvement of the planning and control processes of sea and inland ports. This also includes the consideration of human-technology interaction to reach a new level of employee oriented planning and control of vehicle compounds.

3.1 Planning Tool

The planning tool is expected to fulfil the following requirements: It should be able to compute the efficiency of different planning alternatives, such as choosing different berths for incoming ships or different tracks for incoming trains, and consider parameters such as resource efficiency. On the one hand, resource efficiency holds for technical resources such as shuttle services or parking spaces, on the other hand, it also accounts for human resources, such as handling employees that are responsible for the vehicle movements. By fulfilling these functions, the planning tool can be used for routine planning sessions and also in case of sudden changes that ask for adaptation of the planned scenario. Sudden changes can, e.g., be caused by the delay or failure of a ship or train as well as failure of local resources.

The planning tool is supposed to be interactive. An interactive tool has the advantage that experience-based knowledge of employees can be integrated into the solution. Often it is the case that employees, after many years of intensive work experience, have acquired a certain instinct for useful solutions which, however, cannot be formalized in such a way that it can be integrated in the program code of a software. By choosing for an interactive system, the employees can still integrate their experience-based planning knowledge and restrict the amount of planning alternatives to a number that can be computed by the planning software in a reasonable time.

The planning tool is also supposed to work on a visual and thus mostly intuitive basis. The aspired solution is a multi-touch table. On that table, the layout plan of the port and vehicle compounds will be shown. By touching the screen, different selections can be made, for instance where a ship will berth or a train will arrive. Compared to usual displays, a multi-touch table is relatively large and freely accessible from all sides. Thus, it is especially suitable for interdisciplinary planning meetings where employees from different departments can discuss different planning alternatives while visualizing them on the multi-touch table. In comparison to a simple touch display, a multi-touch table can recognize multiple contacts at the same time (Kin, Agrawala and DeRose, 2009). This is important so that multiple people can interact with the tool at once and thus generate a scenario together.

The computation of planning alternatives is supposed to happen simulation-based. The simulation should evaluate all chosen planning alternatives on the basis of a multi-criteria evaluation and quantify the results in terms of key figures.

Most important criteria that will be considered are due date reliability, throughput times, required employee capacity and space requirement. Furthermore, the simulation based evaluation enables the consideration of disturbances such as delays, failures and other short-termed changes. In addition to the key figures, the simulation software will also compute the impact of all planning alternatives on the following processes and shifts so that those solutions are preferred, which are compatible with a larger time horizon.

Overall, the authors envision the entire planning tool to function as follows: On the multi-touch table, the employees can make a selection of possible planning alternatives. The multi-touch table and the discrete event simulation are connected via a software interface that forwards the chosen planning alternatives to the simulation tool. The simulation computes the outcomes via a multi-criteria evaluation and returns key figures as well as implications on following processes and shifts. Both, key figures and long-term implications are sent back to the multi-touch table where they are visualized for the employees. Based on the presented results, the employees will make a final decision on which planning alternative to implement in practice. In order to deliver reliable results, it is required that the planning tool is integrated into the overall IT-system of the vehicle compound such that the possible planning options and simulation results are always based on up to date information.

Summarizing, an interactive simulation based planning tool will be designed that can integrate experience based knowledge of employees and visualize different planning alternatives and their performance. The usage of an easily accesible multi-touch table will support interdisciplinary planning meetings in an adequate manner. The planning tool is supposed to allow for simulation based verification in case of planning insecurity as well as for simulation-based computation of planning alternatives in case of sudden changes, like delay or failure of external or internal resources.

3.2 Control System

The control system is supposed to fulfil the following requirements: In order to raise flexibility and thus efficiency, the current system of static job lists and fixed driving teams should be substituted by a control system that assigns tasks individually, based on the current order situation and location of handling employees and vehicles (see figure 2). By doing so, not only a given order sequence and thus due date reliability can be pursued, but also route optimization and elimination or minimization of empty runs. This can be reached if the assignment of driving tasks is arranged such that the handling employees transport themselves from one driving task to the next by carrying out driving tasks. Figure 2 examplarily shows the potential of individual order assignments in the form of reduced shuttle tranports based on the current location of handling employees and vehicles. By considering multiple objects like route optimization and due date reliability at once, the idea is to follow an integrated approach in the design of the novel system such that the best possible solutions can be provided.

For the realization of the control system, a tracking and tracing system needs to be designed that generates real-time data of the location of employees as well as vehicles and communicates them to the control system. A special requirement is the urgent need for a very high spatial accuracy that can locate objects within an area of adequate size, preferably on parking lot exactness. In addition, an exact information on longitude and latitude will not be sufficient as vehicle compounds can include multi-storey car parks. Thus, information on heights above ground is also crucial in order to determine on which storey a vehicle is parked. For this reason, usual GPS-based localization systems are not precise enough. Even if an external height sensor would be added, the basic GPS-localization might not be feasible as multi-storey car parks usually involve metal structures that impair the GPS-signal (Böse, Lampe and Scholz-Reiter, 2006).

Alternative active localization systems are proprietary, which will create dependencies. Moreover, these systems are cost intensive. Tag costs are in the mid-double digit euros, maintenance costs will incur and a concept would need to be designed such that the tags can circulate in a closed-loop system. Therefore, it will be investigated if different tracking and tracing methods such as differential-GPS (DGPS) and WLAN-Fingerprinting are adequate for usage in vehicle compound applications. The aim is to combine different sensor technologies, such that an adequate localization will be reached.

Based on the data of the tracking and tracing system, a control algorithm will be designed. This control algorithm will compute an allocation of vehicle transfer tasks to handling employees by considering the different objectives of due date reliability and route optimization. The control algorithm will be developed and validated in two stages. In the first stage, it will be validated by a discrete event simulation and iteratively improved in parallel. In the second stage, the control algorithm will be tested in a field test and checked for its capabilities in reality.

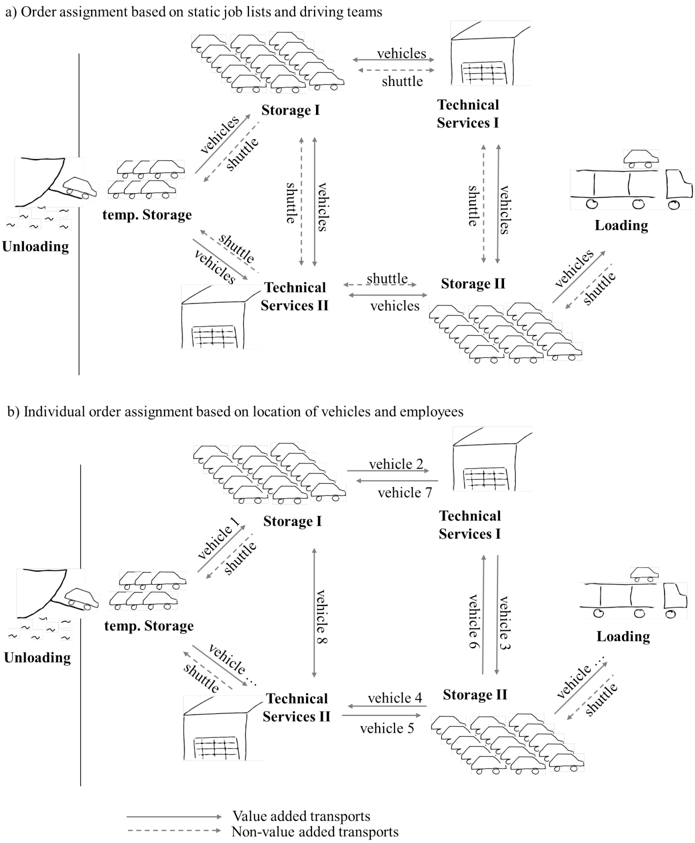

Figure 2: Assignment of tasks based on current order situation and location

Moreover, an IT-architecture will be specified that defines where the control algorithm will finally be implemented. It can either be implemented directly within the central IT-system or in a connected subsystem.

Based on the tracking and tracing system and the control algorithm, vehicle transfer tasks should be communicated to the handling employees. This communication is envisioned to happen via mobile devices. On these devices, the handling employees will receive information about the location and order sequence of vehicles to be moved. Via Auto-ID the vehicles will be identified by the mobile devices and once a vehicle transfer has been completed, the Auto-ID system can check whether the handling employees transferred the vehicle to the correct destination. If so, a status report will be generated and sent automatically, informing the control system about the new position of the transferred vehicle. Furthermore, depending on the situation, order modifications can be communicated and implemented in the system at short-term such that the process accuracy can be improved overall.

Most likely, smartphones will serve as mobile devices. It is envisioned that the final system will be app-based and the aim is to exploit the sensor technology that is included in the smartphones for a precise tracking of the vehicles. This would also allow recording of all routes that the handling employees used and to identify possible bottle necks in terms of routing. The extent of route usage can be visualized via heat maps.

For daily operation, a concept is needed that arranges the availability of the mobile devices. One possibility is that the devices are provided by the compound operator. In this case a charging concept is needed that guarantees a permanent service despite limited battery runtime. In case smartphones are used, another possibility is a “bring your own device” concept. In this case, each employee would be responsible for readiness of the device for each shift.

A main focus of the control system design lies on optimal human-technology interaction. This includes an appropriate and context-sensitive user interface that is intuitive to use. First ideas are that head-up displays can be integrated for a user-friendly and safe manner to display information for the handling employees.

The introduction of the novel control system will imply fundamental changes within the daily work routine of the employees. Therefore, work- and organizational psychological aspects will also be considered in order to increase the acceptance of the employees for this new concept and to ease the transition phase from the old working processes to the new ones. Therefore, the control algorithm will be designed to involve human interaction and to give employees a preferably high decision-making and managing scope. In particular, for every new job, employees will be given a list of possible jobs out of which they can freely choose one.

Overall, through the immediate way of communication it will be possible to design an extremely dynamic and adaptive system such that the flexibility and efficiency of the vehicle transfers will be raised significantly.

3.3 Interaction of both Systems

The planning and the control system are interconnected via the main IT-service of the vehicle compound (see figure 3). The main IT-system takes incoming orders as input. Incoming orders can be related to ship- and rail traffic, dealer demands and technical services. The orders are forwarded as planning information to the planning software where a planning alternative is selected based on the interplay of the multi-touch table, the simulation model and the employee. The data of the selected planning alternative is fed back to the main IT-system. The main IT-system integrates the orders into the order pool and forwards the updated order pool to the control system. Here, the new orders are integrated into the schedule of the handling employees. The updated schedules are communicated to the handling employees. Moreover, whenever a task is completed, a status report is communicated back from the handling employees' mobile device to the main IT-system.

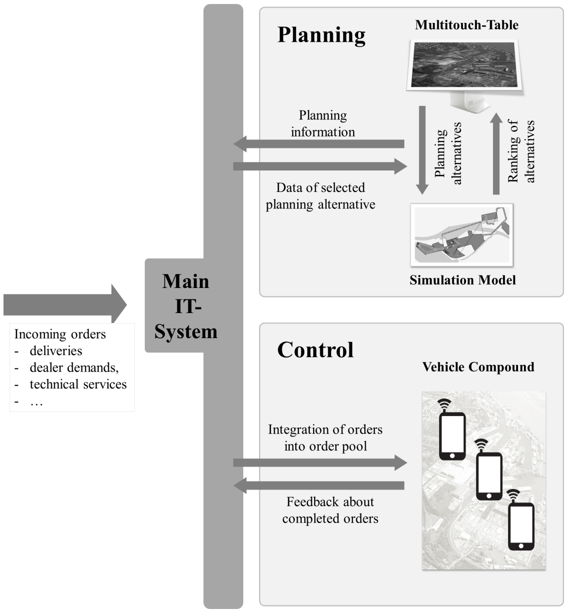

Figure 3: Architecture of the integrated planning and control system

4 Chances and Risks of the Interactive Planning and Control System

The novel planning and control system offers huge chances in terms of efficiency. This, among others, applies to the driving distance which consumes time and fuel costs, to the amount of parking spaces needed and to the coordination effort that is required for planning. The interactivity and the up-to-date technology that is used significantly raise the flexibility of the system and enables short-term reactions to occuring change demands caused by third parties, like delivering trucks, trains or ships. The same applies to other deviations from the forecasted information, such as changes in deliveries or order requests.

However, the novel planning and control system also poses certain risks that have to be considered for the implementation. Thereby, one important issue is related to the social component of the handling employees' work routine. So far the handling employees act in teams and thus are in contact with their colleagues throughout the shift. With the novel control system, handling employees will receive individual tasks such that the social component of small chats in between different work orders are eliminated. Therefore, the handling employees might find it difficult to positively receive the new system. For this reason, work-psychological aspects are considered such that employees will have certain rights for co-decisions within the control system. Furthermore, the introduced approach will also consider employees' right since the tracking and tracing system does not only track and trace the vehicles but also indirectly the handling employees.

5 Conclusion and Outlook

The introduced novel planning and control system involves up-to-date technical equipment and interactive modules for the employees. Therefore, the approach gives a good prerequisite for making operations at vehicle compounds more efficient and flexible in the long run. The integrated nature of the planning and control system will make the system easier to maintain than the currently common heterogeneous systems.

After development, the interactive planning and control system will be implemented for pilot testing on the vehicle port of Bremerhaven. It is one of the largest vehicle ports worldwide and combines all levels of complexity of the application scenario. Vehicles can be delivered and transported further via ship, rail and truck over a total of 18 berths, 16 rail loading ramps and 4 truck disposition areas. The terminal is spread over a large area of 2.400.000 m^2, which includes a total of 95.000 parking lots. A broad range of technical services is offered for import and export vehicles and in 2015 the total annual turnover accounted for 2.3 Mio vehicles (Sommer, 2016). With these characteristics, which are analogue to the application scenario, the port of Bremerhaven is well suited for a first pilot test of the interactive planning and control system.

With a rather complex design of the general scenario, the developers of the novel planning and control system will ensure that the system can be easily transferred to any other vehicle compound that is of similar or smaller complexity compared to the general scenario. This can be either smaller sea or inland ports but also dry ports or hinterland compounds.

Acknowledgements

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References

Böse, F., J. Piotrowski, and Bernd Scholz-Reiter (2008). “Autonomously controlled storage management in vehicle logistics – applications of RFID and mobile computing systems”. In: *International Journal of RF Technologies: Research and Applications*, pp. 1–20.

Böse, V. F., W. Lampe, and B. Scholz-Reiter (2006). “Netzwerk für Millionen Räder: FasTEr – Eine Transponderlösung macht mobil”. In: *RFID im Blick* 7, pp. 20–23.

Cotton, J. L., D. A. Vollrath, K. L. Froggatt, M. L. Lengnick-hall, and K. R. Jennings (1988). “Employee Participation: Diverse Forms and Different Outcomes”. In: *Academy of Management Review* 13.1, pp. 8–22.

DVV Media Group GmbH (2017). *DVZ Seefracht*.

Holweg, M. and J. Miemczyk (2002). “Logistics in the ”three-day car” age: Assessing the responsiveness of vehicle distribution logistics in the UK”. In: *International Journal of Physical Distribution & Logistics Management* 32.10, pp. 829–850.

Holweg, M. and J. Miemczyk (2003). “Delivering the ‘ 3-day car ’— the strategic implications for automotive logistics operations”. In: *Journal of Purchasing & Supply Management* 9, pp. 63–71.

Kin, K., M. Agrawala, and T. DeRose (2009). “Determining the Benefits of Direct-Touch , Bimanual , and Multifinger Input on a Multitouch Workstation”. In: *Proceedings of Graphics interface 2009*.

Klug, F. (2010). *Logistikmanagement in der Automobilindustrie: Grundlagen der Logistik im Automobilbau*. Berlin: Springer.

Ruthenbeck, C., D. Lappe, and W. Lampe (2010). “Informationsmanagement in der Automobillogistik: Ein proaktiver Ansatz für das Informationsmanagement in globalen Lieferketten”. In: *Industrie Management* 26.5, pp. 9–13.

Sommer, M. (2016). *WeltN24*. https://www.welt.de/motor/article156596917/Das-ist-der-groesste-Autoparkplatz-der-Welt.html.

Werthmann, D., D. Brandwein, C. Ruthenbeck, B. Scholz-, and M. Freitag (2016). “Towards a standardised information exchange within finished vehicle logistics based on RFID and EPCIS”. In: *International Journal of Production Research*.

Werthmann, D., C. Ruthenbeck, and B. Scholz-Reiter (2012). “Standardisierter Informationsaustausch in Wertschöpfungsnetzwerken der Automobilindustrie”. In: *Sichere und nachhaltige Logistik*. Ed. by M. Schenk, H. Zadek, G. Müller, K. Richter, and H. Seidel, pp. 145–151.

Part II

Human Factors

Assessing and Improving Countries' Logistics Skills and Training

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Evidence is mounting to suggest that there is a global shortage of people with the right skills to meet the evolving needs of the logistics industry. Especially emerging regions are lagging behind, inhibiting economic growth. Thus, governments should systematically assess and address skills shortages in logistics. Commissioned by the World Bank, we devised a toolkit for assessing the availability of logistics skills within low- and middle-income countries. We built on the maturity model concept and embedded it into an assessment and policy recommendation process. An international panel of logistics training experts provided advice on the toolkit development. The toolkit allows government officials and staff from international organizations to gain a quick but comprehensive overview of the logistics skills and training situation in a particular country. A pilot study done in Togo demonstrated the toolkit's relevance and practicality. The toolkit is the first of its type to help governments undertake a systematic analysis of logistics skills and training at the macro level. Previous research in this area takes a micro-level perspective focusing on the logistics workforce of individual companies.

Keywords: logistics; skills shortage; competences; maturity model

1 Introduction

Logistics is a major growth sector in the world economy in term of the levels of activity and expenditure (Rushton et al. 2017). In addition to being an important sector in its own right, accounting for around 11% of the global gross domestic product (Shepherd 2011), logistics strongly influences the economic performance of other industries and the countries in which they are located (Arvis et al. 2016). Given its critical importance to economic development and social welfare, logistics must be adequately resourced – in a physical sense and regarding human resources. Despite decades of increasing automation and the current trend of digital transformation (Kersten et al. 2017), logistics intrinsically remains a people business (Rushton et al. 2017). On the operational, supervisory, and managerial levels, logistical activities are labor-intensive (McKinnon et al. 2017). This makes the logistics performance of companies and countries highly dependent on the quantity and quality of the workforce (Jhawar et al. 2014).

1.1 The Case for a Logistics Skills Assessment

Logistics employees need to possess a wide range of skills (Derwik et al. 2016). However, since logistics operates in a business environment characterized by constant technological and socio-economic change, relevant skill sets evolve (Fawcett & Rutner 2014; Kotzab & Wünsche 2015). This has been well-documented in the logistics literature for several decades (e.g. Murphy & Poist 1991; Gammelgaard & Larson 2001; Murphy & Poist 2006; Rahman & Yang 2012; Derwik et al. 2016). It has been argued that today's logistics managers should be regarded as "decathletes" (Hoberg et al. 2014). They must have a cross-functional comprehension of various business fields, strategic decision-making, communication, leadership and intercultural skills, and well-developed analytical and IT skills to manage the versatile tasks they face on a daily basis (Flöthmann & Hoberg 2017). In general, logistics employees on all levels need to acquire the ability to think and work on a process basis. They need to look beyond their own functional and occupational silos and understand how their jobs connect to the entire process (Trautrims et al. 2016). Recently, research also began to analyze how the content of study and training programs in logistics match these skill demands (e.g. Lutz et al. 2013; Cronjé 2015). Most studies find that there is an imbalance between demand and supply – either regarding the number of suitable candidates or related to the content of study programs (e.g. Onar et al. 2013; Fawcett & Rutner 2014; Sinha et al. 2016). Thus, it comes as no surprise that there is a global shortage of people with the right competences and skills to meet the evolving needs of the logistics industry. Studies in countries such as China, India, the US, the UK, Vietnam, and Korea have reported that businesses are having difficulty recruiting staff with the required skills in logistics. These skills shortages range from a lack of truck drivers (e.g. Large et al. 2014; Costello & Suarez 2015) to problems in filling senior logistics positions (e.g. Cottrill 2010; Sinha et al. 2016).

A recent multinational study on logistics skills and training by McKinnon et al. (2017) emphasized that qualified logistics staff are in short supply at all occupational levels in both developed and developing countries. The prevailing view is that the logistics recruitment problem is likely to remain the same or worsen over the next five years. The problem is compounded by deficiencies in the skill levels of those currently employed in the logistics sector. This is impairing the productivity of logistics operations and the quality of logistics services (Capgemini & Langley 2017). McKinnon et al. (2017) highlight the need for a major expansion of logistics training and skills development. Emerging regions are lagging behind the developed countries in the resourcing and quality of training, course content, and the nature of the educational experience. Often, training is limited to short-term, on-the-job training – if at all – provided by colleagues during daily operations. Since logistics performance is considered a central driver of economic growth and competitiveness (Arvis et al. 2016) and studies show the positive relationship between logistics skills and logistics performance at a country level (e.g. Jhawar et al. 2014), low- and middle-income countries, in particular, should keep a close eye on the quality and availability of their logistics education. Further, the study describes the roles that the various stakeholder groups can play in the education, training, and development of logistics employees, individually and collectively, to upgrade their logistics skill levels (McKinnon et al. 2017). It is shown that different stakeholders such as companies, employees, professional associations, higher educational institutes, and external training agencies have a mutual interest in this effort. For governments aiming to improve their countries' logistics prospects, the case for supporting these efforts is particularly strong.

1.2 Requirements for a Logistics Skills Assessment Toolkit

To date, little research has been done on logistics skills development in low-income countries (Cronjé 2015). To help to rectify this situation, the World Bank commissioned the Kühne Logistics University to develop a ready-to-use logistics skills toolkit for low- and middle-income countries. The toolkit is intended to assist governments in determining the logistics skills requirements of their economy and assessing to what extent they are being met by the current provision of training and education. If a skills shortage is found, governments should receive guidance on the measures that they can take to address this problem. It was decided that the toolkit should meet five requirements:

1. Target group: The toolkit should be designed for use by government officials from low- and middle-income countries and staff from development finance institutions.
2. Complexity: The toolkit should be easy to understand by users with limited experience in conducting such assessments.
3. Time frame: It should be possible to collect the necessary data for the toolkit within a period of 5-8 days.
4. Data: The toolkit should mainly rely on qualitative data obtained from interviews with different stakeholders. This could, however, be supplemented by quantitative data where possible.
5. Results: The use of the toolkit should lead to the production of a report outlining the nature and scale of skills shortage and recommendations for policy responses.

This paper provides insights into the toolkit's development and piloting. Thus, it sheds light on the research question "How can logistics skills and training be measured and improved by governments?" The remainder of the paper is structured as follows: First, we give an overview of the toolkit's development process. Then, we introduce three of the toolkit's major building blocks that are subsequently integrated into an overall assessment and policy recommendation process. The paper concludes with insights gained from a pilot study in the West African state of Togo and explores future research opportunities.

2 Development Process

We developed the toolkit in multiple distinct steps (see Figure 1). First, we analyzed the literature to review existing methods and tools on the issue. We found no comparable conceptual work viewing the topic of logistics skills shortages from a

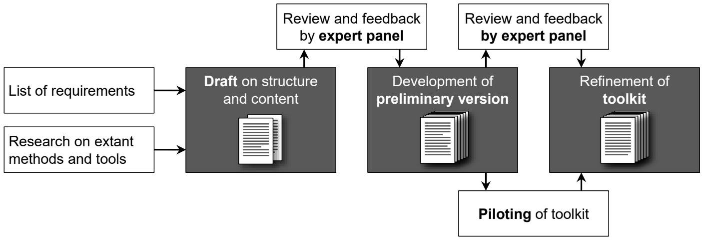

Figure 1: Development of Toolkit

country perspective. However, some literature provides guidance on the development of a logistics-related workforce from an organizational perspective (e.g. Bond & Wollaston 2015; McNelly 2013; Royal Academy of Engineering 2015). While the approaches they adopt are not directly applicable to national governments, they still provide a rich background for the development of the toolkit. Together with the list of requirements, the results of the literature review were the main input for constructing a 4-page draft document on the structure and the general content of the toolkit. To gain external advice on the development of the toolkit, we established an expert panel. It consisted of nine highly knowledgeable and respected individuals from the academic, business, and government domains. Figure 2 provides an overview of the panel. While the experts' common denominator is their engagement in logistics skills development, they also view the topic from different geographical, professional, and stakeholder perspectives. We sent the draft on the structure and content of the toolkit to the members of the expert panel for review and feedback. Most experts provided written comments. Some were also engaged in calls to discuss the issue in greater detail. All feedback was gathered, structured, and analyzed to provide a meaningful foundation for the subsequent development of the preliminary version of the toolkit. This 40-page document was also sent out for review by the expert panel. Further, a pilot study was conducted in Togo. Feedback from both the expert panel and the pilot study was analyzed and considered when preparing the final version of the toolkit.

#	Position	Organization	Country
1	Head of Training Academy	International Transport Organization	Switzerland
2	Executive Officer	International Logistics Organization	Belgium
3	Chief Executive	International Transport Development Organization	United Kingdom
4	Professor of Logistics	Higher Education Institution	Thailand
5	Executive Secretary	Transport Authority	Kenya
6	Supply Chain Workforce Development Specialist	International Health Organization	USA
7	Professor of Business Logistics	Higher Education Institution	Poland
8	Professional Development Project Director	National Logistics Association	United Kingdom
9	Professional Development Coordinator	International Logistics Association	United Kingdom

Figure 2: Composition of Expert Panel

3 Development of the Toolkit's Building Blocks

This section describes the structure and content of the toolkit. We start by explaining the three major building blocks and then integrate them into an overall assessment and policy recommendation process: (1) a differentiation of logistics employment levels, (2) the definition of twenty assessment areas around which to structure the analysis, and (3) a maturity model to qualitatively assess a country's status in each assessment area. We introduce the interconnected building blocks in the following sub-sections.

3.1 Logistics Employment Levels

Skills requirements in logistics are highly dependent on the job type and occupational level. Employee groups need, therefore, to be split into different categories to analyze their skill and training requirements separately. Many classifications

Employment Level	Description	Examples
Operative logistics staff	This group includes all logistics employees who carry out basic operational tasks and do not have any staff responsibility.	Truck drivers, forklift drivers, warehouse pickers
Administrative logistics staff	Staff at this level perform information-processing tasks and have limited supervisory or managerial responsibilities.	Traffic planners, expediters, warehouse clerks, customs clearance officers, customer service employees
Logistics supervisors	Supervisors have frontline responsibility, controlling logistics operations on the ground rather than in the office.	Shift leaders in warehouses, team leaders in traffic departments
Logistics managers	Logistics managers have higher-level decision-making responsibility ranging from junior management roles to board level responsibility for logistics and supply chain strategy.	Warehouse manager, head of logistics operations, chief supply chain officer

Figure 3: Levels of Logistics Employment (based on McKinnon et al. 2017)

of logistics jobs have been devised and are in use today. Most of them are highly specific and distinguish many logistics sub-domains and personnel qualification stages (e.g. CILT 2016; Skills for Logistics 2015). However, for this toolkit, we adopted a simpler and broader classification of logistics staff put forward by McKinnon et al. (2017). A broad classification ensures that toolkit users and interviewees can recognize the distinctions despite huge differences in sector maturity and individual job descriptions. The toolkit distinguishes four main levels of logistics employment as shown in Figure 3. Operative and administrative logistics staff carry out, respectively, manual and information-processing tasks. Logistics supervisors like shift or team leaders control logistics operations on the ground. Finally, logistics managers plan and oversee the logistics activities of a company.

3.2 Assessment Areas

The scope of the assessment is mapped out across 20 distinct assessment areas. This permits tailoring of the assessment to the different types of stakeholders to be interviewed as not all interviewees will be knowledgeable in every aspect of the assessment. Figure 4 provides an initial overview of the assessment areas. The ability of a country to meet the labor requirements of logistics can be

Demand	**A1** Recruitment of operative logistics staff	**A2** Skills level of existing operative logistics employees	**A3** Recruitment of administrative logistics staff	**A4** Skills level of existing administrative logistics employees
	A5 Recruitment of logistics supervisors	**A6** Skills level of existing logistics supervisory employees	**A7** Recruitment of logistics managers	**A8** Skills level of logistics managers currently in post
Supply	**A9** Availability of vocational education in logistics	**A10** Quality of vocational education in logistics	**A11** Availability of logistics education by private training providers	**A12** Quality of logistics education by private training providers
	A13 Availability of logistics education by universities	**A14** Quality of logistics education by universities	**A15** Availability of in-house training	**A16** Quality of in-house training
	A17 Certifications of logistics skills	**A18** Role of associations	**A19** Attractiveness of logistics industry	**A20** Availability of recruitment services

Figure 4: Assessment Areas of the Toolkit

defined in terms of both demand and supply. This is reflected in the assessment matrix. Demand can be measured by the number of personnel required and their required skill levels. For supply, one can measure the number of people being trained and the skills they possess when entering the sector. If the supply does not satisfy the industry demand, a country might face a skills shortage. For demand, eight assessment areas are defined. They pertain to both recruitment of new employees and the skill levels of existing employees on the four levels of logistics employment. The supply section of the grid comprises twelve assessment areas. They are concerned with the availability and quality of different education providers and also cover certification of logistics skills, the role of professional associations in developing these skills, the relative attractiveness of employment in the logistics industry, and the availability of recruitment services.

	Level 1 Minimal Capability	Level 2 Marginal Capability	Level 3 Average Capability	Level 4 Advanced Capability	Level 5 Global Best Practice
A10 Quality of vocational education in logistics	Vocational education in logistics is not widely accepted in industry Programs are not aligned to industry needs Low skills level of graduates		Vocational education in logistics is accepted in industry Programs meet the basic needs of the industry		Vocational education in logistics is widely accepted in industry Close collaboration with industry results in up-to-date program content Certifications and degrees are established and widely known

Figure 5: Exemplary Illustration of Maturity Level Concept

3.3 Maturity Model

To be able to measure a country's capability in the assessment areas, we developed a maturity model. Maturity models have their origins in software development and quality management but are increasingly employed for measuring capabilities in logistics and supply chain management (e.g. Battista & Schiraldi 2013; Mehmann et al. 2015; Mendes Jr. et al. 2016). The basic idea of such models is the notion of evolution: an organization is considered to pass through distinct intermediate states on its way to maturity. Each of these states is described as typical behaviors the organization exhibits when it has reached a certain maturity level (Lahti et al. 2009). Figure 5 illustrates the maturity level concept for one of the 20 assessment areas. Maturity levels two and four deliberately contain no descriptions to keep the assessment simple and flexible.

4 Introduction to the Toolkit

The three building blocks introduced above were embedded into an overall assessment and policy recommendation process. Figure 6 gives an overview. We describe the three phases of the process in more detail in the following sections. Because of space limitations, only the key aspects of the assessment process will be summarized here.

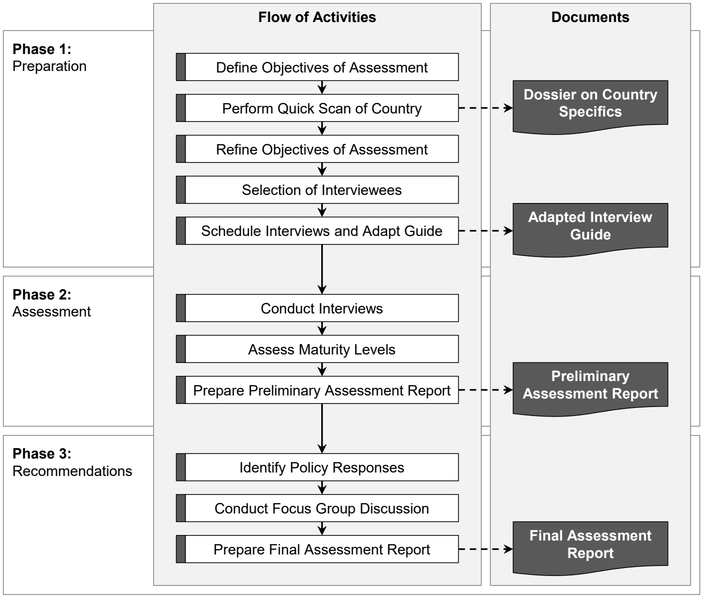

Figure 6: Flowchart of Assessment Process

4.1 Phase 1: Preparation

The first phase enables the toolkit user to gain an initial overview of the country under investigation through a quick scan, tailor the scope of the assessment to the country, and plan the data collection phase by identifying experts for interview. This phase is likely to be based on data available online and so could be completed prior to any fieldwork in the country.

4.1.1 Define Objectives of Assessment

Before starting the assessment process, it is of high importance to prepare a clear statement of the objectives of the assessment. However, they can be refined after the toolkit user has become familiar with the specific situation in the country.

4.1.2 Perform Quick Scan of Country

The quick scan is a desk-based research activity intended to familiarize the toolkit user with country specifics. Information relevant to the assessment should be collected from published reports or internet searches. Two kinds of information are to be collected. First, general information about the demographics, economy, and educational system of the country is needed. Second, the quick scan should produce contact information for suitable interviewees for the second phase of the assessment. For this purpose, the toolkit provides the user with examples and sources of relevant data. It is assumed that a thorough quick scan takes about two weeks of the toolkit user's time.

4.1.3 Refine Objectives of the Assessment

Based on the results from the quick scan, the objectives of the assessment might have to be revised. For example, it will need to reflect the country's level of economic development and the relative importance of different transport modes and logistics services. The toolkit user might also choose to limit the focus to specific sectors, particular regions, or levels of logistics employment.

4.1.4 Selection of Interviewees

Given the assessment's limited timeframe of 5-8 days in the country and the breadth of issues to be covered, the choice of interviewees is critical to the success of the assessment (see Figure 7 for an overview of potential interviewees). Visiting the interviewee's premises may involve significant travel time, limiting the number of interviews that can be carried out per day. Comparable assessments have shown that one person – depending on the distances that have to be traveled – can conduct two to three interviews at different organizations per day (The World Bank 2010). It might be difficult therefore to exceed 15-20 interviews during

Stakeholder Group	Category	Examples of Appropriate Interviewees
Government & administration	Ministries	Experts on logistics or education
	Statistics and employment agencies	
Logistics service providers	Local companies (e.g. airport operators, port operators, freight forwarders)	HR-personnel, logistics executives
	Multinational companies (e.g. UPS, DB Schenker, Maersk, DHL, Kühne + Nagel)	
Shippers	Local companies (e.g. mining companies, fruit exporters, agricultural cooperatives)	
	Multinational companies (e.g. Coca-Cola, P&G, Unilever, Samsung)	
Universities & colleges		Logistics and management professors
Training providers	Vocational institutions	Logistics teachers
	Private training providers	CEOs / senior executives
Professional associations	Local associations	Head of professional development
	International associations	Chairs of local branches
Business organizations	Trade bodies	Director generals / CEOs
	Labor unions	General secretaries
Recruitment agencies	General agencies	HR-personnel focused on logistics
	Logistics-specific agencies	

Figure 7: Overview of Potential Interviewees by Stakeholder Group

the 5-8 days of the assessment. This size of interview sample cannot generate statistically reliable data on logistics skills but it can yield differing perspectives and provides a broad overview of the issue.

Stakeholders will often have a limited knowledge of the topic, and so only a specific subset of the 20 assessment areas are likely to be covered in any given interview. The user of the toolkit must judge which of the assessment areas are most appropriate for particular interviewees. At the same time, the toolkit user has to ensure that every assessment area is covered with a minimum number of interview responses. To facilitate the process of selecting interviewees and assigning assessment areas, the toolkit provides a match-making matrix. It includes advice on (1) which assessment areas should be the focus of the interview and discussed with all interviewees and (2) which assessment areas can be included

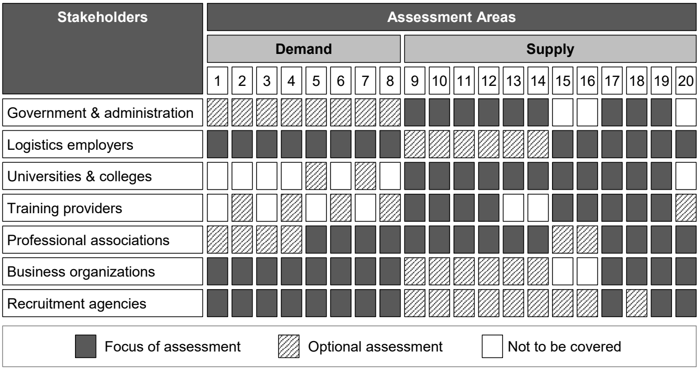

Figure 8: Matching Stakeholder Groups and Assessment Areas

optionally depending on local circumstances and the interviewee's expertise. Figure 8 provides an abbreviated version of this match-making matrix.

4.1.5 Schedule Interviews and Adapt Interview Guide

After a suitable sample of interviewees has been selected, individual meetings have to be scheduled and the interview guides customized accordingly. To facilitate the data collection, the toolkit provides examples of interview questions for every assessment area. The interviewee still has some discretion over the tailoring of questions to the type of interviewee.

4.2 Phase 2: Assessment

The second phase of the assessment outlines the process of collecting data from interviews and offers advice on data analysis. The toolkit user is also provided with methodological recommendations and templates that can be used for data collection and analysis.

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A4: Skills Level of Existing Administrative Logistics Employees

Examples of Interview Questions	Maturity Level				
	Level 1 Minimal Capability	**Level 2** Marginal Capability	**Level 3** Average Capability	**Level 4** Advanced Capability	**Level 5** Global Best Practice
▪ Do administrative logistics staff possess the right skills for their job? ▪ If not, what are the main skills they lack? ▪ What are the consequences of administrative logistics staff lacking the right skills? ▪ What share of administrative logistics staff needs to receive top-up training in their first months of employment? ▪ What share of logistics administrators are promoted to managerial logistics positions within 5 years (period might not apply to small companies)?	Administrative logistics personnel does not possess the necessary skills for their job Incidents caused by a lack of skills happen frequently New employees have to receive introductory training to close skills gaps		Administrative logistics personnel possesses the necessary skills for their job They only seldom have to receive introductory training		Administrative logistics personnel exceeds skills requirements They often participate in advanced training to improve their logistics skills Logistics supervisors are recruited from highly skilled administrative personnel

Evidence for Maturity Assessment:

Maturity Score (1-5):

Figure 9: Example of Template for Data Collection

4.2.1 Conduct Interviews

The toolkit offers a range of recommendations for conducting the interviews. For example, the toolkit user might request the presence of two or three complementary interviewees: in the case of a company, it might be useful to interview HR-personnel together with a logistics executive to get the full picture of recruiting and retaining logistics staff. To facilitate the data collection and maturity assessment, the toolkit provides templates for each assessment area. Figure 9 gives an example. Each template consists of exemplary questions, the maturity levels defined, and a blank space for writing down evidence for the maturity assessment. Also, the toolkit user should indicate his/her assessment score on a 1-5 Likert scale at the bottom of the page. The descriptions that are provided for maturity levels one, three, and five should be considered as generic descriptions and necessarily related to the specific situation in the country. The templates are designed to be used during the interviews. Some questions will be common to all templates and should always be asked to ensure consistency. Others will be tailored to particular stakeholders, but again should be considered compulsory. Interviewers can supplement these questions with others that they wish to include to probe more deeply in particular areas. These can be added during the course of the survey in the light of issues that arise in the early interviews. It will also be helpful to obtain the interviewees' views on the reasons for potential skills shortages and possible ways of correcting the problem. For this reason, the toolkit provides some 'diagnostic' and 'remedial' questions, which can be asked towards the end of the interview to broaden the discussion and generate data for the recommendation section of the study. It is assumed that a typical interview lasts around one hour.

4.2.2 Assess Maturity Levels

Based on the findings from all interviews (all individual maturity assessments), the toolkit user then has to determine the overall maturity level of each assessment area. In some cases, it might be sufficient to calculate the average of the individual scores awarded for each assessments area. In others, the interviewee may wish to adjust this numerical score in the light of the overall impression they gained during the course of the interviews. In this context, it is important to keep in mind that the maturity assessment is subjective and not expected to provide a statistically reliable measure.

4.2.3 Prepare Preliminary Assessment Report

The second phase of the assessment will culminate in a report that uses the empirical data to judge the supply and demand of logistics skills as well as the nature and scale of possible skills shortages. First of all, the report should contain the full list of interviewees along with details on the organization they are associated with. It should also be made clear which assessment areas were discussed with each interviewee. Then, the findings for each assessment area should be discussed in detail. The maturity assessment should be supported by evidence gathered during the interviews. If additional quantitative data became available, it should also be used to make a case for the assessment. To make the findings more manageable, the toolkit user should highlight the assessment areas in which the need for public policy intervention is greatest and which offer the most promising potential for 'quick wins.' These will be the main focus of the subsequent recommendations. It is anticipated that the main audience for the report will be policy makers within the country. However, it should be written in a style that is also accessible to other stakeholder groups and contain enough background information about the country to allow readers elsewhere, e.g. in international organizations, to understand the arguments.

4.3 Phase 3: Recommendations

The third phase of the assessment formulates a series of recommendations to governments and other stakeholders on how to deal with the identified skills shortage in logistics.

4.3.1 Identify Policy Responses

Policy recommendations can come from three sources. First, the toolkit provides a list of actions that could be taken by different stakeholders. Figure 10 gives examples of possible actions. The recommendations are relatively generic and, thus, have to be adapted to the specific situation in the country under investigation. They are intended to function as a starting point for the discussion. Second, the interviews will have yielded some useful ideas on how to tackle specific skills and training issues. Third, the description of the global best practice maturity level of each assessment area provides input for making recommendations. However, toolkit users should be aware that the best practice scenario might not be a realistic goal for most low- and middle-income countries.

4.3.2 Conduct Focus Group Discussion

The development and subsequent endorsement of policy recommendations can be assisted by a focus group discussion (Sanchez Rodrigues et al. 2010). The focus group would comprise 8-10 key participants with a strong interest and expertise in logistics skills/HR issues and represent the main stakeholders. It is likely that many of them will already have been interviewed. The group will participate in a discussion typically lasting a half-day and professionally facilitated. They will be given a summary of the results of the skills assessment (including the prioritization of assessment areas) and then invited to discuss a range of issues, including (1) their reactions to the skills assessment (2) reasons for the observed skills shortages, (3) what can be done to reduce these shortages and (4)

Stakeholders	Examples of Actions					
Government & administration	Supplement infrastructure investments with logistics capability investments	Use regulation to improve working conditions in the logistics sector	Facilitate multi-stakeholder collaboration	Enhance the image of logistics within the country	Raise skill level in state-owned logistics businesses	…
Logistics employers	Implement regular in-house training by internal experts	Design standardized training programs with external support	Consider further development of soft and leadership skills	Device career paths for logisticians	Implement regular performance reviews of employees	…
Educational institutions	Collaborate with institutions specializing in logistics abroad	Leverage logistics associations and public-private-partnerships	Design logistics student exchange programs	Set up joint logistics programs with universities abroad	Facilitate collaboration with local companies	…
Associations & organizations	Offer training at local (or even discounted) rates	Consult governments	Provide train-the-trainer education	Collaborate closely with industry to keep the training up-to-date	Adopt recognized skill certification programs for logistics and transport	…

Figure 10: Example of Actions to be taken by Different Stakeholders

what should be the roles of the various stakeholders. A focus group discussion is expected to better inform the policy process and also to secure support for subsequent action from the various stakeholder groups.

4.3.3 Prepare Final Assessment Report

Phase 3 again culminates in a report, this time summarizing the recommendations for policy responses. If possible, the recommendations should be defined in a SMART way as they should be specific, measurable, assignable, realistic and time-related (Doran 1981): they should target a particular area for improvement (specific), should quantify or at least suggest an indicator of progress (measurable), should identify the responsible stakeholder (assignable), should state what results can actually be achieved given available resources (realistic) and should indicate when the result can be achieved (time-related). Also, the recommendations should be limited to a manageable number of effective actions that could truly improve logistics skills and training in the country.

5 Piloting the Toolkit

To test and further refine the toolkit, a pilot study of the first two phases was performed. Togo was chosen as a suitable pilot country. Togo is a small, sub-Saharan economy located between Benin and Ghana. It has a population of around 7.8 million with nearly 60% of the people being younger than 25 years (CIA 2017). Since Togo exports significant amounts of phosphates, cocoa, coffee, and cotton, logistics is key to economic prosperity. Togo ranks 92nd in the World Bank's 2016 Logistics Performance Index (LPI) with a score of 2.62 (Arvis et al. 2016). Taking into account the 2014 results (139th, LPI score of 2.32), the country improved substantially and is now considered being among the top-performing low-income countries. In summary, Togo seemed to be a good fit for a pilot study.

The assessment was carried out in January 2017 within a span of 10 days and encompassed 24 in-depth interviews with local logistics stakeholders. The interviewees were selected so as to cover all stakeholders groups identified in the toolkit. Interviews were carried out with logistics service providers, shippers, private training providers, national ministries dealing with transport and professional training, recruitment agencies, logistics industry associations, and the Chamber of Commerce. The interviews covered a wide range of assessment areas. The main results were:

- At the administrative and managerial levels, most logistics staff possess the necessary skills for their job. At the operative and supervisory levels, however, only about half of staff were deemed to be sufficiently qualified.
- Staff shortages were reported at varying degrees at all four employment levels.
- No clear career paths exist for logistics employees.
- None of the universities based in Togo offers specialized courses in logistics.
- Views on the quality of private training providers in logistics varied widely.
- Vocational training in logistics is not widely offered.
- Very few employees have specialist qualifications/certifications in logistics.

— Specialized recruitment agencies, if at all, are mostly used for employment levels 3 and 4.

A more detailed analysis of the interviews is currently being prepared. The results of the pilot study will inform a Technical Assistance activity carried out by the World Bank that focuses on enhancing the competitiveness of logistics services in Togo. The activity will entail financial support to train freight forwarders including curriculum development and a train-the-trainer scheme. The creation of youth employment and retraining of older workers displaced by reforms will be two of the main objectives.

6 Conclusion and Outlook

This paper introduces a toolkit to measure logistics skills shortages in developing countries and defining adequate policy responses. It is mainly aimed at national governments in low- and middle-income countries and provides a broad overview based on qualitative data. The paper explains how the toolkit was developed, what it contains, and how we piloted it. Future research opportunities will include (1) use of more pilot studies to show how the toolkit can be calibrated to countries at different levels of economic development and logistics maturity (i.e. refining scales and adapting questions) and (2) upgrading the toolkit to include the collection of quantitative data and, thus, give the assessment a higher degree of objectivity. Dissemination of the toolkit should help to monitor and facilitate the development of logistics skills worldwide.

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References

Arvis, J.-F., D. Saslavsky, L. Ojala, B. Shepherd, C. Busch, A. Raj, and T. Naula (2016). *Connecting to Compete 2016: Trade Logistics in the Global Economy - The Logistics Performance Index and Its Indicators*. Washington, D.C.: The World Bank.

Battista, C. and M. M. Schiraldi (2013). "The Logistic Maturity Model: Application to a Fashion Company". In: *International Journal of Engineering Business Management* 5.29, pp. 1–11.

Bond, S. and H. Wollaston (2015). *Routes to Diversity & Inclusion - A Toolkit to Help Employers Recruit, Retain and Develop a Diverse Workforce*. London: Chartered Institution of Highways & Transportation.

Capgemini and C. J. Langley (2017). *21st Annual Third-Party Logistics Study: The State of Logistics Outsourcing*. Atlanta: Capgemini Consulting.

CIA (2017). *World Factbook: Togo*. Washington, D.C.: Central Intelligence Agency.

CILT (2016). *Professional Development Directory 2016 - Qualifications and Training*. London: Chartered Institute of Logistics and Transport.

Costello, B. and R. Suarez (2015). *Truck Driver Shortage Analysis*. Arlington: American Trucking Associations.

Cottrill, K. (2010). *Are You Prepared for the Supply Chain Talent Crisis?* Cambridge: MIT Center for Transportation & Logistics.

Cronjé, J. N. (2015). "Logistics Management Skills Development: A Zimbabwean Case". In: *Journal of Transport and Supply Chain Management* 9.1, pp. 1–9.

Derwik, P., D. Hellström, and S. Karlsson (2016). "Manager Competences in Logistics and Supply Chain Practice". In: *Journal of Business Research* 69.11, pp. 4820–4825.

Doran, G. (1981). "There's a S.M.A.R.T. Way to Write Management's Goals and Objectives". In: *Management Review* 70.11, pp. 35–36.

Fawcett, S. E. and S. M. Rutner (2014). "A Longitudinal View of Supply Chain Education: Assessing the Challenge of Retaining Relevance in Today's Dynamic Marketplace". In: *International Journal of Logistics Management* 25.1, pp. 180–201.

Flöthmann, C. and K. Hoberg (2017). "Career Patterns of Supply Chain Executives: An Optimal Matching Analysis". In: *Journal of Business Logistics* 38.1, pp. 35–54.

Gammelgaard, B. and P. D. Larson (2001). "Logistics Skills and Competencies for Supply Chain Management". In: *Journal of Business Logistics* 22.2, pp. 27–50.

Hoberg, K., K. Alicke, C. Flöthmann, and J. Lundin (2014). "The DNA of Supply Chain Executives". In: *Supply Chain Management Review* November, pp. 36–43.

Jhawar, A., S. K. Garg, and S. N. Khera (2014). "Analysis of the Skilled Work Force Effect on the Logistics Performance Index: Case Study from India". In: *Logistics Research* 117.7, pp. 1–10.

Kersten, W., M. Seiter, B. von See, N. Hackius, and T. Maurer (2017). *Trends and Strategies in Logistics and Supply Chain Management – Digital Transformation Opportunities*. Hamburg: DVV Media Group.

Kotzab, H. and S. Wünsche (2015). "Competences and Qualifications of Logistic Managers - An Empirical Analysis of Job Postings in Germany". In: *Logistics Management*. Ed. by J. Dethloff, H. Haasis, H. Kopfer, H. Kotzab, and J. Schönberger. Cham: Springer, pp. 517–527.

Lahti, M., A. H. M. Shamsuzzoha, and P. Helo (2009). "Developing a Maturity Model for Supply Chain Management". In: *International Journal of Logistics Systems and Management* 5.6, pp. 654–678.

Large, R. O., T. Breitling, and N. Kramer (2014). "Driver Shortage and Fluctuation: Occupational and Organizational Commitment of Truck Drivers". In: *Supply Chain Forum: An International Journal* 15.3, pp. 66–72.

Lutz, H. and L. Birou (2013). "Logistics Education: A Look at the Current State of the Art and Science". In: *Supply Chain Management: An International Journal* 18.4, pp. 455–467.

McKinnon, A., C. Flöthmann, K. Hoberg, and C. Busch (2017). *Logistics Competences, Skills and Training: A Global Overview*. Washington, D.C.: The World Bank.

McNelly, J. (2013). *Developing Skilled Workers: A Toolkit for Manufacturers on Recruiting and Training a Quality Workforce*. Washington, D.C.: The Manufacturing Institute.

Mehmann, J., V. Frehe, and F. Teuteberg (2015). “Crowd Logistics – A Literature Review and Maturity Model”. In: *Innovations and Strategies for Logistics and Supply Chains*. Ed. by W. Kersten, T. Blecker, and C. Ringle. Hamburg: epubli, pp. 117–145.

Mendes Jr., P., J. E. Leal, and A. M. T. Thomé (2016). “A Maturity Model for Demand-Driven Supply Chains in the Consumer Product Goods Industry”. In: *International Journal of Production Economics* 179, pp. 153–165.

Murphy, P. R. and R. F. Poist (1991). “Skill Requirements of Senior-Level Logistics Executives: An Empirical Investigation”. In: *Journal of Business Logistics* 12.2, pp. 73–95.

Murphy, P. R. and R. F. Poist (2006). “Skill Requirements of Contemporary Senior- and Entry-Level Logistics Managers: A Comparative Analysis”. In: *Transportation Journal* 45.3, pp. 46–60.

Onar, S. C., E. Aktas, Y. I. Topcu, and D. Doran (2013). “An Analysis of Supply Chain Related Graduate Programmes in Europe”. In: *Supply Chain Management: An International Journal* 18.4, pp. 398–412.

Rahman, S. and L. Yang (2012). “Skill Requirements for Logistics Professionals in China: An Importance- Expertise Matrix Analysis.” In: *Supply Chain Forum: An International Journal* 13.2, pp. 40–52.

Royal Academy of Engineering (2015). *Increasing Diversity and Inclusion in Engineering – A Case Study Toolkit*. London: Royal Academy of Engineering.

Rushton, A., P. Croucher, and P. Baker (2017). *The Handbook of Logistics and Distribution Management*. 6th ed. London: Kogan Page.

Sanchez Rodrigues, V., M. Piecyk, A. Potter, A. McKinnon, M. Naim, and J. Edwards (2010). “Assessing the Application of Focus Groups as a Method for Collecting Data in Logistics”. In: *International Journal of Logistics: Research and Applications* 13.1, pp. 75–94.

Shepherd, B. (2011). *Logistics Costs and Competitiveness: Measurement and Trade Policy Applications*. Washington, D.C.: The World Bank.

Sinha, A., W. P. Millhiser, and Y. He (2016). “Matching Supply with Demand in Supply Chain Management Education”. In: *The International Journal of Logistics Management* 27.3, pp. 837–861.

Skills for Logistics (2015). *The Professional Development Stairway for Logistics*. Bristol: Skills for Logistics.

The World Bank (2010). *Trade and Transport Facilitation Assessment - A Practical Toolkit for Country Implementation*. Washington, D.C.: The World Bank.

Trautrims, A., C. Defee, and T. Farris (2016). “Preparing Business Students for Workplace Reality – Using Global Virtual Teams in Logistics and SCM Education”. In: *The International Journal of Logistics Management* 27.3, pp. 886–907.

Digitalization of Logistics Processes and the Human Perspective

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This contribution presents an analysis of the increasing consequences of digitalization with a focus on self-monitoring of personnel in logistics and production processes. This is of interest as digitalization requires large-scale innovative implementation and change management approaches in logistics and production processes. Based on standard DIN ISO 10.075 ('risk assessment') an application-oriented instrument is developed to evaluate und test new job systems, which are impacted by digitalization. This enables the development of digitalization strategies and an option analysis for further digitalization investments based on human workforce orientation. Furthermore, individual concepts for recruiting and selecting qualified personnel for digital job systems could be derived. Such an application-oriented risk assessment tool has the goal of analyzing the increasing digitalization concerning the self-monitoring of personnel and delivers options for the organization and formation of job systems in production and logistics. Afterwards, additional measures for innovative digital job systems for SCM processes and tasks can be derived. These additional measures can also be transferred to other industries in the service sector. This contribution presents first results concerning an in-depth document analysis based on DIN ISO 10.075 in comparison with existing logistics research literature and business practice knowledge.

Keywords: digitalization; risk assessment; change management; mental stress

1 Introduction

Digitalization and automation developments are an important trend in logistics and transportation processes, usually connected to many expectations regarding cost reduction as well as environmental and social (e.g. work conditions, safety) improvements (Caballini et al., 2016; Zijm and Klumpp, 2016; Abdallah et al., 2015; Nossack and Pesch, 2013; Wang and Yun, 2013). For example, in road transportation as one of the major processes in global supply chains as well as a huge employment sector, autonomous driving is foreseen to bring about a revolution in effectiveness in economic as well as environmental and social terms (Bazilinskyy and de Winter, 2017; Brown et al., 2017; Meyer et al., 2017; Ni and Hu, 2017; Pham and Jeon, 2017; Kalra and Paddick, 2016; Levin and Boyles, 2016; Rodriguez-Castano et al., 2016; Talebpour and Mahmassani, 2016; Wietholt and Harding, 2016). Though obviously the persons involved – e.g. truck drivers – are affected greatly, research and business development does largely neglect the "human factor" within such developments, mostly technical and economic aspects are addressed in publications as well as projects (Klumpp, 2017a; Königs and Gijselaers, 2015; Koo et al., 2015; Weyer et al., 2015). This is connected to the concept of a balanced triple bottom line approach for forwarders and logistics service providers (Klumpp, 2017b) as well as a future importance of especially social and security dimensions in road transport (Anund et al., 2017; Nowakowski et al., 2015; Ohlson and Asvalder, 2015; Nuzzolo and Comi, 2014; Wu and Huang, 2013; Meech and Parreira, 2011), also labelled the "human factor". This again is linked to the questions of e.g. further logistics management and driver training (e.g. Todorova et al., 2016) as well as a further calculation of sustainability improvements compared to the current situation (emission and reduction simulations based on existing models, Zhang et al., 2016; Valverde et al., 2016). This also adheres to the core mission of logistics regarding competitive advantages of supply chain actors (Kasarda, 2017). The research question regarding digitalization applications therefore is: RQ: How can an economic, environmental and social viable integration and preparation of human workers within the expected digitalization of logistics processes be attained in the future?

This analysis is affiliated with developments regarding digitalization and the physical internet and industry 4.0 concepts with e.g. big data applications at the core of those developments (Handfield, 2017; Montreuil et al., 2012; Montreuil, 2011).

The contribution is structured as follows: After this introduction, the second section outlines trend developments in logistics. Section three describes the crucial significance of the human factor in logistics and transportation processes. Section four provides a detailed outline of the relevant international standards regarding mental health of workers connected to digitalization. Section five finally outlines implications for specific logistics fields.

2 Trends in Logistics Processes

Digitalization is driven by technological progress in three different areas. First, there is the part ’IT and software’, which includes cloud technologies, mobile applications, big data technologies and artificial intelligence. The second part is ’robotic and sensor technology’ and the third part contains ’networking’, which means cyber physical systems for internet of things and industry 4.0 (BMWi et al., 2017, p. 5; Zijm and Klumpp, 2016, p. 2). This builds the foundation for current trends in logistics processes.

In a current study, which analyzes trends in the field of logistic and SCM, the authors structured trends in the categories ’business process management’, ’competitive advantage’, ’strategic management’ and ’network structure’ (Zijm and Klumpp, 2017, p. 367). The first category business process management means management of activities with the aim of output supply for customer requirements, e.g. reverse logistics, tracking & tracing and inventory/warehouse. Competitive advantage contains all the innovations, which helps companies to reach advantages, e.g. information technology/industry 4.0, sustainability or demographic change. Strategic management describes the ambition to reach efficiency resource allocation, e.g. human resources, organizational learning and skills/-competences. Network structure contains information and material flows as well as potentials, which originate in vertical or horizontal cooperation, e.g. collaboration, cooperation and supply chain integration (Zijm and Klumpp, 2017, p. 367).

Logistics trends could be further distinguished in ’global trends’, ’basal trends’, ’customer trends’ and ’economic cycle trends’. Global trends are for example the increasing integration of world trade (globalization) or corporate social responsibility (CSR). Basal trends, which mean technological and organizational developments, are for example physical internet and Auto-ID technologies as for example RFID. Customer trends could be special services, flexibility of individualization, for example mass customization. Economic cycle trends as GDP or autonomous trends as workload of international competitors or demand cycles are also factors, which influence logistic activities (Klumpp et al., 2016, pp. 4-11).

The logistic trend radar published by DHL distinguishes between 'social & business trends' on the one hand and 'technology trends' on the other hand. A typical example for social & business trends is 'fair & responsible logistics', therefore logistic players combine the economic aim of generating revenues with the social aim of increasing sustainability. Another example is 'on-demand delivery', which should satisfy the customer requirements concerning delivery time and locations, which means delivering their purchase at any time and any place. Typical examples for technology trends, which are in the focus of this publication, are 'augmented reality', 'bionic enhancement', 'robotic & automation' and 'self-driving vehicles'. Augmented reality provides with help of heads-up displays, e.g. smart glasses, contextual information to workers at the right time and in the right place. Bionic enhancement, for example wearable technologies and exoskeletons, helps the workers expand physical boundaries and reduce health and safety risks. Robotics and automation offer a wide range of support concerning manual handling activities. Self-driving vehicles, e.g. autonomous forklifts or driverless trucks, create new logistics aspects regarding safety, efficiency and quality (DHL, 2016, p. 13-17; Zijm and Klumpp, 2016, p. 2).

3 Significance of the Human Factor

Concerning the aforementioned trends in logistics processes, it is necessary that organizations rethink their educational systems, so that staff can handle new technologies and can work in the context of future concepts like the physical internet or cyber-physical-systems (Zijm and Klumpp, 2017, p. 367). Despite the proceeding digitalization in all logistics and production processes, the human factor still plays an important role (Becker, 2015, p. 25). In comparison to machines, human beings are clearly superior with their cognitive and sensorimotor skills as well as their creativity, experience and ability of solving problems - and so will still be needed in cyber-physical-systems (Günthner et al., 2014, p. 309). Furthermore, human beings are clearly superior compared to machines because of their ability of association, so they can be easy reskilled to other tasks und can react rapidly on modifications - a machine can just do for what it is constructed, but in a very rapid way with high accuracy of repetition (Schließmann, 2014, p. 454).

However, for future production and logistics systems, it has to be developed in which ways the human-machine-interaction takes place. However, human beings will still be in charge of the planning, controlling, managing and scheduling activities. For sure the work contents, work tasks, work processes and the environmental conditions will change. Furthermore, the requirements concerning the functional, regional and timely conditions will change for workers. Especially the aspects complexity, abstraction, problem solving, self-directed actions, communication and self-organization will be modified regarding their requirements for workers (Becker, 2015, p. 25-27). On the one hand, there will be work contents with high technical, technological, economical and IT-specific requirements and on the other hand, there will be work for low qualified workers (Becker, 2015, p. 27; Tödter et al., 2015, p. 73). The main tasks will change from manual, physical work to monitoring activities. The problem is that most of the low qualified worker will not understand what to do in case of interferences (Hirsch-Kreinsen, 2015, p. 90). To solve this problem it is necessary, that workers have a qualification profile which combines theoretical knowledge with practical experience (Hirsch-Kreinsen, 2015, pp. 90-91). It can be assumed that working places with low qualification requirements and easy, repetitive work will be substituted by machines; furthermore, tasks for high-qualified workers could not be needed in this form anymore, because of the automation of easy machine handling activities, material adjustments as well as some kinds of controlling and monitoring functions (Hirsch-Kreinsen, 2015, p. 91). These new tasks could be done by lower qualified und cheaper workers instead of high-qualified workers. Nevertheless, there can also be expected a requirement for higher qualified workers, because of the increased complexity and IT-based decentralization of decision, control and coordination activities (Hirsch-Kreinsen, 2015, pp. 91-92). The operative workers have to plan and coordinate the processes self-contained (Hirsch-Kreinsen, 2015, p. 92). A wide knowledge of the total processes as well as social competences with a high integration of different working groups and functional areas will be needed. Manual tasks will be less important, while particular programming knowledge as well as coordinating, managing and adjusting of complex systems will be more and more important. It seems that there will be a polarization of qualification: on the one hand, there will be needed high-qualified 'managers' for planning, controlling and coordination activities and on the other hand, there will be needed low qualified workers for easy tasks. The middle qualified workers will be substituted by automated cyber physical systems und will not be needed anymore, because these tasks are well structured and could be algorithmatized very easily (Hirsch-Kreinsen, 2015, pp. 92-95). Therefore, it is important that staff have the necessary education and qualification for new workplaces requirements, which has to be implemented into educational systems and advanced training systems.

4 International Standard for Mental Work-Load

4.1 Ergonomic Principles related to Mental Work-Load (DIN ISO 10075)

The basis for the risk assessment tool is the standard DIN ISO 10075 ('risk assessment'). Because of digitalization, job specifications and the qualification requirements for workers will change und causes new aspects concerning mental workload.

The first part of this standard (DIN ISO 10075-1:2015) determines general concepts, terms and definitions for ergonomic principles related to mental workload (DIN, 2015, p. 1). Mental stress can result from any activity, even a mostly physical activity, and is described as a result from any external influences, which concern human beings in a mentally way. It is possible, that mental stress results in positive and negative effects on human beings (DIN, 2015, p. 6). The term "mental stress" means all external influences, which concern human beings or workers mentally (DIN, 2015, p. 6). Mental stress comprises generally several external stress factors, which influence in their combination, not isolated, human beings and leads to cognitive, informational und emotional processes (DIN, 2015, p. 6). These stress factors can be categorized in four different parts (DIN, 2015, p. 13):

The first category 'task requirements' contains sustained attention (e.g. supervising a monitor for a very long time), information processing (e.g. to deal with a very high number of information or to deal with incomplete information), responsibility (e.g. to be responsible for co-workers health and safety), duration, temporal pattern and temporal position of action (e.g. distribution of working hours, rest periods and shift work), task content (e.g. the calculating, planning, executing and evaluating parts of work) and danger (e.g. underground working, handling explosive or dangerous goods, working directly beside highways).

The second category ’physical conditions’ contains lighting (e.g. very bright or dark lights, glare), climatic conditions (e.g. extreme heat or cold, air moisture), noise (e.g. very loud working areas), weather (e.g. working outside with extreme rain, storm, snow or extreme insolation) and odors (e.g intense or disgusting fragrances).

The third category ’social and organizational factors’ contains type of organization (e.g. organizational structure, hierarchy, communicational politics), organization climate (e.g. interpersonal relationships, meaning of human factor), group factors (e.g. size of working groups, cohesion), leadership (e.g. high or less controlling leadership), conflicts (e.g. between workers or between leader and workers) and social contacts (e.g. much teamwork and contacts to others or isolated workplaces).

The fourths category ’societal factors’ contains social demands (e.g. social corporate responsibility), cultural standards (e.g. good working conditions) and economic situation (e.g. labor market).

Mental stress, which will exceed human ability of information processing, will lead straight to errors in human performance. In this cases the mental stress reaches a level in which accomplishing tasks is generally impossible. So it is necessary that human-machine-interfaces will be modeled in an adequately way to avoid such mental stress situations (DIN, 2015, p. 7).

The term mental strain means the immediate effect of mental stress for every human being, which depends on individual preconditions (DIN, 2015, p. 9). Examples for individual preconditions can be grouped into four categories (DIN, 2015, p. 13):

Examples for the first category are level of aspiration, confidence in one’s own capabilities, motivation, attitude and coping style of each human being. The second category includes for example abilities, skills, knowledge and experience of human beings. General condition, health, age, gender, physical constitution and nutrition of human beings are examples for the third category. The last one, the fourth category describes for example actual condition and initial activation level of human beings.

4.2 Short- and long-term Effects

Mental strain can have different effects on human beings. On the one hand, it can have facilitating effects with short-term or long-term potential and on the other hand, it can have impairing effects with short-term or long-term potential (DIN, 2015, pp. 9-11).

There are four different examples for facilitating effects with short-term potential. The first one is the warming-up effect, which is a frequent effect of mental strain and results soon after the task begins in a reduction of effort compared to the effort at the beginning of this task. The next one is the activation effect, which is an internal state with increased mental and physical functional competence. Learning is another facilitating effect with short-term potential and is a process based on work experiences which results in changes concerning behavior or behavioral potential, for example for plans, attitudes and values. The last one of this category is the practice effect and means a permanent change in individual performances which results from the repeatedly reaction to mental strain (DIN, 2015, p. 9-10).

A facilitating effect with long-term potential is competence development, which comes from an intense discussion with a certain tasks. Impairing effects with long-term potential could be described by six different examples: mental fatigue, fatigue-like states of human beings, monotony, reduced vigilance, mental satiation and stress response (DIN, 2015, p. 11).

An impairing effect with long-term potential is burnout, which is a state of sensed mental, emotional and/or physical exhaustion. It is a distant attitude concerning own tasks and a perceived reduced performance as a result from prolonging exposure against mental stress, which results in impairing short-term effects (DIN, 2015, p. 11).

5 Implications for Logistics Processes

5.1 Implications for Augmented Reality

Generally, it can be determined that all digitalization processes have to be accepted by workers, so they work in efficiency ways and do their very best (BMWi et al., 2917, p. 21). Furthermore there has to be considered the privacy for each worker, because it can be necessary to use sensible data from workers for controlling such technical systems (Günthner et al., 2014, p. 318). The fear against the possibility of 'glassy staff' will influence the acceptance of digitalization processes (Hirsch-Kreinsen, 2015, pp. 92).

Augmented reality integrates background information for users into the field of view through smart glasses (DHL, 2016, p. 35; Günthner et al., 2014, p. 315). It can be used in several processes in warehouse operations, e.g. for picking processes; it is called in this context 'pick-by-vision-system' (DHL, 2016, p. 35; Günthner et al., 2014, p. 316; Schraven, 2017, p. 25). For workers this means an increase in process efficiency as well as an efficiency in quality and a reduction of strain in labor-intensive activities (DHL, 2016, p. 35; Günthner et al., 2014, p. 316). Furthermore smart glasses can be used to scan barcodes on the one hand and to navigate through warehouses on the other hand (DHL, 2016, p. 35). These information, for example for warehouse workers could be parking positions, article numbers, final destination of goods and are displayed at the edge of the visual field (Schraven, 2017, p. 25). Therefore, the user can see his working area in reality and the needed information virtually at the same time (Schraven, 2017, p. 25). Furthermore, augmented reality can be used to visualize danger areas at roads for drivers as a next generation of navigation and driver-assistance systems (DHL, 2016, p. 35). At least it can be used for intelligent loading in the way that the user sees through the smart glasses the optimal loading sequence of each shipment (DHL, 2016, p. 35).

The opportunities of this technology are hand-free operations, shorter handling-times in warehouses and a fast training because of very easy interface and the flexibility of language settings (DHL, 2016, p. 35). This technology is actually limited concerning deep frozen areas, because in these areas only very short working time is possible. It is necessary that these smart glasses have a high wearing comfort and the rack must take part in the several courses of movements of the user (Schraven, 2017, p. 25). Therefore, the weight has to be relatively low and the balance has to be well-adjusted (Schraven, 2017, p. 25). Smart glasses can be also used in driving processes as driving a forklift (Günthner et al., 2014, p. 316). The challenge for drivers is that their visual field is limited because of the mast and the loading units and additional information through smart glasses will limit the visual field additionally (Günthner et al., 2014, p. 317).

DIN ISO 10075-1 has the following implications for augmented reality as the first example for digitalization in logistics processes. From the first category of standard DIN ISO 10075-1 'task requirement' the aspects 'information processing' and 'task content' is relevant. Users get the information needed through the smart glasses. The aspect 'information processing' means that users get too much information through these glasses, more then they need and too much so handle. So they feel overstrained and overloaded because of too much information and too high complexity. Furthermore, the aspect 'task content' means that the users are not able to plan, control or evaluate the data shown by smart glasses. The users just execute what the smart glasses told them. A consequence could be that these users feel externally controlled by a virtual machine.

From the second category 'physical conditions' the aspect 'lightening' is relevant, because the smart glasses could have a gleaning effect. Furthermore, the weight of the glasses can affect the user as well as the wearing comfort.

The third category 'social and organizational factors' is relevant concerning two aspects. The first is 'leadership', which means in this context that users of smart glasses feel very controlled by their supervisors. This is because smart glasses should be connected directly into an information system. So, the supervisors can control for example at picking systems when which worker picks which item. As well the times needed for each pick and the times of non-work will be monitored. The second is 'social contacts' which can result in isolated workplaces and less interactions between co-workers, because the smart glasses 'show' the user everything what he has to know and no communications between human beings are necessary in extreme cases.

5.2 Implications for Bionic Enhancement

Bionic arms or smart contact lenses as examples for bionic enhancement can assist logistics work concerning communication and process implementation on the one hand and can reduce risks for workers health and safety on the other hand (DHL, 2016, p. 37). The idea is to reduce stress and strain which result from cyclical actions in all kind of manual handling activities (DHL, 2016, p. 37). In the future with help of smart wearable and ergonomically bionics work-related injuries should be purged (DHL, 2016, p. 37). Exoskeletons as one example of bionic enhancement can increase the user's strength and staying power, so older workers can execute longer their tasks (DHL, 2016, p. 37). Robo-Mate exoskeletons for example allow holding of things that are normally too heavy for a worker's hand (DHL, 2016, p. 37). Another advantage beside the decrease in work-related injuries is an increase in productivity and efficiency (DHL, 2016, p. 37).

DIN ISO 10075-1 has the following implications for bionic enhancement as the second example for digitalization in logistics processes. From the first category of standard DIN ISO 10075-1 'task requirement' the aspect 'danger' is relevant. Wearing bionic arms or smart contact lenses for example can lead to negative influences to the health of human bodies. There are no long-term studies concerning wearing exoskeletons all day long und use them in working activities.

The third category 'social and organizational factors' is relevant concerning two aspects. The first is 'group factors', which means in this context that the co-worker is a technical thing as a Robo-mate exoskeleton for example. It is not possible to have group factors like cohesion with a technical thing. The second is 'social contacts', which can result in isolated workplaces and less interactions between co-workers, because the exoskeletons take the role of a co-worker, but without human communication interaction.

5.3 Implications for Robotic & Automation

Robotics & Automation offers new opportunities in logistics processes and maintain a zero-defect process and increase in efficiency (DHL, 2016, p. 42; Hülsbömer, 2017, p. 48). One application for robots and automation is in warehousing and fulfillment processes by using them as assist workers for item picking, packing and sorting (DHL, 2016, p. 42; Hülsbömer, 2017, p. 49; Tödter et al., 2015, p. 71). These robots are prepared with high-definition cameras, pressure transducer and self-learning skills (DHL, 2016, p. 42; Hülsbömer, 2017, p. 49). Another example is using robots to load and unload trailer and container to benefit from robots strength (DHL, 2016, p. 42). The third example is robots, which are used for local delivery processes (DHL, 2016, p. 42). They can be used as assistant to delivery workers in the way that they go after the workers by transporting heavy items to the customers (DHL, 2016, p. 42). Furthermore, they can re-sort packages in the delivery vehicle or can transport autonomously letters or packages to fixed gathering places (DHL, 2016, p. 42). Beside more efficiency, another advantage is that robots help with physically and stressfully tasks, so workers can concentrate on more complex and planning activities (DHL, 2016, p. 42; Tödter et al., 2015, p. 74-75).

DIN ISO 10075-1 has the following implications for robotics & automation as the second example for digitalization in logistics processes. From the first category of standard DIN ISO 10075-1 'task requirement' two aspects are relevant. The first aspect is 'task content'. The workers have not programmed the robots and normally are not able to reprogram them in situations where the robots should do something else. So workers feel losing control over their assistants. Because the robots are machines, workers can't talk to them, ask them anything or discuss anything with them in situation where this could be necessary. The second relevant aspect is 'danger'. Working together very close with robots could be dangerous for human beings. Actual there exist legal restrictions on the use of robots near human workers (DHL, 2016, p. 42).

The third category 'social and organizational factors' is relevant concerning two aspects. The first is 'group factors', which means in this context that the assistant of a worker is a robot. It is not possible to have group factors like cohesion with a technical thing, in this case a robot. The second is 'social contacts' which can result in isolated workplaces and less interactions between workers, because the robot assistant can't talk, interact, discuss or have any human abilities which define human interactions or interpersonal relationships.

5.4 Implications for Self-Driving vehicles

The first step of self-driving vehicles took place in accurately monitored environments such as warehouses or yards for example (DHL, 2016, p. 43; Hülsbömer, 2017, p. 50; Lassau, 2017, p. 15; Tödter et al., 2015, pp. 69-70). The next step is self-driving vehicles in common and open areas, for example highways or streets (DHL, 2016, p. 43). Actually there are very exact laws concerning the usage of such vehicles in open areas, but there will be still worked on the acceptance of fully driverless vehicles (DHL, 2016, p. 43). There are four different applications for self-driving vehicles. The first one is the use of autonomous forklifts, pallet movers and swarm conveyor belt systems in warehouses (DHL, 2016, p. 43; Hülsbömer, 2017, p. 50; Lassau, 2017, p. 15). The second possibility are outdoor logistics operations for automate container handling at terminals, in which self-driving vehicles that are intelligently composed, transport and stack the containers as needed (DHL, 2016, p. 43; Hülsbömer, 2017, p. 50). The third option is line-haul transportation, which often includes very long tours overnight (DHL, 2016, p. 43). One possibility is an autonomous highway, which needs the driver only for entering and leaving the highway (DHL, 2016, p. 43). The last possibility is an autonomous last-mile delivery, where self-driving trolleys go after workers and can support them by transporting the packages (DHL, 2016, p. 43). The problems are that legal restrictions in many countries forbid driverless vehicles (DHL, 2016,

p. 43). Furthermore, there is a risk from hackers and software bugs, affirmation and responsibility aspects must be reconsidered and the social acceptances of such systems by workers on the one hand and by public on the other hand have to be considered (DHL, 2016, p. 43).

DIN ISO 10075-1 has the following implications for self-driving vehicles as the fourth and last example for digitalization in logistics processes. From the first category of standard DIN ISO 10075-1 'task requirement' four aspects are relevant. The first aspect is 'sustained attention'. This means for example watching a screen for prolonged periods. Currently it is not allowed that completely self-driving vehicles operate on public areas, so a human driver has to be inside such vehicle. Because of the self-driving competence of the vehicle a driver is for a long time in a non-working period. Just in case of any problems, the driver has to react and interfere. The problem is that after a long period of non-use human beings fall into some kind of stand by modus and then it is difficult for them to react very fast and with high concentration. The second one is 'duration, temporal pattern and position of action'. The argumentation is nearly the same as for the first aspect 'sustained attention'. Drivers have a long period of non-use, which is very exhausting and unsatisfactory and then they have to react immediately in dangerous situations. The third relevant aspect is 'task content'. Generally the main task of a driver is driving. If self-driving vehicles will take care of this task and the driver has just a monitoring task, the task content will change completely. The fourth relevant aspect is 'danger'. Being in a self-driving vehicle could be dangerous if hackers or software bugs lead to any kind of accidences. Drivers could feel other-directed by the self-driving vehicle and have to trust it concerning his live and health.

6 Conclusions

Digitalization will definitively shape logistics and supply chain processes in the future. However, the core question of future economic and social competitiveness of corporate operations will be how digitalization is implemented and especially how human workers are integrated in and prepared for these developments.

Regarding the propose research question of how an economic, environmental and social viable integration and preparation of human workers within the expected digitalization of logistics processes can be attained in the future, the detailed answer proposed in this contribution is by extensively looking into specific areas and processes in the logistics sector, e.g. with the structural help of industry standards like the analyzed DIN ISO 10.075. As outlined in section 5, many implication areas for logistics can be identified and therefore further enquiries and research are necessitated.

Viable options for further research are piloting and testing endeavors in real-life business contexts as well as further in-depth analysis of further sections of the DIN ISO 10.075 standard (desk research). In combination, this may shed more light onto the future developments that await us in the logistics domain regarding digitalization and the integration of human workers within this major development of our economies and global value chains.

References

Anund, A., C. Fors, and C. Ahlstrom (2017). “The severity of driver fatigue in terms of line crossing: a pilot study comparing day- and night time driving in simulator.” In: *European Transport Research Review* 9.31.

Bauernhansl, T., M. ten Hompel, and B. Vogel-Heuser, eds. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Wiesbaden: Springer Fachmedien Wiesbaden.

Bazilinskyy, P. and J. de Winter (2017). “Analyzing crowdsourced ratings of speech-based take-over requests for automated driving.” In: *Applied Ergonomics* 64, pp. 56–64.

Becker, K.-D. (2015). “Arbeit in der Industrie 4.0 - Erwartungen des Instituts für angewandte Arbeitswissenschaften e.V.” In: *Zukunft der Arbeit in Industrie 4.0*. Ed. by A. Botthof and E. A. Hartmann. Berlin: Springer, pp. 23–29.

Ben Abdallah, K., M. Belloumi, and D. de Wolf (2015). “International comparisons of energy and environmental efficiency in the road transport sector”. In: *Energy* 93, pp. 2087–2101.

Botthof, A. and E. A. Hartmann, eds. (2015). *Zukunft der Arbeit in Industrie 4.0*. Berlin: Springer.

Brown, M., J. Funke, S. Erlien, and J. C. Gerdes (2017). “Safe driving envelopes for path tracking in autonomous vehicles”. In: *Control Engineering Practice* 61, pp. 307–316.

Bundesministerium für Wirtschaft und Energie, Bundesminsterium für Arbeit und Soziales (BMAS), Bundesministerium der Justiz und für Verbraucherschutz (n.d.). *Digitalpolitik für Wirtschaft, Arbeit und Verbraucher. Trends - Chancen - Herausforderungen.* www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/digitalpolitik.pdf.

Caballini, C., S. Sacone, and M. Saeednia (2016). “Cooperation among truck carriers in seaport containerized transportation”. In: *Transportation Research Part E: Logistics and Transportation Review* 93, pp. 38–56.

Dailey-Hebert, A. and K. S. Dennis, eds. (2015). *Transformative perspectives and processes in higher education*. Vol. 6. Advances in Business Education and Training. Cham: Springer International Publishing.

Deutsches Institut für Normung e.V. (n.d.). *Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung - Teil 1: Allgemeine Konzepte und Begriffe (ISO/DIS 10075-1:2015)*. Berlin.

DHL Customer Solutions & Innovation (2016). *Logistics Trend Radar*.

Freitag, M., H. Kotzab, and J. Pannek, eds. (2017). *Dynamics in logistics: Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany*. Lecture notes in logistics. Cham, Switzerland: Springer.

Günthner, W., E. Klenk, and P. Tenerowicz-Wirth (2014). "Adaptive Logistiksysteme als Wegbereiter der Industrie 4.0". In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by T. Bauernhansl, M. ten Hompel, and B. Vogel-Heuser. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 297–323.

Handfield, R. (2017). "Preparing for the Era of the Digitally Transparent Supply Chain: A Call to Research in a New Kind of Journal." In: *Logistics* 1.2.

Hirsch-Kreinsen, H. (2015). "Entwicklungsperspektiven von Produktionsarbeit." In: *Zukunft der Arbeit in Industrie 4.0*. Ed. by A. Botthof and E. A. Hartmann. Berlin: Springer, pp. 89–98.

Hülsbömer, D. (n.d.). "Wie von Geisterhand gesteuert. Smarte Intralogistik. Eine ganze Branche ist in Bewegung geraten: In den Lagern ziehen automatische Systeme ein und bringen Einsparungen mit sich. Ein einzelner Roboter rechnet sich nach einigen Jahren, elektromagnetische Antriebe lohnen sich bei großen Neubauten." In: *BIP Business Logistics* 8.2, pp. 48–50.

Kalra, N. and S. M. Paddock (2016). "Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?" In: *Transportation Research Part A: Policy and Practice* 94, pp. 182–193.

Kasarda, J. (2017). "Logistics Is about Competitiveness and More". In: *Logistics* 1.1, p. 1.

Klumpp, M., T. Neukirchen, and S. Jäger (2016). "Logistikqualifikation und Gamification – Der wissenschaftliche und fachpraktische Ansatz des Projektes MARTINA". In: *ild Schriftenreihe Logistikforschung* 51.

Klumpp, M. (2017a). "Artificial Divide: The New Challenge of Human-Artificial Performance in Logistics". In: *Innovative Produkte und Dienstleistungen in der Mobilität*. Ed. by H. Proff and T. M. Fojcik. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 583–593.

Klumpp, M. (2017b). "Do Forwarders Improve Sustainability Efficiency? Evidence from a European DEA Malmquist Index Calculation". In: *Sustainability* 9.5, p. 842.

Königs, K. D. and W. H. Gijselaers (2015). "Bringing learning to the workplace: A smartphone app for reflection and increased authenticity of learning." In: *Transformative perspectives and processes in higher education*. Ed. by A. Dailey-Hebert and K. S. Dennis. Vol. 6. Advances in Business Education and Training. Cham: Springer International Publishing, pp. 117–135.

Koo, J., J. Kwac, W. Ju, M. Steinert, L. Leifer, and C. Nass (2015). "Why did my car just do that? Explaining semi-autonomous driving actions to improve driver understanding, trust, and performance." In: *International Journal on Interactive Design and Manufacturing* 9.4, pp. 269–275.

Lassau, G. (2017). "Flexibilisierung ist Trumpf. Die Anforderungen an flexible Prozesse in der Logistik werden durch E-Commerce und Digitalisierung weiter steigen. Durchgängige Softwarelösungen sind gefragt." In: *Logistik heute, Software in der Logistik, Sonderheft*, pp. 14–15.

Levin, M. W. and S. D. Boyles (2016). "A multiclass cell transmission model for shared human and autonomous vehicle roads". In: *Transportation Research Part C: Emerging Technologies* 62, pp. 103–116.

Meech, J. and J. Parreira (2011). "An interactive simulation model of human drivers to study autonomous haulage trucks". In: *Procedia Computer Science* 6, pp. 118–123.

Meyer, J., H. Becker, P. M. Bösch, and K. W. Axhausen (2017). "Autonomous vehicles: The next jump in accessibilities?" In: *Research in Transportation Economics*.

Montreuil, B. (2011). “Toward a Physical Internet: meeting the global logistics sustainability grand challenge”. In: *Logistics Research* 3.2-3, pp. 71–87.

Montreuil, B., R. D. Meller, and E. Ballot (2012). “Physical Internet Foundations”. In: *IFAC Proceedings Volumes* 45.6, pp. 26–30.

Ni, J. and J. Hu (2017). “Dynamics control of autonomous vehicle at driving limits and experiment on an autonomous formula racing car”. In: *Mechanical Systems and Signal Processing* 90, pp. 154–174.

Nossack, J. and E. Pesch (2013). “A truck scheduling problem arising in intermodal container transportation”. In: *European Journal of Operational Research* 230.3, pp. 666–680.

Nowakowski, C., E. Shladover, and H.-S. Tan (2015). “Heavy vehicle automation: Human factors lessons learned.” In: *Procedia Manufacturing* 3, pp. 2945–2952.

Nuzzolo, A. and A. Comi (2014). “A system of models to forecast the effects of demographic changes on urban shop restocking”. In: *Research in Transportation Business & Management* 11, pp. 142–151.

Ohlson, E. and A.-L. Osvalder (2015). “Truck Drivers’ Postural and Visual Behavior an Explorative Study to Understand Expectations on Current Designs and Future Vehicles”. In: *Procedia Manufacturing* 3, pp. 6116–6123.

Pham, C. C. and J. W. Jeon (2017). “Robust object proposals re-ranking for object detection in autonomous driving using convolutional neural networks”. In: *Signal Processing: Image Communication* 53, pp. 110–122.

Proff, H. and T. M. Fojcik, eds. (2017). *Innovative Produkte und Dienstleistungen in der Mobilität*. Wiesbaden: Springer Fachmedien Wiesbaden.

Rodriguez-Castaño, A., G. Heredia, and A. Ollero (2016). “High-speed autonomous navigation system for heavy vehicles”. In: *Applied Soft Computing* 43, pp. 572–582.

Schließmann, A. (2014). “iProduction, die Mensch-Maschine-Kommunikation in der Smart Factory”. In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by T. Bauernhansl, M. ten Hompel, and B. Vogel-Heuser. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 451–480.

Schraven, R. (2017). “Neue Sichtweisen. Pick-by-Vision-systeme können Vorteile für eine effiziente, durchgehend vernetze Supply Chain bieten - nicht nur, wenn es um schnelldrehende Konsumgüter geht.” In: *Logistik heute, Software in der Logistik, Sonderheft*, pp. 24–26.

Talebpour, A. and H. S. Mahmassani (2016). “Influence of connected and autonomous vehicles on traffic flow stability and throughput”. In: *Transportation Research Part C: Emerging Technologies* 71, pp. 143–163.

Todorova, M., A. Dzhaleva-Chonkova, and K. Karagyozov (2016). “KNOW-IN Project Outcomes in Support of Training Road Transport Managers”. In: *Transportation Research Procedia* 14, pp. 1492–1499.

Tödter, J., V. Viereck, T. Krüger-Basjmeleh, and T. Wittmann (2015). “Steigerung des Autonomiegrades von autonomen Transportrobotern im Bereich der Intralogistik - technische Entwicklungen und Implikationen für die Arbeitswelt 4.0”. In: *Zukunft der Arbeit in Industrie 4.0*. Ed. by A. Botthof and E. A. Hartmann. Berlin: Springer, pp. 69–75.

Valverde, V., M. T. Pay, and J. M. Baldasano (2016). “Ozone attributed to Madrid and Barcelona on-road transport emissions: Characterization of plume dynamics over the Iberian Peninsula”. In: *Science of The Total Environment* 543, pp. 670–682.

Wang, W. F. and W. Y. Yun (2013). “Scheduling for inland container truck and train transportation”. In: *International Journal of Production Economics* 143.2, pp. 349–356.

Weyer, J., R. D. Fink, and F. Adelt (2015). “Human–machine cooperation in smart cars. An empirical investigation of the loss-of-control thesis”. In: *Safety Science* 72, pp. 199–208.

Wietholt, T. and J. Harding (2016). “Influence of Dynamic Traffic Control Systems and Autonomous Driving on Motorway Traffic Flow”. In: *Transportation Research Procedia* 15, pp. 176–186.

Wu, Y. J. and K. Huang (n.d.). “Making online logistics training sustainable through e-learning”. In: *Computers in Human Behavior* 29, pp. 323–328.

Zhang, W., J. Lu, and Y. Zhang (2016). “Comprehensive Evaluation Index System of Low Carbon Road Transport Based on Fuzzy Evaluation Method”. In: *Procedia Engineering* 137, pp. 659–668.

Zijm, H., M. Klumpp, U. Clausen, and M. ten Hompel, eds. (2016). *Logistics and supply chain innovation: Bridging the gap between theory and practice*. Cham et al.: Springer.

Zijm, W. and M. Klumpp (2016). “Logistics and supply chain management: Developments and Trends.” In: *Logistics and supply chain innovation*. Ed. by H. Zijm, M. Klumpp, U. Clausen, and M. ten Hompel. Cham et al.: Springer, pp. 1–20.

Zijm, W. and M. Klumpp (2017). “Future Logistics: What to Expect, How to Adapt”. In: *Dynamics in logistics*. Ed. by M. Freitag, H. Kotzab, and J. Pannek. Lecture notes in logistics. Cham, Switzerland: Springer, pp. 365–379.

Topical Map for Continuing Education: AHP Expert Survey

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This contribution presents an analysis of recent trend topics in logistics and supply chain management with a focus on education and training on the job, applying an Analytic Hierarchy Process (AHP).Based on a comprehensive literature survey for the identification of trends that have persisted over the ten years considered (2005-2015), expert interviews have been conducted, aggregated and evaluated with an AHP. The particular context for this contribution is the research project MARTINA, which is concerned with innovative design for logistics education and thus encompasses iterative development of education software (app for mobile training). With this in mind, a dichotomous structure according to professional areas has been chosen ('blue-collar' and 'white-collar') for the questionnaires and corresponding hierarchy.Our AHP had the goal of identifying topics for the design prototype (android-based app). Criteria included addressed the target groups 'blue collar' as well as 'white collar'; 14 alternatives were to be ranked and 45 completely answered questionnaires have been evaluated with the resultant ranking e-mobility, sharing economy, first aid training, cooperation, and diversity as the top 5 over both groups.The resultant topical ranking yields interesting results: First, we present an updated assessment of topics which will significantly shape logistics, logistics research and the related debate in the near future. Second, our results serve as guidelines for the development of new education concepts and are directly informing the design efforts taking place in the aforementioned project, thus being transformed into artifacts of the design cycle of an android-based smartphone and tablet application.

Keywords: Analytic Hierarchy Process; trend topics; education; training

1 Introduction

Intelligent logistics is based and depends on a multitude of technical, managerial and human requirements. For logistics employees in particular, this includes skill requirements for the use of new technologies and organizational paradigms. Given the situation of shortage of skilled labor in logistics two crucial competitive factors are identified: raising attractiveness of employment in the field of logistics generally as well as goal-oriented and efficient education and training for employees currently working in logistics. This contribution on current developments in logistics education and training focuses on what we call 'qualification topics' as these encompass both education and training for all professional areas (thus 'blue-collar' and 'white-collar'). Research conducted for this contribution is connected to the research and software development project MARTINA. The contribution is structured as follows: Section 2.1 presents an overview of trend topics in logistics of the past decade up until the present, which lays the groundwork for our analysis of expert interviews we conducted using the AHP-method (Section 4). Section 2.2 sketches out the research project MARTINA, which is still running until June 2018. Section 3.1 therefore gives a short outline of the AHP-method, section 3.2 describes our application of the method, section 3.3 succinctly touches upon aggregation procedures for group evaluations with AHP, section 4 presents evaluation and results, section 5 concludes.

2 Logistics Trends: Innovation and Education

Zijm, Klumpp (2017) define four areas which provide a structure for the categorization of trending topics identified in their literature survey: business process management, competitive advantage, strategic management, network structure. Related studies with focus on current trends in logistics vary the structure, for instance by providing a dual structure with social and business vs. technology trends, while yielding similar results (compare section 2.1).

2.1 Trend Topics in the Logistics Literature

Using a sample of more than 3400 articles from logistics and SCM for their literature survey, Zijm and Klumpp (2017) examined publications from the decade 2005-

2015 for the trending topics persisting through this period. The resultant ranking is organized within a fourfold structure provided by the categories business process management, competitive advantage, strategic management, and network structure. A related study by Stank et al. (2013) includes a similar structure, using strategy & performance, planning & execution, talent & information, and relationship management. Their results have their origin in interviews conducted with 160 supply chain professionals, of whom each had to give their assessment of a list of 10 trend topics (customer service to customer relationship management, adversarial relationships to collaborative relationships, incremental change to a transformational agile strategy, functional focus to process integration, absolute value for the firm to relative value for customers, forecasting to endcasting (demand management), training to knowledge-based learning, vertical integration to virtual integration, information hoarding to information sharing and visibility, managerial accounting to value-based management).

In the context of the Zijm/Klumpp study the meaning of the term business process management is ‘management of activities with the goal of provision of particular outputs addressing customer demand’. Competitive advantage is to be understood as ‘innovations causing competitive advantages for an organization’. Strategic management describes the ‘definition and pursuit of objectives based on comprehensive internal as well as external factors conditional on efficient resource allocation’. Network structure includes flows of information and materials, and value created from vertical and horizontal cooperation. According to Zijm and Klumpp (2017), logistics faces a multitude of challenges resulting from climate change, sustainability requirements in production and services, political disruptions, mass individualization, as well as artificial intelligence and cyber-physical systems. This entails rethinking and novel concepts for organization, management of information and employee qualification. A close look on current as well as emerging technological and socio-economic innovations yields a variety of scenarios (van Breedam, 2016), representing significant requirements for education and training:

Continuing education and training on the job should qualify employees for efficient use of technology that is present at the workplace. Competitive advantage which stems from the use of technology can only be maxed out when employee qualification is adequate. For logistics, pervasive computing (Lucke and Rensing, 2014) represents the key term this changes individual learning behavior as well as the definition and evaluation of education progress and goals.

Innovations from the areas lightweight materials and engine technologies have major effects on cost efficiency and ecological footprints, with the latter being further positively affected by smart packaging, biodegradable material and additive manufacturing. Modular product design, additive manufacturing and their interrelation with mass individualization can positively affect distance to customers, stock volumes and lead times. With Automation we see that likely within the next few decades the way towards completely unmanned transport logistics is being paved, as current developments go beyond visible, established systems such as RFID and robotics toward automation of whole far-reaching decision processes. Information systems, business models, property rights and cooperation need to be regarded as one interconnected system: Given an economy where the importance of servitization and sharing economy rises, property rights and whole supply chain structures need to be re-thought. For instance, with an environment characterized by many stakeholders making decisions in parallel and on the same hierarchical level, new decision processes are mapped into novel concepts on the side of information systems (Anand, et al., 2016). Their effective use requires, in addition to vertical cooperation along the more obvious part of the value chain, horizontal cooperation: This may require single, private companies to give up their decision autonomy to some degree (while not necessarily conceding advantages) in order to achieve equilibrium solutions which are fair in the sense of allocation of gains from cooperation.

In total, we have the picture of a movement starting currently with horizontal collaboration and the alignment of socio-economic, ecological and security goals, having its endpoint in the conceptual vision known as the ‘Physical Internet’ (Montreuil, 2011). A vital step in that is of course digitial transformation, whose opportunities have been lucidly explored in a most recent study by Kersten et al. (2017).

2.2 Innovative Continuing Education in Logistics

The research project ’MARTINA’ is aimed at the development of innovative concepts for logistics education and training. After an initial period of desk research regarding qualification trends in logistics, the main project activity has quickly and consequently turned to software development, with the rise of digitization and the high mobility of some logistics employees in mind (blue collar, e.g. truck drivers). Thus the apparent challenge: Training on the job, using mobile devices. It is this particular background which justifies to the authors of the current study to succinctly ponder their view on approaches to continuing education: Continuing education has the goal of qualifying employees for the efficient use of current technologies and organization concepts. Realization of competitive advantages in business practice can only happen if qualification levels of employees match technology requirements. Such an approach includes necessary changes in individual learning behavior depending on personal competence status and history. Ensuring efficient use of established workplace technology therefore implies: Every step ahead on technological grounds has to be met with one in user qualification and motivation due to increasing human-machine interaction. Then, by provision of potential for innovation we address that only individuals and organizations appropriating the state of the art in relevant technology or media literacy, thus keeping close to the education innovation frontier, can be expected to generate novel ideas and concepts. Regarding logistics, the term 'Pervasive Computing' (Lucke, Rensing, 2014) represents important current challenges, as it changes both methods of learning and teaching as well as individual learning behavior, factually challenging the very definition of learning. Recent developments require the understanding, competence and motivation especially of, but not limited to, the attached blue-collar personnel in order to be applied properly and efficiently. For the specific task of training and integration of blue-collar employees in logistics, research as well as management practice has provided very little in terms of innovation and new approaches in the last decade – during the rise of smartphones, gamification and edutainment applications as well as modern-day individualized training on the job and e-learning concepts in other industries. Therefore, this gap is addressed subsequently as descriptions of the efforts in the software development project 'MARTINA' are described, preceded by a section treating the process of identifying education topics to be selected for demonstrational app development purposes. This topic selection was based substantially on an Analytical hierarchy Process (AHP)-based expert survey. The method is outlined in the next chapter, while particular application for the current project and results are presented in the ensuing fourth chapter.

3 Expert Survey Using the Analytic Hierarchy Process

For topic selection, the authors used an expert survey designed, conducted and evaluated using the Analytic Hierarchy Process (AHP, Saaty, 1980). The AHP is used to transform non-material, intangible aspects (preferences, for instance) into numerical, thus measurable and comparable values. From a set of alternatives, pairs are compared with respect to some criterion from a set of criteria. From these comparisons, conducted over all alternatives, priorities result, as well as local and one global ranking. Criterion is taken as a fundamental concept, that is, no further definitions and formal descriptions of this is given in the assumptions underlying the AHP. The Construct ('hierarchy') 'alternative-higher level-criterion' is repeated in a way such that criteria for pairwise comparisons on the lowest level have the state of alternatives within the following step, with the complete hierarchy finally peaking in a singular main criterion ('goal'). With this structure, an AHP can be used to analyze some given problem exhaustively. Structure and process are given, thus the tool like character of the procedure.

3.1 Basic Concepts and Definitions

Pairwise comparisons (in our case e.g. green logistics vs. sharing economy, or cargo securing vs. dangerous goods) are expressed as numerical values with the properties of an absolute scale. Preference for one alternative over another with respect to some criterion is thus reflected as a multiple of the value attached to the item one determines to be the alternative of lesser importance (thus if one deems dangerous goods as absolutely outweighing e-mobility in any respect, one would attach '9', compare below). The alternative marked as inferior thus receives the reciprocal value of the one attached to the favored one. Application of this simple procedure over all possible pairs of alternatives yields what is called 'pairwise comparison matrix'. Here, values of the corresponding principal eigenvector are global priorities over alternatives on an absolute scale. This means, by ordering alternatives descending, according to the corresponding values of the principal eigenvector, one gets a ranking of alternatives resulting from the pairwise comparisons of the decision maker. We proceed by succinctly outlining basic definition for those pairwise comparisons, as they are given by Saaty (1986) and Saaty and Kulakowski (2016).

D1: 'Partially ordered set' refers to a relation $\preceq$ on a set X, if this relation has the properties reflexivity, transitivity und antisymmetry. A partially ordered set is a set X with $\preceq \ \subseteq X \times X; (X, \preceq)$ (also called 'poset' for 'partially ordered set').

$$
\begin{aligned}
\text{reflexivity:} \quad & x \preceq x \forall x \in X \\
\text{transitivity:} \quad & x \preceq y \wedge y \preceq z \Rightarrow x \preceq z \forall x, y, z \in X \\
\text{antisymmetry:} \quad & x \preceq y \wedge y \preceq x \Rightarrow x = y \forall x, y \in X
\end{aligned}
$$

For shorthand we note $x \preceq y \wedge x \neq y$ also as $x \prec y$.

D2: A subset $E \subseteq (X, \preceq)$ is called 'bounded from above (below)', if an element s exists with $s \in X | x \preceq s (x \succeq s) \forall x \in E$; such an s is called 'upper (lower) bound' of E. Whenever there exists a largest lower bound for the set E, this is also called lower limit or infimum of E, thus a lower bound is either smaller or equal to the infimum. The terms maximum element, largest element, upper bound and upper limit, or supremum, respectively, are analogously defined.

D3: The $p+q+1$-tuple $R = (X, R_1, \ldots, R_p, o_1, \ldots, o_q)$,$q \geq 0, p \geq 1$ is called relational system. X is a set of objects, R_i are relations over these objects, o_i are binary operators.

D4 (homomorphism): For two relational systems $R = (X, R_1, \ldots, R_p, o_1, \ldots, o_q)$ and $Q = (X, R_1, \ldots, R_p, o_1, \ldots, o_q), q \geq 0$,$p \geq 1$ a map $f : R \rightarrow Q$ is called 'homomorphism' between R and Q, if for all $A_1, \ldots, A_x \in X$, given $(A_1, \ldots, A_x) \in R_i$ and $(f(A_1), \ldots, f(A_x)) \in R'_i$, and if it holds for two arbitrarily chosen $A, B \in X$ that $f(A_1 o_j A_2) = f(A_1) o'_j f(A_2)$, with $i \in \{1, \ldots, p\}, j \in \{1, \ldots, q\}$.

The correspondence to a numerical scale (as used in the AHP) is clearly visible, as soon as one looks at relational systems over sets of numbers: A map between a relational system and a set of numbers defines a numerical scale; any triple (R, Q, f), satisfying the definitions in D4, with $Q \in R$, ($R+$ for the AHP), is called numerical scale, per convention this often refers to f itself (a pairwise comparison in the AHP corresponds to a map of a pair of alternatives into $R+$). Using f we are able to give some meaning to the notion of intensity of preference between alternatives.

D5 (preferences): Given a numerical scale (R, Q, f_c), with c referring to the criterion with respect to which the pairwise comparison is done. Define relational systems $R = (\Omega^2, \succeq)$ and $Q = (R+, \geq)$ and an homorphism $f_c : \Omega^2 \rightarrow R+; \Omega$ being the finite set of alternatives. Then:

$$
\begin{aligned}
-\omega_i \succ c\omega_j &\iff f_c(\omega_i, \omega_j) > 1 \\
-\omega_i \sim c\omega_j &\iff f_c(\omega_i, \omega_j) = 1, \forall \omega_i, \omega_j \in \Omega.
\end{aligned}
$$

Meaning, fc maps how much an alternative is preferred over another, assuming for the AHP that $f_c(\omega_i, \omega_j) = 1/(f_c(\omega_j, \omega_i))$, enabling pairwise reciprocal comparisons and their representation as pairwise comparison matrices.

D6 (hierarchy): Further assumptions lay the foundations for the hierarchy representation of the decision problem, particularly for the differentiation of hierarchical (concepts inner dependence, outer dependence, Saaty and Kulakowski, 2016).

D7 (homogenity): Necessary to incorporate that people make mistakes while comparing inherently different things/alternatives with diverse units or orders of magnitude. This ensures comparisons are limited to alternatives which have some kind of similarity if they are located on the same layer. Analogously, the archimedian axiom is well known, for two real numbers $y > x > 0$ there is a natural number n with $nx > y$.

D8 (completeness): All criteria (here: type of occupation, goal) and alternatives (here: education topics) necessary to resolve the decision problem are included in the hierarchy used to address the decision problem. For applications, this means: participants have to ensure that all criteria and preferences are included in the procedure as to their particular status of information. While not being a rationality assumption, this means that the result of the procedure depends essentially on the way that particular AHP is constructed, meaning in turn that on a strategic level, these ‚preparations' may be seen as vital in applying the procedure, given the 'rules' can be assumed common knowledge. In addition, rankings for group decisions depend almost entirely on the particular aggregation procedure one uses (Grošelj, et al., 2015).

3.2 Methodological Procedure for an Application of the AHP

Preparation of a decision problem for the use of an AHP consist of the following four steps (Saaty, 2008):

1. Problem definition, determination of general properties of the solution such as dimension
2. Structuring of the hierarchy: top-down, staring at the goal and along subsequent criteria to the bottom layer containing the set of alternatives
3. Construction of pairwise comparison- and evaluation-matrices: elements from one layer serve as criteria for pairwise comparisons of elements from the next (lower) layer

4. Use local priorities for weighting on the corresponding layer as well as for cumulative priorities: product of pairwise comparative judgements along the path from judgements on the lowest level throughout and up to the highest level

We give a short overview of Saaty's Fundamental Scale (Saaty, 2008), as needed in the present study: For instance, indicating "1" for intensity of importance corresponds to a definition of "equal importance", meaning that two choices contribute equally to the objective. "2" is defined as "weak or slight", "3" as "moderate importance", supposed to mean that experience and judgement favor one alternative over another. Then, at the other end of the scale, for instance "8" is translated as "very, very, strong", while "9" serves as the other "extreme importance", meaning evidence, rather than just judgement and experience, favoring one alternative over another is at the highest possible order of affirmation. For the reciprocals it holds that whenever i is assigned one of the above numbers in comparison with j, then j has the reciprocal value when compared with i.

As described in 3.1, comparisons are done on a "fundamental scale of absolute numbers" (Saaty, 2008, p.86). With respect to ensuing calculation of eigenvalues the following definition holds: An entry aij larger than 1 expresses a decision maker's preference for the element denoting the line, thus (D5) this is mirrored in the reciprocal value aji in column j. The scale described in the preceding paragraph is commonly used, however subject to debate at times (Fülöp, Koczkodaj, and Szarek, 2010).

From the eigenvectors of the evaluation matrix associated with the maximum eigenvalue one arbitrarily picked eigenvector is normed, whose components represent evaluation indices in the following. Considerations on consistency of the particular procedure are commonly expressed with the aid of consistency index (CI) and consistency ratio (CR), the latter being the ratio of CI and a random index (RI), which represents an ideal situation (Saaty, 2001).

3.3 Aggregation Procedure for the Group Evaluation

One AHP application is group decision procedures. Regardless of practical considerations individual to any organization, from the point of view of data evaluation the manner one choses to aggregate individual judgements into on global judgement representing a group matters. This is discussed in extenso in "comparison of some aggregation techniques using group analytic hierarchy process" (Gróselj, et al., 2015), whereas in the current study we chose one of the many procedures treated, which is the relatively simple WGMM defined as

$$\omega_{ij}^{WGMM} = \prod_{k=1}^{m} \left(\omega_{ij}^{k}\right)^{\alpha_k}, \alpha_k > 0, \sum_{k=1}^{m} \alpha_k = 1, k \in \{1, \ldots, m\} \cap \mathbb{N}$$

The actual choice may be of particular concern when inhomogeneous groups, for instance with respect to hierarchical levels or power asymmetries are concerned. We went with the procedure above, since we put efforts into selecting experts from similar professional backgrounds, thus 'speaking one language', as is further elaborated in the discussion in the following evaluation chapter 4.

4 Evaluation and Results

The decision in question for the project 'MARTINA' is depicted in the following hierarchy (figure 1). The procedure of having experts rank topics based on a list that originates from literature surveys has been used before (Stank, et al., 2013).

Our expert survey yielded 45 completed questionnaires, where completed refers to "answered all pairwise comparisons presented in random order with exactly one judgement for each". Experts had professional backgrounds in logistics, most currently employed in a logistics related position in administration or operations. We gained from this the following ranking depicted in table 1(consistency 0.07979 (blue collar, left column), 0.00665 (white collar)):

Table 1: Topics and AHP-Priorities

Topic (blue collar)	Priority	Topic (white collar)	Priority
E-mobility	0,21315	Sharing economy	0,20554
First aid	0,19992	Cooperation	0,17932
Integration/immigration	0,13479	Diversity	0,17437
Dangerous goods	0,13334	Green logistics	0,14694
Efficient driving	0,12483	Flexibility/lean	0,12877
GPS-acceptance	0,10543	Risk management	0,08668
Cargo Securing	0,08854	Integrated SC	0,07838

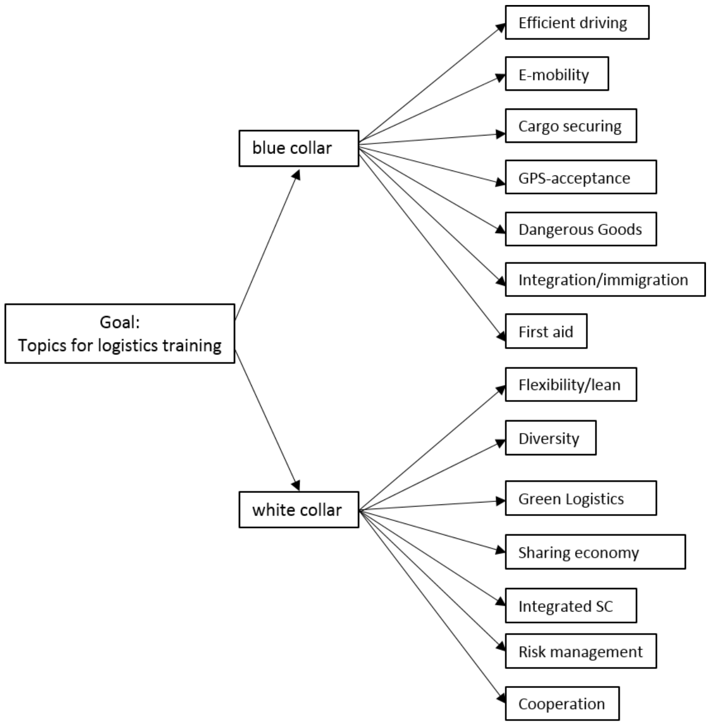

Figure 1: Decision Hierarchy for Logistics Education Topics

A discussion of this AHP-study can take place on three levels: First one can criticize the method of the AHP per se (Harker and Vargas, 1990, Dyer, 1990). Second, adequacy of the method for the given decision problem and its application in the particular context can be subject of discussion, including matters of data collection, aggregation and construction of the hierarchy. Third, context as well as interpretation of results are important: A critique of the resulting ranking happens on the premise that one knows the meaning of the terms as it was during the conduction if that particular questionnaire, thus, what exactly the terms meant to the subjects at that particular time. It is not important, however, whether subjects' understanding of terms was in accordance with a singular, common, and explicit definition, nor is it important if researchers had either assumed some explicit definition or rather, known the exact definition subjects had in their minds. Rather it should be stressed, that effort is put into having subjects with a common or similar, thus to a degree homogenous understanding of the terms amongst the group members. We achieved this by selecting subjects with quite similar professional backgrounds, thus 'speaking a common language'. This can be exemplified with a few terms from the questionnaire. However, it is not necessary to discuss all entries of our ranking. For example, a common understanding of logistics terms could suggest a rather large intersection of the topics cargo securing and dangerous goods. However, concerning legal procedure and definitions, these can be clearly separated from the standpoint of prescriptions: For dangerous goods, for instance, clear prescriptions for labelling exist (UNECE, 2015), while legal disputes with respect to cargo securing often need experts' assessments to be solved. This difference and the resulting requirements for professional training is common knowledge among our subject pool of logistics professionals.

Then given a particular context such training here, one can argue that such topics which can be related to clearly defined legal rules and by extension, clearly defined subject matters on the part of education and training, are more salient. On the other hand, one could argue that topics covered by explicit, well-tried, and formal rules do not generate as much need for additional information or training as those which leave ample room for debate. This may also explain some variation in rankings over subjects, as for the latter topics, informal rules may vary notably between employing firms. Further, an ordering criterion not made explicit can be level of abstraction of the terms presented, for instance comparing first aid and flexibility/lean. Per assumption, this may not jeopardize validity of the results (D7), as long as terms on the same layer remain sufficiently similar; however, this may hint at subjects' understanding of the term topic for training or trend themselves. This is also in reference to the assumption of a criterion in the AHP as

Figure 2: Screenshots of Cargo Securing Game and Map (v0.3)

a fundamental concept, which has been discussed in the past (Harker and Vargas, 1990).

On the one hand, this paper is an updated contribution to the ample supply of trend surveys, on the other, and this was the intended primary use of the study, findings have been used to inform a software development project ('MARTINA') with the aim of providing a mobile learning solution for logistics professionals (regarding the top-ranked topics resulting from the reported survey). For instance, applications for cargo securing (figure 2) and dangerous goods training (figure 3) are being developed. The software development project itself draws methodologically from design science research in information systems, the central part of which lies in the iterative provision of artifacts, prototypes of a piece of software, providing basic and core functionalities. These can be field-tested (with supervision) and, with feedback gained from test subjects, a new iteration including an updated artifact can be initiated. As the research project is still running until mid-2018, we can, due to this procedure, present both results and define new questions for development and research with respect to the artifact.

On an applied level, research efforts within the scope of the project encompass the development of a mobile device-based application ('artifact') as well as related efforts towards defining a topical map for ongoing qualification in logistics, thus

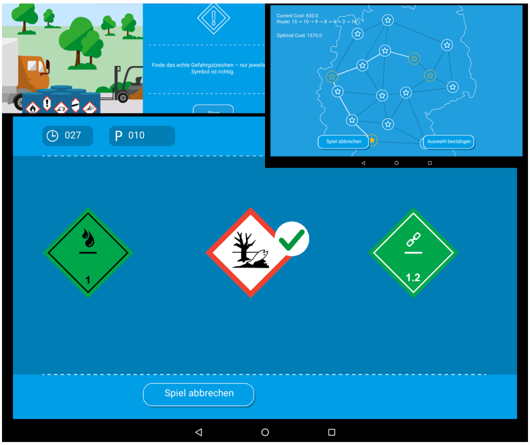

Figure 3: Screenshots of dangerous Goods and Routing Games (v0.3)

ensuring that the resulting application will be relevant and useful for blue- and white-collar employees.

Further benefits are transferability of game concepts to multiple upcoming qualification topics. Numerous theories and accounts on the psychology of motivation with special focus on game design, educational gaming and gamification (Richter, et al., 2014, Mekler, et al., 2015) testify to the importance of mechanisms which foster intrinsic motivation. In general, self-determination theory and the flow-concept are widely known (Deci and Ryan, 2004, Csikszentmihalyi, 2000), while a narrowing to gamification has been provided comprehensively by Nicholson (2015, RECIPE for gamification).

In particular, measures taken aim at strengthening competencies and the incorporation of directives into work routines:

— Development of purely digital training solutions involving a heterogeneous target group and inspiring to see the bigger picture beyond one's own role in a company,

— Strengthen and document user's competencies by each of the challenges provided through mini-games,

— Reach a broad audience by tailoring the application to hardware that is widely used.

Thus the range of in-game applications currently being prototyped/tested includes topics cargo securing, dangerous goods, first aid, route optimization, and customer service.

Currently, procedures largely correspond to agile methods as they are widely used in software development projects of similar scale. After planning, identification and architecture design, the ensuing iterative development process consists of the steps evaluation, selection, development, discussion, each cycle defined by the release of an updated prototype ready to be field-tested. Acknowledging the uncertainty inherent to software engineering, agile procedures (rather than waterfall) are the method of choice, as "it is impossible to fully specify or test an interactive system designed to respond to external inputs" (Wegner, 1997). Accordingly, full specification of the software being developed is impossible, thus it is necessary to build it in incremental steps to ensure fit to requirements. Also, full specification of the software process we use to develop is not possible, thus using administratively heavy processes like RUP or V-models is not to be

Table 2: Survey Results for Version 0.3

item	description	value
	participants	n=30
	age range	19-56
	average age	35,04
2.1	handling (1=very intuitive; 5=instructions required)	2,30
3.1	readability (1=optimal, 5=unreadable)	1,32
3.2	look, general appeal (1=very good, 5=poor)	1,61
	general impression for each game, (range as in 3.2)	
4.1	first aid	1,52
4.2	cargo securing	2,52
4.3	customer service	1,88
4.4	dangerous goods	2,39
	difficulty (1=too easy, 5=too hard)	
5.1	first aid	2,22
5.2	cargo securing	3,00
5.3	customer service	1,58
5.4	dangerous goods	3,26

recommended. Preference is given to the above process, which is designed to respond to change.

In the following we present preliminary results from a user survey gained during prototype testing of the app in its version 0.3, containing mini-games for the topics first aid, cargo securing, dangerous goods, and customer service. These test were conducted with logistics personnel from logistics companies the size of which ranged from 50 to 500 employees. 24 Questions were to be answered, most by indicating agreement/assessment on a five-level scale, some gave room for text. This prototype cycle had at its focus the balancing of difficulty, thus researchers were mainly interested in user's assessment of difficulty and handling (table 2; 1 corresponds to the best possible rating, 5 corresponds to the poorest rating). Accordingly, for next iterations, cargos securing and dangerous goods have been chosen as targets for improvement difficulty- and handling-wise, as well as with regards to a lot of quite differentiated comments received in the free-text forms and conversations.

5 Conclusions and Outlook

One obvious measure to address these effects of long-term commitment to an education measure, high upfront costs, or opportunity costs (e.g. foregone income; Abel and Deitz, 2014) lies in ongoing education, parallel and therefore synergistically to a related job that generates income. Innovative approaches have been taken in recent years, for instance with learning factory-approaches (Doch et al., 2015; Wagner et al., 2012). To effectively prepare logistics employees, especially those in blue collar occupations and of these truck drivers, for the use of new technology and organization concepts, two short propositions can be made: Efficient use of established workplace technology needs to be ensured. Every step ahead on technological grounds has to be met with one in user qualification. Further, it should provide potential for innovation: Only individuals and organizations appropriating the state of the art in relevant technology or media literacy, thus keeping close to the education innovation frontier, can be expected to generate novel ideas and concepts. Given the issue of skilled labour shortage as a backdrop, approaches are two-fold: Either, one takes a quantitative view, focusing on the number of employees with a given set of skills, or, one treats the issue as one of quality and is thus concerned with matters of competences and ongoing education and training (Klumpp, et al., 2013). With the latter, changes in employees' set of skills are a central aim. The corresponding dual solution concept is the pair of expansive and intensive approaches: One is concerned with, e.g., raising attractiveness of a given field of work (expansive). Targeted efforts at ongoing worker education and training is an instant of the other (intensive). One example of the latter is training on the job using educational games.

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References

Abel, J. R. and R. Deitz (2014). "Do the Benefits of College Still Outweigh the Costs?" In: *Federal Reserve Bank of New York Research Paper Series* 20.3, pp. 1–9.

Anand, N., D. Meijer, J. van Duin, L. Tavasszy, and S. Meijer (2016). "Validation of an agent based model using a participatory simulation gaming approach: The case of city logistics". In: *Transportation Research Part C: Emerging Technologies* 71, pp. 489–499.

Csikszentmihalyi, M. (2000). "Happiness, Flow, and Economics Equality". In: *American Psychologist* 55.10, pp. 1163–1164.

Deci, E. L. and R. M. Ryan (2004). *Handbook of self-determination research*. Rochester, N.Y.: The University of Rochester Press.

DHL Customer Solutions and Innovation (2016). *Logistics Trend Radar*.

Doch, S., S. Merker, F. Straube, and D. Roy (2015). "Aufbau und Umsetzung einer Lernfabrik : Produktionsnahe Lean-Weiterbildung in der Prozess- und Pharmaindustrie." In: *Industrie Management* 25.3, pp. 26–30.

Dyer, J. S. (1990). "Remarks on the Analytic Hierarchy Process". In: *Management Science* 36.3, pp. 249–258.

Freitag, M., H. Kotzab, and J. Pannek, eds. (2017). *Dynamics in logistics: Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany*. Lecture notes in logistics. Cham, Switzerland: Springer.

Fülöp, J., W. W. Koczkodaj, and S. J. Szarek (2010a). "A Different Perspective on a Scale for Pairwise Comparisons". In: *Transactions on Computational Collective Intelligence I*. Ed. by D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, N. T. Nguyen, and R. Kowalczyk. Vol. 6220. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 71–84.

Fülöp, J., W. W. Koczkodaj, and S. J. Szarek (2010b). "A Different Perspective on a Scale for Pairwise Comparisons". In: *Transactions on Computational Collective Intelligence I*. Ed. by D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, N. T. Nguyen, and R. Kowalczyk. Vol. 6220. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 71–84.

Gigerenzer, G. and W. Gaissmaier (2011). "Heuristic decision making". In: *Annual review of psychology* 62, pp. 451–482.

Grošelj, P., L. Zadnik Stirn, N. Ayrilmis, and M. K. Kuzman (2015). "Comparison of some aggregation techniques using group analytic hierarchy process". In: *Expert Systems with Applications* 42.4, pp. 2198–2204.

Harker, P. T. and L. G. Vargas (1990). "Reply to "Remarks on the Analytic Hierarchy Process" by J. S. Dyer". In: *Management Science* 36.3, pp. 269–273.

Hutchison, D., T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, N. T. Nguyen, and R. Kowalczyk, eds. (2010a). *Transactions on Computational Collective Intelligence I*. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg.

Hutchison, D., T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, N. T. Nguyen, and R. Kowalczyk, eds. (2010b). *Transactions on Computational Collective Intelligence I*. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg.

Karelaia, N. (2006). "Thirst for confirmation in multi-attribute choice: Does search for consistency impair decision performance?" In: *Organizational Behavior and Human Decision Processes* 100.1, pp. 128–143.

Katsikopoulos, K. V. and L. Martignon (n.d.[a]). “Naive heuristics for paired comparisons: Some results on their relative accuracy”. In: *Journal of Mathematical Psychology*.

Katsikopoulos, K. V. and L. Martignon (n.d.[b]). “Naive heuristics for paired comparisons: Some results on their relative accuracy”. In: *Journal of Mathematical Psychology*.

Kersten, W., M. Seiter, B. v. See, N. Hackius, and T. Maurer (2017). *Chancen der digitalen Transformation: Trends und Strategien in Logistik und Supply Chain Management*. Hamburg: DVV Media Group GmbH.

Klumpp, M., S. Bioly, and T. Keuschen (n.d.). “Praxissituation der Berufskraftfahrenden”. In: *Logistik für Unternehmen* 2015.9, pp. 55–57.

Klumpp, M. (2009). *Logistiktrends und Logistikausbildung 2020*. Vol. 6. Arbeitspapiere der FOM. Essen: ILD.

Klumpp, M. (2016). “Logistics Qualification: Best-Practice for a Knowledge-Intensive Service Industry”. In: *Logistics and Supply Chain Innovation*. Ed. by W. Zijm, M. Klumpp, U. Clausen, and M. ten Hompel. Heidelberg: Springer, pp. 391–411.

Klumpp, M., H. Abidi, B. Krol, T. Stender, and S. Bioly (2013). *Berufswertigkeit und Logistikqualifikation*. Berlin: Logos.

Lu, M. and J. de Bock, eds. (2016a). *Sustainable Logistics and Supply Chains*. Contributions to Management Science. Cham: Springer International Publishing.

Lu, M. and J. de Bock, eds. (2016b). *Sustainable Logistics and Supply Chains*. Contributions to Management Science. Cham: Springer International Publishing.

Lucke, U. and C. Rensing (2014). “A Survey on Pervasive Education.” In: *Pervasive and Mobile Computing. Special Issue on Pervasive Education* 14, pp. 3–16.

Mekler, E. D., F. Brühlmann, A. N. Tuch, and K. Opwis (2017). “Towards understanding the effects of individual gamification elements on intrinsic motivation and performance”. In: *Computers in Human Behavior* 71, pp. 525–534.

Montreuil, B. (2011). “Towards a Physical Internet: Meeting the Global Logistics Sustainability Grand Challenge”. In: *Logistics Research* 3.2-3, pp. 71–87.

Peters, M., R. Schütte, and S. Zelewski (2006). “Erweiterte Wirtschaftlichkeitsanalyse mithilfe des Analytic Hierarchy Process (AHP) unter Berücksichtigung des Wissensmanagements zur Beurteilung von Filialen eines Handelsunternehmens”. In: *Arbeitsberichte des Instituts für Produktion und Industrielles Informationsmanagement Universität Duisburg-Essen* 30.

Reiners, T. and Wood, L., C., eds. (n.d.). *Gamification in Education and Business*.

Reiners, T. and L. C. Wood (2015). *Gamification in Education and Business*. Cham: Springer International Publishing.

Reise, C., B. Müller, and G. Seliger (n.d.). “Resource Efficiency Learning Game – Electric Scooter Game”. In: *Procedia CIRP* 15, pp. 355–360.

Richter, G., D. R. Raban, and S. Rafaeli (n.d.). “A RECIPE for meaningful gamification”. In: *Gamification in Education and Business*. Ed. by T. Reiners and Wood, L., C., pp. 21–46.

Saaty, T. L. and K. Kulakowski (2017). *Axioms of the Analytic Hierarchy Process (AHP) and its Generalization to Dependence and Feedback: The Analytic Network Process (ANP)*.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Saaty, T. L. (1986). “Axiomatic Foundation of the Analytic Hierarchy Process”. In: *Management Science* 32.7, pp. 841–855.

Saaty, T. L. (2001). *Decision making for leaders - the analytic hierarchy process for decisions in a complex world*. Pittsburgh: RWS Publications.

Saaty, T. L. (2008). “Decision making with the analytic hierarchy process”. In: *International Journal of Services Sciences* 1.1, p. 83.

Stank, T., C. Autry, J. Bell, D. Gilgor, K. Petersen, P. Dittmann, M. Moon, W. Tate, and R. Bradley (2013). “Game-changing Trends in Supply Chain”. In: *Annual Report by the Supply Chain Management Faculty at the University of Tennessee* 1.1.

United Nations Economic Commission for Europe (2015). *European Agreement con-cerning the International Carriage of Dangerous Goods by Road*.

van Breedam, A. (2016a). “Future-Proofing Supply Chains”. In: *Sustainable Logistics and Supply Chains*. Ed. by M. Lu and J. de Bock. Contributions to Management Science. Cham: Springer International Publishing, pp. 53–73.

van Breedam, A. (2016b). “Future-Proofing Supply Chains”. In: *Sustainable Logistics and Supply Chains*. Ed. by M. Lu and J. de Bock. Contributions to Management Science. Cham: Springer International Publishing, pp. 53–73.

Wagner, U., T. AlGeddawy, H. ElMaraghy, and E. Mueller (2012). “The State-of-the-Art and Prospects of Learning Factories”. In: *Procedia CIRP* 3, pp. 109–114.

Wegner, P. (1997). “Why interaction is more powerful than algorithms”. In: *Communications of the ACM* 40.5, pp. 80–91.

Whitaker, R. (2007). “Criticisms of the Analytic Hierarchy Process: Why they often make no sense”. In: *Mathematical and Computer Modelling* 46.7-8, pp. 948–961.

Witt, C. de and C. Gloerfeld (n.d.). “Mobile Learning in der beruflichen Bildung – Grundlagen, Konzept, Best Practice”. In: *Handbuch für Aus- und Weiterbildung (HAW)* 4318, pp. 1–22.

Zijm, W., M. Klumpp, U. Clausen, and M. ten Hompel, eds. (2016). *Logistics and Supply Chain Innovation*. Heidelberg: Springer.

Zijm, W. and M. Klumpp (2017). “Future Logistics”. In: *Dynamics in logistics*. Ed. by M. Freitag, H. Kotzab, and J. Pannek. Lecture notes in logistics. Cham, Switzerland: Springer, pp. 365–379.

Part III

Sustainability

Literature Review of Drivers of Sustainable Supply Chain Management

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The incremental awareness regarding social and environmental issues has pushed organizations to adopt sustainable practices. Over the last few years, organizations are considered to be responsible for their business activities that affect the environment, society, and the economy of their own business as well as their supply chain participants. Different stakeholders pressurize organizations and their supply chains to follow sustainable actions in order to achieve sustainable supply chain management (SSCM) goals. However, not all stakeholders have the ability to force organizations to take sustainability initiatives. Some of them help organizations at least to be aware of sustainability issues such as media/press while others emphasize to adopt a certain level of commitment and implement sustainability goals such as NGOs, customers, government, shareholders, community activists, global competition, etc. This research paper aims to identify drivers that push organizations towards achieving sustainability in their operations. The systematic literature review of scientific journal articles has identified "regulatory pressures" and "market pressures" as the most frequently cited drivers for the implementation of sustainability initiatives.

Keywords: Sustainable supply chain management; Drivers of sustainable supply chain management; Systematic literature review

1 Introduction

Since the introduction of the idea, sustainability and the terms associated with it - corporate social responsibility (CSR), sustainable development, business ethics, socially responsible businesses, corporate citizenship, corporate responsibility, triple bottom line, etc. - have been constantly evolving and have numerous interpretations by scholars (Weitzman, 1997; Diesendorf, 2001; Mihelcic, et al., 2003; Kleindorfer, Singhal and van Wassenhove, 2005; Seuring, et al., 2008; Carter and Easton, 2011; Schaltegger and Burritt, 2014; Broman, et al., 2017; Köksal, et al., 2017). With an increasing awareness, stakeholders especially consumers are more concerned about the environmental and social issues associated with the development and the use of products. Over the past few decades, sustainability within the operations of organizations as well as within the supply chain has become an important area of research. The implementation of sustainability initiatives not only improves the environmental and social performance of organizations but also provides them a competitive advantage by acquiring a new set of competencies (Adebanjo, Teh and Ahmed, 2016).

Several internal and external factors influence organizations to take decisions for the implementation of sustainability initiatives within and outside of the organizational boundaries. The aim of this paper is to identify these influencing factors by addressing the following "what drives organizations to implement sustainability initiatives in their operations and how can these drivers be categorized?". This research article provides a clear understanding and a better categorization of the drivers of SSCM. To the best of authors' knowledge, none of the previous research articles have identified an exhaustive list of drivers of SSCM, categorized and defined them clearly. A systematic literature review is conducted that attempts to address the problem by providing a comprehensive list of drivers of SSCM including their degree of influence as well as a holistic classification.

The remainder of the paper consists of four sections. Section 2 presents the state of the art in the field of SSCM, as well as understanding and classification of drivers of SSCM. Section 3 briefly presents the research methodology. Section 4 provides a detailed analysis of the findings of the literature review. Finally, section 5 presents the conclu-sions and limitations of the research.

2 Research background

The basic terminologies related to the topic of sustainability, SSCM, drivers of SSCM and classification of drivers of SSCM are described below in detail.

2.1 Sustainability

Sustainability or sustainable development has become a widely discussed term in almost every business or society e.g. sustainability in supply chains (Seuring and Müller, 2008a; Pagell and Wu, 2009; Carter and Easton, 2011), sustainability at local government level (Brugmann, 1996), sustainable tourism (Tao and Wall, 2009; Fodness, 2016), sustainable cities (Berke, 2016) and many more. The concept of sustainable development combines the idea of sustainability with the concept of development and was first defined as an issue of intergenerational equity in the Brundtland report, entitled 'Our Common Future', then adopted by United Nations' World Commission on Economic Development (WCED). It is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This definition serves as the basis for the current as well as future research in the field of sustainability.

Several authors have considered sustainable development as a process to achieve sustainability (Diesendorf, 2001; Brockhaus, 2013) while others have considered sustainability as an environmental dimension of sustainable development (Holden, Linnerud and Banister, 2014). However, many authors have contended and tried to ignore the difference between "sustainable development" and "sustainability" (Mihelcic, et al., 2003; Seuring, et al., 2008; Carter and Easton, 2011; Ahi and Searcy, 2013). The concept "triple bottom line" (TBL) proposed by John Elkington (Elkington, 1997) has extended the traditional approach from single bottom line of corporate health in terms of profit and loss (Kleindorfer, Singhal and van Wassenhove, 2005) to two other bottom lines, also known as environmental and social dimensions of sustainability.

Weitzman (1997) has defined sustainability as "annuity-equivalent" level of resource consumption and considered both social and environmental resources as a form of capital that needs to be improved. Mihelcic, et al. (2003) defined sustainability as "the design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment". Therefore, sustainability is an approach that prevents from or eliminates the irresponsible behaviors that damage environmental, economic, and/or social systems.

Organizations are considered responsible for their own as well as their supply chain partners' activities (Pagell and Wu, 2009). To achieve the sustainability across the whole supply chain, the importance of integration and collaboration for managing social and environmental issues (Caniato, et al., 2012) at each level in the supply chain has increased (Pagell and Wu, 2009).

2.2 Sustainable Supply Chain Management

The term SSCM incorporates the sustainability view to the supply chain management (SCM) definition and discussed in literature as green supply chain management (GSCM), ethical or responsible SCM, corporate social responsibility (CSR), etc. (Seuring and Müller, 2008b; Varsei, et al., 2014; Broman, et al., 2017). Several literature reviews on SSCM have been published in recent years (Carter and Rogers, 2008; Seuring and Müller, 2008b; Carter and Easton, 2011; Ahi and Searcy, 2013; Köksal, et al., 2017). Carter and Rogers (2008) defined SSCM as "the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual organization and its supply chains". They mention the need for inter-organizational coordination with the prime focus on long-term economic performance. According to Pagell and Wu (2009), a truly sustainable supply chain does not harm the environment and the society. In addition, non-economic dimensions (environmental and social) must complement economic dimension and vice versa.

To achieve sustainability organizations are required to redesign their current supply chains to incorporate sustainability goals into their operations from purchasing till distribution (Bansal, 2002). Ben Abdelaziz, Saeed and Benleulmi, (2015) have identified the goals of an SSCM i.e. to provide maximum value to all stakeholders and to fulfill customer requirements by achieving sustainable flows of products, services, information, and capital as well as enabling the cooperation among supply chain participants.

The scientific literature has identified the need for an increased level of cooperation among different supply chain partners for achieving higher levels of value creation in sustainability (Seuring and Müller, 2008a; Brockhaus, Kersten and Knemeyer, 2013). Further, it has highlighted the customers' and other stakeholders' needs while improving the sustainability of an organization and its supply chain (Ben Abdelaziz, Saeed and Benleulmi, 2015). The relationships of the focal organization within its supply chain have prime importance for the implementation of sustainability initiatives as the focal organization has to coordinate with suppliers to achieve customers' and other stakeholders' goals.

2.3 Drivers for SSCM

Organizations and their supply chains are pressurized to adopt sustainability practices (Hsu, et al., 2013; Varsei, et al., 2014). These pressures are defined in literature synonymously as triggers, enablers, and drivers (Caniato, et al., 2012; Hsu, et al., 2013; Köksal, et al., 2017). Caniato, et al. (2012) defined these pressures as drivers that push organizations towards the implementation of specific sustainable practices. Hsu, et al. (2013) defined drivers as motivators that encourage organizations to adopt green/sustainability initiatives within and across the organizational boundaries. Therefore, drivers for SSCM are defined as motivators or influencers that encourage or push organizations to implement sustainability initiatives throughout the supply chain.

Drivers of SSCM can influence either one or more sustainability dimensions and emerge from pressures of both internal and external stakeholders (Hsu, et al., 2013; Meixell and Luoma, 2015). Different drivers affect supply chain decisions to a distinct extent (Haverkamp, Bremmers and Omta, 2010). Furthermore, due to the rising transparency, offered by new forms of mass communication such as social media (Ben Abdelaziz, Saeed and Benleulmi, 2015), consumers are more eager to know about the conditions under which products were manufactured and want to be more informed about the sustainability of products and/or brands.

Drivers of SSCM are classified, in the literature, according to their degree of influence and their contribution or significance within the supply chain (Walker, Di Sisto and McBain, 2008; Caniato, et al., 2012; Ayuso, Roca and Colomé, 2013; Glover, et al., 2014; Schrettle, et al., 2014). According to institutional theory, drivers of SSCM can be categorized as coercive drivers, normative drivers and mimetic drivers (Zhu and Sarkis, 2007; Hsu, et al., 2013; Glover, et al., 2014). Stakeholder theory

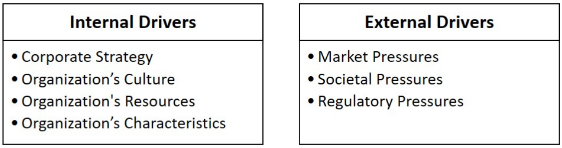

Figure 1: Classification of drivers of SSCM

helps to understand the role of pressure exerted by different stakeholders for the implementation of sustainability initiatives (Varsei, et al., 2014).

In accordance with institutional and stakeholder theory drivers of SSCM are identified and divided into external and internal drivers (Zhu and Sarkis, 2007; Walker, Di Sisto and McBain, 2008; González-Benito and González-Benito, 2009; Haverkamp, Bremmers and Omta, 2010; Harms, Hansen and Schaltegger, 2013; Schrettle, et al., 2014), as shown in figure 1.

2.3.1 External Drivers

External drivers refer to exogenous pressures generated outside the organization and considered to have more influence than internal drivers (Walker, Di Sisto and McBain, 2008). The research on external drivers of SSCM predominates in the literature (Bai, Sarkis and Dou, 2015). These drivers are categorized into three groups: (1) regulatory pressures, (2) societal pressures, and (3) market pressures.

Regulatory pressures

Regulatory pressures are one of the most cited drivers in the literature (Beamon, 1999; Walker, Di Sisto and McBain, 2008) and are exerted by both national or supranational (regional or international) regulatory institutions in the form of standards, laws, procedures, and incentives to promote sustainability practices (Hsu, et al., 2013; Xu, et al., 2013). These drivers have a significant impact on the organizations' sustainability approaches and can have the ability to dictate organizations to adopt certain sustainability practices (Haverkamp, Bremmers and Omta, 2010; Schrettle, et al., 2014). Adopting enforced legislations prevent organizations from fines or penalties. This driver category includes pressure from government agencies, regional (e.g. EU) or international regulators, certification (e.g. ISO), trade/professional associations, financial incentives, etc. (Beamon, 1999; Zhu and Sarkis, 2007; Walker, Di Sisto and McBain, 2008; González-Benito and González-Benito, 2009; Haverkamp, Bremmers and Omta, 2010; Huang and Kung, 2010; Tate, Ellram and Kirchoff, 2010; Giunipero, Hooker and Denslow, 2012; Harms and Klewitz, 2013; Hsu, et al., 2013; Xu, et al., 2013; Schrettle, et al., 2014).

Societal pressures

Societal pressures, also named in literature as societal values and norms (Schrettle, et al., 2014), are expectations or demands of different interest groups from organizations to adopt sustainability practices in their operations (Walker, Di Sisto and McBain, 2008; Schrettle, et al., 2014). These pressures help to increase public awareness regarding different sustainability issues e.g. scarcity of resources, environmental damages, hu-man rights, social well-beings, health and safety, etc., (Walker, Di Sisto and McBain, 2008; González-Benito and González-Benito, 2009). Societal pressure drivers include pressures from NGOs, media/press, societal groups (inhabitants, environmental organ-izations), value based networks, consumer organizations, community, etc. (Beamon, 1999; Walker, Di Sisto and McBain, 2008; Freeman, 2010; Haverkamp, Bremmers and Omta, 2010; Harms, Hansen and Schaltegger, 2013; Hsu, et al., 2013; Schrettle, et al., 2014).

Market Pressures

Market drivers are responsible for the market shape (Schrettle, et al., 2014) which is considered as one of the main concern by organizations. Investors can withdraw in-vestments if organizations fail to achieve sustainability goals (González-Benito and González-Benito, 2009; Schrettle, et al., 2014) this results in increased risks and damag-es to organizations' reputation. This drivers' group includes pressures such as custom-ers/consumers, competitors, shareholders, suppliers and buyers, investors, reputa-tion/image, financial institution, competitive advantage, supply chain and network, etc. (Zhu and Sarkis, 2007; Walker, Di Sisto and McBain, 2008; Freeman, 2010; Haverkamp, Bremmers and Omta, 2010; Huang and Kung, 2010; Caniato, et al., 2012; Giunipero, Hooker and Denslow, 2012; Ayuso, Roca and

Colomé, 2013; Harms, Hansen and Schaltegger, 2013; Bai, Sarkis and Dou, 2015; Govindan, et al., 2016).

2.3.2 Internal Drivers

Internal drivers are pressures generated within the organization (Caniato, et al., 2012) and predict a proactive sustainability behavior of an organization (González-Benito and González-Benito, 2009). These drivers are categorized into four groups: (1) corporate strategy (2) organization's culture (3) organization's resources (4) organization's characteristics.

Corporate strategy

The integration of sustainability principle at a strategic level is the pre-requisite for a successful achievement of the organizations' sustainability goals (Haverkamp, Bremmers and Omta, 2010; Schrettle, et al., 2014). This driver group includes organiza-tion's sustainability strategy, top management commitment, cost related pressures, operational performance, etc. (Carter and Dresner, 2001; Walker, Di Sisto and McBain, 2008; González-Benito and González-Benito, 2009; Giunipero, Hooker and Denslow, 2012; Hsu, et al., 2013; Xu, et al., 2013; Govindan, et al., 2016).

Organization's culture

Organization's culture has a direct influence on the organization's motivation for sustainability. This driver category includes information dissemination, innovativeness, health and safety issue, code of conduct, etc. (Haverkamp, Bremmers and Omta, 2010; Harms and Klewitz, 2013; Hsu, et al., 2013; Schrettle, et al., 2014; Paulraj, Chen and Blome, 2015; Govindan, et al., 2016).

Organization's resources

The access to adequate resources is an important driver in achieving sustainability goals by an organization (Schrettle, et al., 2014). This driver category includes organiza-tions resources, human resources, organizational capabilities, physical capital (tech-nology, equipment), human capital (skills and capabilities), employees, etc. (Henriques and Sadorsky, 1999; Carter and Dresner, 2001; Walker, Di Sisto and McBain, 2008; Haverkamp, Bremmers and Omta, 2010; Hsu, et al., 2013; Schrettle, et al., 2014; Go-vindan, et al., 2016).

Organization's characteristics

The pressure for adopting sustainability practices does not only depend on the perceived pressures as mentioned above but also on the organization's characteristics (González-Benito and González-Benito, 2009; Haverkamp, Bremmers and Omta, 2010). This driver category includes organization's size, current level of environmental actions, degree of internationalization, geographical location, position in the supply chain, industrial sector, etc. (González-Benito and González-Benito, 2009; Haverkamp, Bremmers and Omta, 2010; Tate, Ellram and Kirchoff, 2010; Schrettle, et al., 2014; Bai, Sarkis and Dou, 2015; Mzembe, et al., 2016).

Drivers of SSCM are also classified as primary and secondary drivers according to their access to supply chain knowledge and value-contribution. The more the knowledge about the supply chain and the greater the value contribution the greater will be the importance of the pressure group. Primary drivers include government, shareholders, suppliers, employees, unions, customers/consumers, financial institutions, regulatory agents (Zhu and Sarkis, 2007; González-Benito and González-Benito, 2009; Alblas, Peters and Wortmann, 2014), competitor pressure (Hsu, et al., 2013), top management commitment, cost related pressures, resource utilizations, competitive advantage (Giunipero, Hooker and Denslow, 2012). Secondary drivers include media/press, NGOs, communities, social groups (González-Benito and González-Benito, 2009), reputation/image (Zhu and Sarkis, 2007), socio cultural responsibility/public pressure (Hsu, et al., 2013) certifications, financial benefits (Giunipero, Hooker and Denslow, 2012).

3 Research Methodology

In order to address the identified research question, a multi-step systematic literature review methodology (Tranfield, Denyer and Smart, 2003) methodology was followed to investigate the information published in scientific literature related to drivers of SSCM. Fink, (2014) has defined systematic literature review as “a

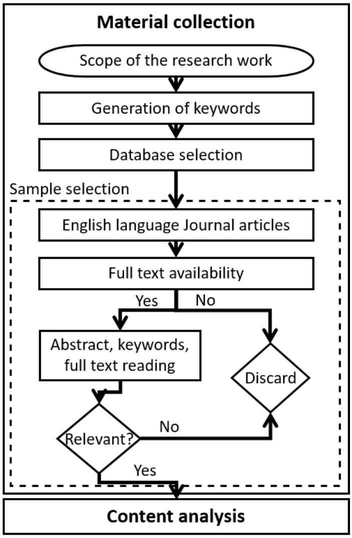

Figure 2: Systematic literature review process flow

systematic, explicit, comprehensive and reproducible approach for identifying, evaluating, and interpreting the existing body of documented work produced by academicians and practitioners". The steps followed to identify drivers for SSCM, as shown in figure 2, are explained in next subsection.

3.1 Material Collection

Scientific literature articles published until the year 2016 in the field of drivers of SSCM were considered for the scope of this research work. An initial literature review has helped to identify related keywords which were later refined with rigorous trials and test searches of specific terminologies in different scientific databases. A final combination consisting of two keywords was developed, as shown in Table 1. The first keyword is a combination of two terms i.e. sustainab*

Table 1: Keyword combinations and number of outcomes

Data Source[a]	Keyword 1	Keyword 2	Articles with repetition	Unique articles	Full-text available	Relevant/ Irrelevant (R/IR)
Science Direct	Sustainab* AND ”supply chain”	Trigg* OR pressur* OR driv*	160	503	462	217 (R) 245 (IR)
Web of Science			458			

’AND “supply chain”, which has helped to identify articles in the field of SSCM. Whereas the second keyword is a combination of three terms i.e. driv* OR trigg* OR pressur*, which has helped to identify articles within that sample and have discussed or mentioned drivers of SSCM. The use of asterisk “*” sign here has led to access a wide range of publications as authors use slightly different keywords to discuss the same idea.

Two well-renowned scientific databases, namely Elsevier’s Science Direct (www.sciencedirect.com) and the Web of Science (www.webofknowledge.com) were selected to collect related scientific articles. A pilot keyword search was performed before conducting a thorough search in the two databases selected which helped to validate the keyword combinations (Kersten and Saeed, 2014). The search field “abstract, title, keywords” was selected. Due to the impartiality in reviews and quality of the manuscript, search results were constrained only to peer reviewed journals. As a result, 618 articles were initially identified from two databases i.e. 458 from Science Direct and 160 from the Seb of Science. After cleaning and removal of duplicates (115), 503 unique articles were left, out of which 41 articles were inaccessible from the University VPN (Virtual Private Network). That has led the sample to 462 articles. The identified articles were further processed carefully by authors to ensure quality and validity. Articles that have mentioned drivers or pressures in aspects other than SSCM (e.g. water pressure), it was excluded from the final dataset. Out of 462 collected articles, 217 articles at least mentioned the drivers of SSCM.

[a] Text search categories were ’Title’, ’Abstract’ and ’Keyword’

3.2 Content Analysis

Drivers of SSCM were identified from the identified articles using a content analysis approach. It is a technique used to reduce documentary material into manageable bits of data (Weber, 2008). Drivers' information given in the form of tables, figures, appendices, or anywhere in the content of the publication was extracted. The exact wording and page numbers in the publication, for each driver, were documented for transparency and replicability purposes. In total 1,559 drivers were identified.

Drivers were classified according to main driver categories (see section 2.3) and sub-categories. Assumed sub-categories (identified from the initial literature review) and inferred sub categories (identified during the focused coding process) are given in table 4 and table 5. Drivers with similar meanings were grouped together such as "government regulations", "government legislations" or "government pressures", etc. In some cases, during the classification, the coherent and standardized driver names have resulted in some variation from the original text mentioned in publications. Further, a unique identification number was assigned to each driver. The content related to drivers of SSCM was collected in Microsoft-Excel spreadsheet for the analysis purpose. Therefore, this content analysis provides an essential starting point for the development of a conceptual structure and a coherent set of standardized SSCM drivers.

The systematic use of keywords search and documentation of each process step have ensured reliability in the material collection process. Both assumed and inferred driver categories are based on the extensive literature review. Furthermore, the validity of the coding process was ensured by involving two coders from the start of the research and differing judgments were resolved after detailed discussions.

4 Results and Findings

The application of a reference management software 'Citavi' has provided authors the opportunity to better manage the data. The classification of drivers of SSCM in different categorization has resulted in a quantitative data set from the qualitative content of scientific publications. The basic bibliographic information (author's name, journal's name, year of publication, page number, article's title, etc.) were exported from Citavi to Microsoft-Excel for conducting further analysis. This part

Table 2: Percentage of publications per year

Pub. Year	#	%	Pub. Year	#	%	Pub. Year	#	%
2003	1	0.5%	2009	5	2.3%	2014	36	16.6%
2005	1	0.5%	2010	9	4.1%	2015	43	19.8%
2006	1	0.5%	2011	8	3.7%	2016	51	23.5%
2007	5	2.3%	2012	28	12.9%			
2008	3	1.4%	2013	26	12%			
						Total articles: 217		

of the article presents and discusses the findings in a way that provides some practical guidance for academics and practitioners in the field of SSCM.

4.1 Descriptive Analysis

The importance of the research regarding drivers of SSCM over time and other descriptive features such as year of publication, the journal for each publication and publication authors are presented in this section. A continuous growth in the number of publications has been identified as shown in table 2. In addition, more than 80% of the total articles were published after the year 2011. This rapid increase in the number of publications is a direct indication of the growing attention towards the research field of adopting sustainability practices across the supply chain.

In total, 79 journals have published articles related to drivers of SSCM, only 29 of them have published more than two articles. Table 3 shows, the ten journals with the most number of publications on SSCM. The ”Journal of cleaner production” is leading with maximum publications (39) and is the only journal that has published more than 30 articles. Whereas, ”International journal of production economics”, ”Supply chain management - an international journal”, ”International journal of operations & production management” and ”Business strategy and the environment” are the only journals that have published more than ten articles.

Author ‘Sarkis, J.’ has published a maximum number of fourteen articles in the field of drivers of SSCM. ‘Zhu, Q.’ has published eleven articles, and Govindan, K. has published eight articles. Figure 3 shows the list of authors who have published

Table 3: List of top-ten Journals in dataset

International Journal	# of Publications
Journal of cleaner production	39
International journal of production economics	15
Supply chain management-an international journal	14
International journal of operations & production management	13
Business strategy an the environment	12
Journal of business ethics	6
Journal of purchasing and supply management	5
Resources consevation and recycling	5
Resources policy	5
International journal of physical distribution & logistics management	4

at least four articles in this research area, either individually or together with a research group. The analysis has shown that a majority of the publications identified for this research are from developed countries and the majority of authors are affiliated with research centers from developed countries.

4.2 Frequency Analysis of Drivers of SSCM

Drivers of SSCM were identified, extracted, documented and coded in a spreadsheet to perform frequency analysis. Frequency analysis helps to determine how often a driver of SSCM is mentioned in the sample. It yields a greater level of understanding of the use of drivers in SSCM literature as summarized in table 4 and table 5. The frequency analysis table represents the distribution of drivers of SSCM for each driver's category.

”Internal drivers” were cited 537 times and ”external drivers” were cited 1022 times in this literature review. In case of external drivers' category, the ”market pressures” (495) and the ”regulatory pressures” (323) categories were mostly discussed in the literature review. The ”corporate strategy” (220) and ”organization's culture” (114) were most frequently cited in the case of internal drivers' category.

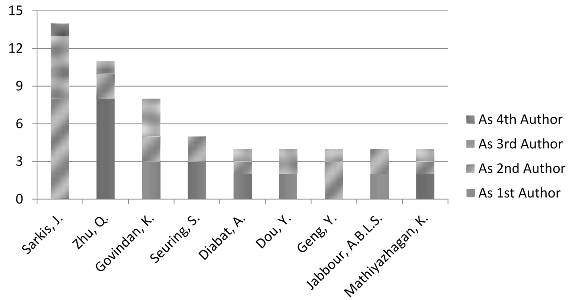

Figure 3: Authors’ distribution in the dataset

Based on the frequency analysis, it can be predicted that the more frequently a driver is cited in the literature the more influence it has for the implementation of sustainability initiatives and proven to be more important than other drivers of SSCM.

The ”primary drivers” were cited 1029 times and ”secondary drivers” were cited 530 times in this literature review. The ”customer pressure” (141) has more influence in primary drivers’ category and ”NGOs pressure” (70) has more influence in second/ary drivers’ category based on how frequently a driver is cited in the literature.

Table 4: Frequency analysis of drivers of SSCM – External Drivers

	External Drivers (1022)		
	Regulatory Pressures (323)	Societal Pressures (204)	Market Pressures (495)
Primary Drivers (1029)	Professional/ trade associations (19)		Shareholders/ investors' pressure (29)
	Regulators (115)		Suppliers Pressure (40) Competitors/ competitors' pressure (53) Customers' pressure/ demand (196) Institutional pressure (34) Reputation/ Image (53)
Secondary Drivers (530)	Certifications (33)	Media/Press (22)	Globalization (28)
	Financial benefits (22)	NGOs Pressures (70)	
		Public pressure (societal group) (56) Value based networks (5) Social wellbeing/ community focus (37)	

Table 5: Frequency analysis of drivers of SSCM – Internal Drivers

	Internal Drivers (537)			
	Corporate strategy (220)	Organization's Culture (114)	Organization's Resources (111)	Organization's Characteristics (92)
Primary Drivers (1029)	Top management commitment (62)	Health and Safety (10)	Organizations resources (32)	Industrial sector (18)
	Organizations' strategy (37)		Resource depletion (16)	Geographical location (3)
	Cost related pressures (68)		Employees' pressure/ involvement (21)	Position in supply chain (13)
Secondary Drivers (530)	Operational/ economic performance (53)	Socio cultural responsibility (50)	Training & development (14)	Organization size (17)
		Innovativeness (17)	Physical capital, technology, equipment (10)	Degree of internationalizations (12)
		Code of conduct (14)	Human capital (skills and capabilities) (18)	Current level of sustainability actions (29)
		Information dissemination (23)		

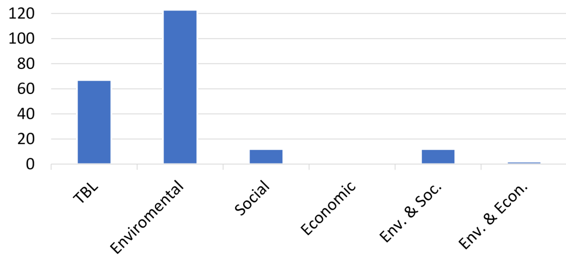

Figure 4: Distribution of sustainability dimensions

4.3 Dimensions of Sustainability

In the context of sustainability dimensions (see section 2.1), identified articles were also analyzed based on the TBL approach. The systematic literature review has shown that the environmental dimension of sustainability has attracted more attention and is most frequently discussed. This is also in accordance with the findings of other authors (Seuring and Müller, 2008b; Carter and Easton, 2011; Varsei, et al., 2014). Furthermore, 67 (31%) articles have been identified that have addressed all three sustainability dimensions (TBL) as shown in figure 4. Out of those 44 (66%) were published between 2014 and 2016 which entails a rapid increase in the interest of researchers in the field of TBL of SSCM. Whereas, 16 articles have addressed two sustainability dimensions i.e. either 'economic and social' (14) or 'environmental and social' (2).

4.4 Distribution by Methodology Applied

An inquiry into the research paper methodology has indicated that a range of methodologies were applied by different authors to address different research questions in their research articles considered for this study. Many authors have adopted multiple methodologies in their research and a majority of them have combined literature reviews with other methodological approaches. For the purpose of analysis, in case of multiple methodologies, each methodology is counted as one. The methodological approach of surveys (91), which is an empirical data

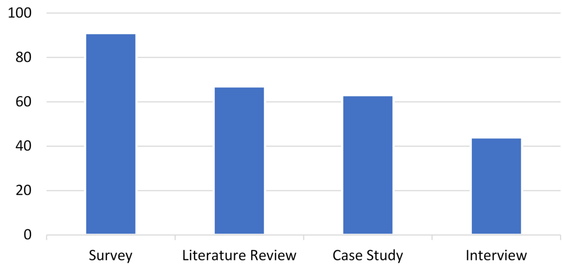

Figure 5: Top research methodologies applied

collection approach, is the most frequent methodology applied among all methods used. It is also in accordance with the findings of Bai, et al. (2015). Other methods are literature review (67), case study (63) and interviews (44) as shown in figure 5. In addition, some other methodologies were also applied by researchers such as DEMATEL, Interpretive Structural Modelling, etc.

4.5 Industrial Sectors

The industrial sector analysis of research articles has led to the conclusion that 42 articles have addressed multiple industries. Results suggest that manufacturing industrial sector along with automotive industrial sector is under increased pressure to adopt sustainability practices and 39 articles have addressed the manufacturing sector while 17 articles have addressed the automotive industrial sector as shown in figure 6. Due to the food safety issues, the food industry has attracted more attention (Bai, Sarkis and Dou, 2015) and 20 articles have addressed food-related industry. In addition, other industries such as textile, electronics, services, construction, etc. were also addressed.

4.6 Geographical Origin of Research Publications

Sustainability has become a global issue of importance, however, the majority of the articles identified are from developed countries. The analysis of the geographical origin of the data source, used in identified research articles, has shown that

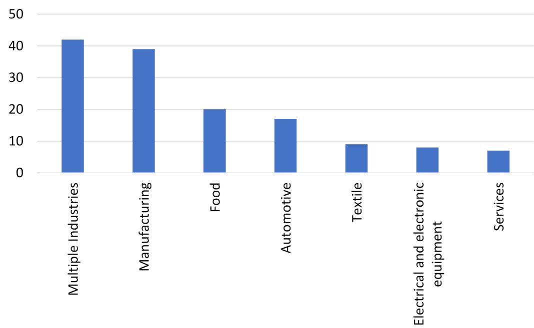

Figure 6: Top industrial sectors addressed in dataset

the majority of the publications are from the OECD (organization for economic co-operation and development) member countries i.e. 129 publications, whereas 88 publications are from non-OECD member countries as shown in figure 7. In addition, first author's university affiliation is used as a geographical location, if the origin of the data source is not clearly mentioned in the research article. It has led to a very interesting conclusion that sustainability issues are not only limited to developed countries. Organizations in developing countries are also influenced by both internal and external drivers to adopt sustainability practices. In terms of a number of publications, research articles addressing sustainability issues from developing countries e.g. India (26) and China (21) are among top five countries. However, 67 publications are from EU member states and 26 publications are from UK which makes 72% of the total publications from OECD member countries. On the other hand, publications from India, China, and Brazil makes 63% of the total publications from non-OECD member states. Furthermore, 85% of the publications from the developing countries are published between 2012-2016. It indicates that researchers have recently started focusing on sustainability issues in developing countries. Despite getting importance in developing countries, a clear gap still exists between developed and developing countries.

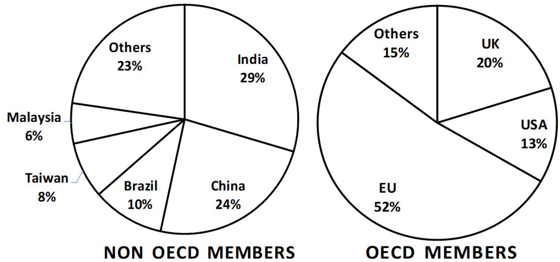

Figure 7: Geographical distribution data sources of selected research articles

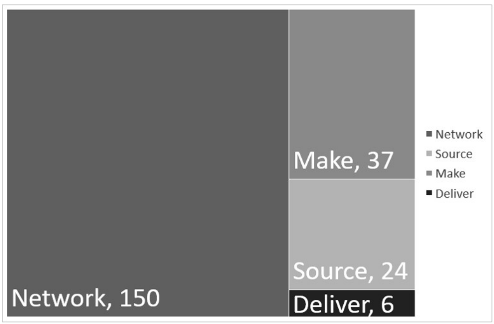

Figure 8: Distribution of SCM processes

4.7 Supply Chain Functions

From the systematic literature review conducted, 150 articles were identified dealing with the network level of a supply chain. Out of which more than 100 articles were published between 2013-2016. This is a direct indication of the growing importance of the sustainability topic at the supply chain network level. With an increase in the awareness, stakeholders put pressures on organizations to implement sustainability initiatives across their supply chain. Furthermore, the analysis has shown that sustainability issues are not only addressed at supply chain network but also at individual function levels. Other supply chain functions identified in the literature view such as source (24), make (37) and deliver (6) as shown in figure 8.

5 Conclusions and Outlook

The main objective of this research article was to identify drivers of SSCM and to understand their role in the implementation of sustainability initiatives. The objective of the study has guided to adopt a systematic literature review to address the research question posed at the start of this study. This systematic literature review has provided a comprehensive review of drivers of SSCM. The findings of this research can help practitioners in decision making while adopting sustainability practices. As drivers of SSCM pressurize organizations to implement sustainability initiatives. However, understanding sustainability issues of importance identified by drivers of SSCM and precise selection of a certain sustainability initiative require a detailed knowledge of sustainability drivers. Which defines organization's future actions towards the adoption of sustainability practices. Therefore, both drivers of SSCM and decision making regarding sustainability actions are interlinked and this might lead organizations towards improved sustainable behaviors.

The findings of the frequency analysis have shown that the topic of drivers of SSCM is more of a network supply chain issue than individual supply chain functions. ”External drivers” have more importance for adopting sustainability practices than ”internal drivers”. In addition, due to the influence, ”primary drivers” are cited more than ”secondary drivers”. ”Market Pressures”, ”regulatory pressures” and ”corporate strategy” dominate the literature. Different industrial sectors are facing more regulatory and societal pressures than others. Furthermore, developed countries such as OECD member countries were represented more

(60%) in the sample than non-OECD member countries. But at the same time, the number of articles from developing countries such as India, China, and Brazil have also increased. However, to identify country specific drivers of SSCM and to understand the sustainability issues of importance in case of developing countries, further research is required from countries other than China, India, and Brazil. As current research is centered either around developed countries or few developing countries such as China, India, and Brazil.

Despite its contribution, many improvements and specifications can be added to this frame of reference. Our research sample does not pretend to be exhaustive, as the findings of this study are based only on journal publications from two scientific databases. However, it is expected to provide a reliable systematic literature review of the current research related to drivers of SSCM. As data saturation was noticed after reviewing articles from ”web-of-science” and ”science-direct” databases. Nevertheless, research focus can be extended by including other forms of literature e.g. books, conference proceedings, etc.

Future research is required to empirically verify the findings of this research article, to check the relevance of different drivers of SSCM and to analyze the interconnection among different drivers. Furthermore, the consideration of articles from other scientific data sources might have an effect on the findings of this research paper. In addition, further research is required to identify industry specific drivers of SSCM as well as geographically significant drivers of SSCM.

References

Adebanjo, D., P.-L. Teh, and P. K. Ahmed (2016). “The impact of external pressure and sustainable management practices on manufacturing performance and environmental outcomes”. In: *International Journal of Operations & Production Management* 36.9, pp. 995–1013.

Ahi, P. and C. Searcy (2013). “A comparative literature analysis of definitions for green and sustainable supply chain management”. In: *Journal of Cleaner Production* 52, pp. 329–341.

Alblas, A. A., K. Peters, and J. C. Wortmann (2014). “Fuzzy sustainability incentives in new product development”. In: *International Journal of Operations & Production Management* 34.4, pp. 513–545.

Ayuso, S., M. Roca, and R. Colomé (2013). “SMEs as “transmitters” of CSR requirements in the supply chain”. In: *Supply Chain Management: An International Journal* 18.5, pp. 497–508.

Bai, C., J. Sarkis, and Y. Dou (2015). “Corporate sustainability development in China: Review and analysis”. In: *Industrial Management & Data Systems* 115.1, pp. 5–40.

Bansal, P. (2002). “The corporate challenges of sustainable development”. In: *Academy of Management Executive* 16.2, pp. 122–131.

Beamon, B. M. (1999). “Designing the green supply chain”. In: *Logistics Information Management* 12, pp. 332–342.

Ben Abdelaziz, S. I., M. A. Saeed, and A. Z. Benleulmi (2015). “Social media effect on sustainable products purchase”. In: *Innovations and strategies for logistics and supply chains: Technologies, business models and risk management*. Ed. by W. Kersten, T. Blecker, and C. M. Ringle. Proceedings of the Hamburg International Conference of Logistics. Berlin: epubli GmbH, pp. 64–93.

Berke, P. (2016). “Twenty years after campbell’s vision: Have we achieved more sustainable cities?” In: *Journal of the American Planning Association* 82.4, pp. 380–382.

Brockhaus, S., W. Kersten, and A. M. Knemeyer (2013). “Where do we go from here? Progressing sustainability implementation efforts across supply chains”. In: *Journal of Business Logistics* 34, pp. 167–182.

Brockhaus, S., W. Kersten, and M. Knemeyer (2013). *Analyzing the effect of sustainability on supply chain relationships*. 1st ed. Vol. 15. Lohmar: Eul.

Broman, G., K.-H. Robèrt, T. J. Collins, G. Basile, R. J. Baumgartner, T. Larsson, and D. Huisingh (2017). “Science in support of systematic leadership towards sustainability”. In: *Journal of Cleaner Production* 140, pp. 1–9.

Brugmann, J. (1996). “Planning for sustainability at the local government level”. In: *Environmental Impact Assessment Review* 16.4-6, pp. 363–379.

Caniato, F., M. Caridi, L. Crippa, and A. Moretto (2012). “Environmental sustainability in fashion supply chains: An exploratory case based research”. In: *International Journal of Production Economics* 135, pp. 659–670.

Carter, C. R. and M. Dresner (2001). “Purchasing’s role in environmental management: Cross-functional development of grounded theory”. In: *The Journal of Supply Chain Management* 37, pp. 12–27.

Carter, C. R. and P. L. Easton (2011). “Sustainable supply chain management: Evolution and future directions”. In: *International Journal of Physical Distribution & Logistics Management* 41, pp. 46–62.

Carter, C. R. and D. S. Rogers (2008). “A framework of sustainable supply chain management: Moving toward new theory”. In: *International Journal of Physical Distribution & Logistics Management* 38, pp. 360–387.

Diesendorf, M. (2001). “Models of sustainability and sustainable development”. In: *International Journal of Agricultural Resources, Governance and Ecology* 1, p. 109.

Elkington, J. and J. Elkington (1997). *Cannibals with forks: The triple bottom line of 21st century business*. Oxford: Capstone.

Fink, A. (2014). *Conducting research literature reviews: From the internet to paper*. 4th ed. Thousand Oaks California: Sage.

Fodness, D. (2016). “The problematic nature of sustainable tourism: Some implications for planners and managers”. In: *Current Issues in Tourism* 86.5, pp. 1–13.

Freeman, R. E. (2010). *Strategic management: a stakeholder approach*. Cambridge: Cambridge University Press.

Giunipero, L. C., R. E. Hooker, and D. Denslow (2012). “Purchasing and supply management sustainability: Drivers and barriers”. In: *Journal of Purchasing and Supply Management* 18.4, pp. 258–269.

Glover, J. L., D. Champion, K. J. Daniels, and A. Dainty (2014). “An Institutional Theory perspective on sustainable practices across the dairy supply chain”. In: *International Journal of Production Economics* 152, pp. 102–111.

Gonzalez-Benito, J. and O. Gonzalez-Benito (2009). “A study of determinant factors of stakeholder environmental pressure perceived by industrial companies”. In: *Business Strategy and the Environment* 42.5, n/a–n/a.

Govindan, K., K. Muduli, K. Devika, and A. Barve (2016). “Investigation of the influential strength of factors on adoption of green supply chain management practices: An Indian mining scenario”. In: *Resources, Conservation and Recycling* 107, pp. 185–194.

Harms, D., E. G. Hansen, and S. Schaltegger (2013). “Strategies in sustainable supply chain management: An empirical investigation of large German companies”. In: *Corporate Social Responsibility and Environmental Management* 20, pp. 205–218.

Harms, D. and J. Klewitz (2013). “Innovation in sustainable supply chains – Interaction for resources from an SME perspective”. In: *Supply management research*. Ed. by R. Bogaschewsky, M. Eßig, R. Lasch, and W. Stölzle. Advanced Studies in Supply Management. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 105–130.

Haverkamp, D.-.-.-J., H. Bremmers, and O. Omta (2010). “Stimulating environmental management performance”. In: *British Food Journal* 112.11, pp. 1237–1251.

Henriques, I. and P. Sadorsky (1999). “The relationship between environmental commitment and managerial perceptions of stakeholder importance”. In: *Academy of Management Journal* 42, pp. 87–99.

Holden, E., K. Linnerud, and D. Banister (2014). “Sustainable development: Our common future revisited”. In: *Global Environmental Change* 26, pp. 130–139.

Hsu, C.-.-.-C., K. Choon Tan, S. Hanim Mohamad Zailani, and V. Jayaraman (2013). “Supply chain drivers that foster the development of green initiatives in an emerging economy”. In: *International Journal of Operations & Production Management* 33.6, pp. 656–688.

Huang, C.-L. and F.-H. Kung (2010). “Drivers of environmental disclosure and stakeholder expectation: Evidence from Taiwan”. In: *Journal of Business Ethics* 96, pp. 435–451.

Kersten, W. and M. A. Saeed (2014). “A SCOR based analysis of simulation in supply chain management”. In: *28th European Conference on Modelling and Simulation*. Ed. by F. Squazzoni, F. Baronio, C. Archetti, and M. Castellani. Brescia, Italy, pp. 461–469.

Kleindorfer, P. R., K. Singhal, and L. N. van Wassenhove (2005). “Sustainable operations management”. In: *Production and Operations Management* 14, pp. 482–492.

Köksal, D., J. Strähle, M. Müller, and M. Freise (2017). “Social sustainable supply chain management in the textile and apparel industry - A literature review”. In: *Sustainability* 9, pp. 1–32.

Meixell, M. J. and P. Luoma (2015). “Stakeholder pressure in sustainable supply chain management”. In: *International Journal of Physical Distribution & Logistics Management* 45, pp. 69–89.

Mihelcic, J. R., J. C. Crittenden, M. J. Small, D. R. Shonnard, D. R. Hokanson, Q. Zhang, H. Chen, S. A. Sorby, V. U. James, J. W. Sutherland, and J. L. Schnoor (2003). “Sustainability science and engineering: The Emergence of a new metadiscipline”. In: *Environmental Science & Technology* 37, pp. 5314–5324.

Mzembe, A. N., A. Lindgreen, F. Maon, and J. Vanhamme (2016). “Investigating the Drivers of Corporate Social Responsibility in the Global Tea Supply Chain: A Case Study of Eastern Produce Limited in Malawi”. In: *Corporate Social Responsibility and Environmental Management* 23.3, pp. 165–178.

Pagell, M. and Z. Wu (2009). “Building a more complete theory of sustainable supply chain management using case studies of 10 examplars”. In: *Journal of Supply Chain Management* 45, pp. 37–56.

Paulraj, A., I. J. Chen, and C. Blome (2015). “Motives and performance outcomes of sustainable supply chain management practices: A multi-theoretical perspective”. In: *Journal of Business Ethics* 25, p. 299.

Schaltegger, S. and R. Burritt (2014). “Measuring and managing sustainability performance of supply chains: Review and sustainability supply chain management framework”. In: *Supply Chain Management: An International Journal* 19, pp. 232–241.

Schrettle, S., A. Hinz, M. Scherrer-Rathje, and T. Friedli (2014). “Turning sustainability into action: Explaining firms’ sustainability efforts and their impact on firm performance”. In: *International Journal of Production Economics* 147, pp. 73–84.

Seuring, S. and M. Mueller (2008a). “Core issues in sustainable supply chain management - a Delphi study”. In: *Business Strategy and the Environment* 17, pp. 455–466.

Seuring, S. and M. Mueller (2008b). “From a literature review to a conceptual framework for sustainable supply chain management”. In: *Journal of Cleaner Production* 16, pp. 1699–1710.

Seuring, S., J. Sarkis, M. Müller, and P. Rao (2008). “Sustainability and supply chain management – An introduction to the special issue”. In: *Journal of Cleaner Production* 16, pp. 1545–1551.

Tao, T. C. and G. Wall (2009). “Tourism as a sustainable livelihood strategy”. In: *Tourism Management* 30, pp. 90–98.

Tate, W. L., L. M. Ellram, and J. F. Kirchoff (2010). “Corporate social responsibility reports: A thematic analysis related to supply chain management”. In: *Journal of Supply Chain Management* 46, pp. 19–44.

Tranfield, D., D. Denyer, and P. Smart (2003). “Towards a methodology for developing evidence-informed management knowledge by means of systematic review”. In: *British Journal of Management* 14, pp. 207–222.

Varsei, M., C. Soosay, B. Fahimnia, and J. Sarkis (2014). “Framing sustainability performance of supply chains with multidimensional indicators”. In: *Supply Chain Management: An International Journal* 19, pp. 242–257.

Walker, H., L. Di Sisto, and D. McBain (2008). “Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors”. In: *Journal of Purchasing and Supply Management* 14, pp. 69–85.

WCED (1987). *Our common future*. Reprint. Oxford paperbacks. Oxford: Oxford Univ. Press.

Weber, R. P. (2008). *Basic content analysis*. 2nd ed. Vol. 49. Sage Publication.

Weitzman, M. L. (1997). “Sustainability and technical Progress”. In: *The Scandinavian journal of economics* 99, pp. 1–14.

Xu, L., K. Mathiyazhagan, K. Govindan, A. Noorul Haq, N. V. Ramachandran, and A. Ashokkumar (2013). “Multiple comparative studies of Green Supply Chain Management: Pressures analysis”. In: *Resources, Conservation and Recycling* 78, pp. 26–35.

Zhu, Q. and J. Sarkis (2007). “The moderating effects of institutional pressures on emergent green supply chain practices and performance”. In: *International Journal of Production Research* 45.18-19, pp. 4333–4355.

Improving Sustainability through Digitalisation in Reverse Logistics

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Online purchases of clothes are increasing rapidly and with it, the number of returns. Return rates of clothing bought online can be up to 70%, involving high reverse logistics costs to retailers as well as sustainability costs to society. This paper seeks to illustrate how digitalisation can potentially decrease both such costs.

The paper is based on a literature review and subsequent empirical research. Qualitative information was obtained through detailed interviews with key personnel and observations of the reverse logistics operations of five major clothing retailers and two major logistics companies in Sweden, carried out in Spring 2017.

The research confirmed the importance to the retailers of reverse logistics and highlighted some of the environmental consequences of the reverse logistics operations. It also unveiled several areas where digitalisation could both reduce the number of returns made in the first place and improve the efficiency of the reverse logistics processes involved in dealing with returns.

There is very little research on reverse logistics in the online clothing industry despite it being the single biggest sector of online purchases in practically every country in the world. This paper brings to light some of the little-considered issues involved as well as suggesting ways in which technology can improve the sustainability of such operations. Both elements are original.

Most retailers are concerned about the costs and sustainability of their operations. By providing insights into how these can be reduced, management can make better informed decisions.

Keywords: Reverse logistics; Clothing returns; Digitalisation; Sweden

1 Introduction

E-commerce has been increasing continuously over the past decade and has now become a feature of everyday life. Clothing has become the single biggest category of goods (by number of items) bought online in most countries in Europe (Eurostat, 2016). Initially, customers bought clothing from existing retailers who opened webshops to complement their existing stores. Catalogue companies took advantage of their knowledge of the market and their existing customer-orientated logistics systems and moved swiftly into the online market. Now, however, the online clothes market has been joined by some major 'pure' e-tailers (i.e. retailers which are purely internet based), such as Zalando, Asos, Amazon, Very and Boozt as well as a huge number of smaller e-tailers.

A major unintended but nevertheless important consequence of the growth in the e-tailing of clothing is returns. On average, 22% of clothing items bought on the internet are returned. In Sweden alone, this amounts to over 3 million return packages per year. However, this average conceals major differences between clothing categories and countries (e-commerce, 2016). In the high fashion sector the return rate is around double the average and in some countries in Europe, notably Germany and Finland, the return rate is much higher still. For high fashion clothing in Germany, for instance, the return rate can be over 60%. The reasons for this anomaly include regulatory, cultural and payment differences in these two countries compared to the rest of Europe.

Returns are very much dependent on consumer behaviour. Clothing returns are made for a variety of reasons such as:

— Damaged/faulty items

— The wrong items being received

— The items not looking like they do on the website/not matching expectations

— The items not fitting

— The customer just changing their mind

When customers buy clothes in a shop, they have the opportunity to try them on. They may take several items into the changing room and reject them all or buy one or two pieces. There is no charge for trying on clothes in changing rooms and rejecting those which are not wanted (for any reason). Buying online does not allow this and to deal with this issue, companies wishing to sell online have had to try to emulate the in-store shopping experience. Part of this is free, convenient returns. Many customers now routinely buy one item of clothing in several colours and/or sizes and return those they do not want.

The outward logistics operations of most companies are usually well organised and fairly efficient. There are well documented sustainability issues concerning the 'last mile' element of the delivery and considerable research is being carried out on ways to improve the environmental sustainability of online deliveries (see for instance Cullinane, 2009; Edwards et al, 2010; Carillo et al, 2014; Mangiaracina, 2015; van Loon et al, 2015). However, the returns process, involving reverse logistics, is much less well researched.

The Reverse Logistics Association defines reverse logistics as: "…the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal" (RLA, 2016). For retailers, dealing with returns has often been almost an afterthought. However, now that the scale of the issue is beginning to be appreciated by the retailers (and particularly the e-tailers), more efficient, sustainable reverse logistics solutions are being sought. From a sustainability and city logistics perspective, it is important that the reverse logistics operations are paid equal attention to the outward logistics operations as essentially it involves all of the same processes as the outward logistics, except in reverse, but is currently being carried out in a less efficient way. Given that the possibility exists of returns increasing still further in the future, particularly as online shopping continues to increase, this poses a big challenge. The case-study retailers involved in this study suggested that the proportion of clothes bought online in Europe would be likely to double over the next few years, implying a huge increase in the volume of returns if no action is taken to reduce their number.

This paper will proceed as follows. After outlining the methodology used for this study, we will briefly discuss some of the major sustainability issues involved in the reverse logistics operations. We will then go on to describe some of the applications of digitalisation that are being used, or are being considered for use to reduce the sustainability problems associated with reverse logistics in the clothing sector. We will divide the solutions into two categories; those associated with reducing the number of returns in the first place and those associated with improving the efficiency of the reverse logistics process.

2 Methodology

Existing research on reverse logistics in the clothing retail industry is minimal and research on the sustainability of the reverse logistics in the clothing retail industry is even less. Following an extensive literature review of the general issues involved, it was decided that qualitative, case study based research was required to investigate the specific subject in some depth. Case study based research involves the investigation of a contemporary phenomenon in depth and in a real-life context using multiple sources of evidence combined with prior theoretical declarations (Yin, 2009). The emphasis is on intensive examination of a specific issue (Bryman and Bell, 2011). During the spring of 2017, in-depth semi-structured interviews took place with five major clothing retailers and two major distribution companies (including the Swedish national carrier) in Sweden. Interview schedules were written in advance to guide the interviews. However, interviewees were given a great deal of flexibility within the interviews to develop their arguments and discussions. Observations of the reverse logistics operations in these companies also took place. Within each company, interviews involved between 1-6 key people at their head offices. Interviews lasted approximately 3 hours at each company. Clothing retailers included mixed clothing retailers (traditional bricks and mortar companies with an online platform) and pure e-tailers (companies with no bricks and mortar stores) and included some of the largest retailers in Sweden. All companies traded internationally. As we are only discussing general principles in this paper rather than trying to pinpoint specific issues, the details of the companies are unimportant and will not be described. In this text, (r)e-tailers denotes both companies which are bricks and mortar retailers with an online platform and pure-etailers

3 Findings in relation to sustainability

The findings are confined to general issues as they are not the main focus of the paper. They are presented in order to highlight some of the areas where digitalisation can help provide solutions. In order to give some context to the work, table

Table 1: Returns, by country and brand, 2016

	Brand A (low fashion)		Brand B (high fashion)	
Country	% returns (on an item basis)	Items returned	% returns (on an item basis)	Items returned
Finland	24.5	126,000	45	51,700
Sweden	15.6	248,000	31.6	176,000
Denmark	13.9	44,000	25.7	10,000
Norway	14.2	74,000	25.3	7,500

Source: Case-study company

1 shows the returns from one of the (smaller) case study companies which sells mostly (but not exclusively) to the Nordic countries. It is an online (ex-catalogue) company with 2 major clothing brands. Brand A is more traditional, aimed at slightly older people, whereas brand B is more high fashion, aimed more at young people. All the returns are made to a warehouse located in southern Sweden before being transported to Estonia for sorting, processing and re-packaging and then being transported back to the same warehouse in Sweden and being re-sold.

The reverse logistics operations associated with online clothing returns are complex, time consuming and expensive. The first crucial element in the returns process is what may be termed 'the first mile' (in contrast to the 'last-mile' in the outward delivery operation), where the package leaves the customer's home. It may involve an element of passenger transport as customers may take the return parcel to a pick-up or collection point. Alternatively, a parcel carrier may pick the parcel up from the customer's home. Generally, the process involves the transportation of packages from individual dispersed customers to an initial hub where the parcels will be consolidated and subsequently often line-hauled to a retail company's warehouse (i.e. from the many to the few). The sustainability of this element of the process is affected by the mode of transport used by the individual in the process of taking the parcel to the distribution point; the journey type (whether or not it is part of a trip chain); the parcel pick-up density (i.e. the number of parcels collected by the parcel company per pick up) and the sustainability of the transport mode used by the parcel carrier.

Once the return parcel has been received by the retailer, the reverse logistics operation involves a time-consuming process of opening, sorting, processing, re-packaging and (where possible) re-selling the product. Resources used include people, warehouse space, mechanical handling equipment and a variety of transportation vehicles all requiring energy. In two of the five case study companies, returns from all over the world are consolidated in a distribution centre in Sweden, sent by truck to a sorting centre in Eastern Europe and then brought back to Sweden to be re-sold. Specifically, one company sent 3 full semi-trailer loads of returns for processing per week to Poland and received 2 semi-trailer loads back with returns and another company sent all their returns to Estonia using the national carrier which consolidated other goods into the vehicles. This off-shoring is recognised by the retailers to be environmentally problematical but is carried out purely for cost reduction purposes.

4 Sustainability improvements and digitalisation.

The solutions discussed below have emerged from the discussions with the retailers and distribution companies as well as from the literature. They are divided into two categories; first, reducing the number/rate of returns to start with and second, making the reverse logistics process more efficient.

4.1 The role of digitalisation in reducing the number/rate of returns

4.1.1 Digital changing rooms

As outlined above, customers make returns for various reasons, including incorrect sizing and failure of the image on the website to properly represent the actual product so that a difference exists between what the customer perceives on the website and the product in reality. Digitalisation can reduce this gap through developments such as virtual changing rooms and other augmented reality apps in which customers can input their measurements and other key body descriptors. The use of avatars or similar can then help the customer with sizing whilst at the same time showing an image of what the clothing item looks like on them and even how it combines with other elements of their wardrobe. Once customer data has been stored, the company can then target customers individually with clothes that they think might be suitable for them, providing personal, customised shopping. Some companies are also pioneering virtual reality changing rooms where the customer can even ‘touch’ and ‘feel’ the product and can discuss the product with friends through social media. Webpages can be tailored to individuals promoting styles and sizes based on a customer’s previous shopping habits making it less likely that items will be returned.

4.1.2 Social media

Social media is a direct outcome of digitalisation. It has brought about unprecedented connectivity, transparency and communication between all sorts of social and business networks enabling the sharing of information, opinions and ideas. Generation Y, the digital natives who use social media as a matter of course, have had and continue to have a massive impact on the consumer’s buying behaviour. However, social media can be used by companies in a variety of ways to reduce returns. By communicating with customers via social media, products can be described more personally and realistically. In addition, companies monitoring social media can view how their products are being perceived by their customers. If a product is continuously being described as being wrongly sized or badly made, it gives the retailer the opportunity to address such problems on the website by changing either the image or the description of the product to more accurately reflect it. If an item has a great many ‘dislikes’, it gives the company the opportunity to determine why.

4.2 Improving the efficiency of reverse logistics

4.2.1 Apps

All manner of apps now exist; some more useful than others. As alluded to above, apps can be used by companies to improve the quality of information provided to customers so that returns can be reduced. Parcel tracking apps can provide the customer with real-time information about when their return parcel will be picked up by the parcel carrier. This should reduce the number of failed pick-up calls by parcel carriers, thereby improving sustainability. Some companies are providing customers with apps linked to smart devices which will enable parcel carriers to access locations at people’s homes using PIN codes to enable them to pick up returns parcels. The complication with making the returns process more reliable and convenient for the customer is that it could actually stimulate them to make more returns!

4.2.2 Electronic data interchange (EDI)

EDI has a big part to play in improving the efficiency of reverse logistics. EDI has been used in logistics operations for a long time. It is essentially EDI which has enabled the globalisation of logistics. EDI is becoming increasingly sophisticated as it develops and evolves. In conjunction with Application Programming Interfaces (APIs) applications can be built enabling previously proprietary, sometimes bespoke, legacy based software programmes to communicate with each other. EDI provides end-to-end visibility of the return enabling monitoring and track and trace. Such digital transformation enables functionality between different channels and thus important collaboration between partners in the chain. Used properly, it allows companies to fully exploit both internal and external communications and integration processes. As has been discussed above, the journey taken by a returned item is quite complex, involving both the consumer and the parcel collection company. Additionally, during much of this journey there is little product visibility, making stock control difficult. Improving the quantity and quality of this information could mean fewer wasted resources in terms of product and resource use.

A combination of EDI and barcodes can enable swifter turnarounds and improved lead time. It has the potential to radically alter the returns process. With such systems, retailers with physical stores will have cross-channel connectivity, enabling products ordered online to be returned in-store (and maybe vice-versa). Customers can then be refunded immediately and stock control systems will be able to take these returns into account enabling the movement of physical flows of goods to be reduced.

In another possible development being discussed, for goods ordered online rather than items being returned to the retailer, customers could be able to send their return item direct to the next customer, thus becoming a C2C transaction and reducing hugely the resources used in the reverse logistics process. In this case, the initial customer would be sent (electronically) a barcode label to print out and stick onto the return packaging which would allow that package to be re-directed to the next customer. As long as the parcel carrier was part of the EDI system, the parcel could be intercepted from its normal returns journey. This type of system obviously requires a degree of trust between customers and may not be possible, but with appropriate customer profiling or similar, it could work with at least a proportion of returns.

Parcel carrier routing and scheduling can also be hugely improved with the use of appropriate digitalisation applications. As with the last mile in the outward, delivery direction, the sustainability of the first mile in the reverse logistics process is increased as the pick-up density increases. Routes can be planned to maximise pick-up densities and these can be improved using real time information provided initially by the customers. This is equally applicable where the customers are individuals or business customers advising on pick-ups from collection points. Although maybe a little less immediately possible due to competition issues, different parcel carriers should also be able to communicate to work together in this sphere, obviating the duplication of trips and thereby improving sustainability.

Digitalising the whole of the returns flow can enable swifter processing of the returns when they arrive back at the (r)e-tailers warehouse. The sorting process is very labour intensive and often requires several separate computer inputs by the sorter(s). One of the case study companies had speeded up the process considerably through the use of hand-held scanners, which both improved the accuracy of the information, speeded up the sorting process and also the speed in which the goods were able to be added back into the stock-keeping system.

4.2.3 Radio Frequency Identification (RFID)

RFID can play a part in improving the efficiency of the reverse logistics process by enabling the (r)e-tailer to track and identify the returning parcel much more quickly. Companies obviously want to re-sell as many of the returns as possible and the higher proportion they re-sell, the greater the sustainability (assuming that disposal is the least sustainable option). Item tracking and identification can help in many parts of the process, but an example from one of the case study companies may highlight an unexpected benefit. When the returns for this company arrive back at the warehouse, they are delivered in cages, each of which holds around 500 parcels. The retailer knows the contents of the cage as a whole, but if it is seeking to re-send one particular item to a new customer, it has to find that item in the cage. This can take a long time as all the parcels will need to be searched. If RFID tags were used, the item could be found much more quickly, using fewer resources. None of the case study companies used RFID tags as they were deemed to be insufficiently sensitive and robust and were too expensive, but this is likely to change in the future as RFID technology improves

4.2.4 Customer Profiling

Customer profiling in a manner suggested by Hjőrt et al. (2013) can also be facilitated by EDI. Hjőrt et al argue that customers should be charged differentially for returns according to their past returns behaviour and their ordering profile, so that a customer who serially returns items whilst purchasing only a very small percent of the items they order would pay more for returns than a customer who returns only a very small proportion of their orders or who buys a lot from the company. Only two of the case study companies had any idea of their customer’s returns profile.

4.2.5 Packaging

Although perhaps a minor aspect in terms of the sustainability of reverse logistics, packaging is nevertheless important. At present, many (r)e-tailers include in their package a pre-printed return label and a form asking for information about why the item is being returned. Several of the case study companies were considering replacing these with a downloadable digital version to be printed out by the customer in the event of them wanting to make a return. This saving of paper improves the sustainability of the process, albeit probably only very slightly.

4.2.6 Discussion

Whilst some of the digitalisation possibilities discussed above offer relatively quick and definite benefits, others are potentially very expensive and at the same time very risky. Clothing returns are nothing new, but the VOLUME of returns is comparatively new and companies are struggling to know how best to deal with the issue and which route to, and form of, digitalisation is best for them. The new ’pure’ e-tailers have almost been established with digitalisation at their core, as part of their business model; the mixed (r)e-tailers have so many alternative courses of action that choosing between them is almost impossible and getting it wrong can be VERY costly. Implementing new computer systems of any sort is fraught with difficulties as well as being very expensive. All of the personnel that we interviewed in the case-study companies said that dealing with returns was a very high level of priority for them as the cost of dealing with them was so high and the potential loss of customer orders if they got it wrong was also high. They all admitted that they were daunted by future and a little ’lost’ as to the next moves to take.

5 Summary and Conclusions

This paper has sought to show how digitalisation can improve the sustainability of the reverse logistics of clothing. We have only just scratched the surface of this issue and there are likely to be many more developments. Developments in augmented and virtual reality improve the visualisation of the clothing products being bought online and may also be able to improve other important aspects such as the ‘feel’ of a product. These developments may reduce the number of returns made by consumers. However, we must also bear in mind that processes that make returns easier, and even processes that make online shopping easier and more reliable, might actually increase the number and rate of returns. It might be that at the end of the day, if we really want to reduce the number of returns we actually have to appeal to people’s sense of environmentalism to simply not return as many goods as they are currently doing. This could be done by making them more aware of the sustainability issues involved. Somewhat contradictorily, however, as returns increase, it could be argued that on a per parcel basis, sustainability improves as generally higher parcel consolidation and reduced parcel flow fragmentation is positively correlated with sustainability. EDI and other digital developments can assist in this domain.

In summary, it is likely that combining digitalisation measures to reduce the number of returns with those aimed at improving the efficiency of the reverse logistics process will be required to improve the sustainability of reverse logistics operations in cities and elsewhere.

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References

Bryman, A. and E. Bell (2011). *Business Research Methods*. Oxford University Press.

Carrillo, J., A. Vakharia, and R. Wang (2014). "Environmental implications for online retailing". In: *European Journal of Operational Research* 239, pp. 744–755.

Cullinane, S. L. (2009). "From Bricks to Clicks: The impact of online retailing on transport and the environment". In: *Transport Reviews* 29.6, pp. 759–776.

Ecommerce-Europe (2016). "Fashion Benchmark report".

Edwards, J. B., A. C. McKinnon, and S. L. Cullinane (2010). "Comparative analysis of the carbon footprints of conventional and online retailing: A "last mile" perspective, International Journal of Physical Distribution & Logistics Man-agement". In: *Vol.* 40, pp. 103–123.

Hjört, K., B. Lantz, D. Ericsson, and J. Gattorna (2013). "Customer segmentation based on buying and returning behaviour". In: *International Journal of Physical Distribution and Logistics Management* 43.10, pp. 852–865.

Mangiaracina, R., G. Marchet, S. Perotti, and A. Tumino (2015). "A review of the envi-ronmental implications of B2C e-commerce: a logistics perspective". In: *International Journal of Physical Distribution and Logistics Management* 45.6, pp. 565–591.

Van Loon, P., L. Deketele, J. Dewaele, A. C. McKinnon, and C. Rutherford (2015). "A comparative analysis of carbon emissions from online retailing of fast moving consumer goods". In: *Journal of Cleaner Production* 106, pp. 478–486.

Yin, R. K. (2009). "Case Study Research – Design and Methods". In: 4.

Simulation of Climatic Effects on Temperature-Controlled Containerized Cargo

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This paper describes the so-called CORE Simulation Environment (CORE-SE), a scenario based simulation environment which was developed in the scope of the EU project CORE. CORE-SE in particular provides means for the simulation of logistics scenarios. It consists of a software agent platform that facilitates a multiagent-based simulation (MABS) approach. In MABS, the environment and the objects acting therein are modelled by a number of software agents. CORE-SE provides a platform to create and configure different simulation scenarios and finally "run" them by the emulation of the agents' behaviours in a coordinated and controlled way. CORE-SE, as described in this paper, has been applied in a specific supply chain sce-nario related to product integrity due to cargo temperature requirements where higher temperature (and solar radiation) could result in fluctuating product integrity in terms of quality loss and damage. During the simulated transport, climatic and weather-related factors like ambient temperature, ground temperature, solar radiation, and wind speed together with the resulting effects on the inner container temperature are simulated and respectively calculated according to the actual transport route of the container by usage of a climatic data model. The paper presents first results of the analysis, which are used to optimize the temperature control of the cargo, thereby better taking into account the mentioned external factors.

Keywords: Containerized Cargo; Container; Clima; Climatic Effects

1 Introduction

Procter & Gamble (P&G) has a large number of finished products and raw materials which do not normally require a temperature controlled supply chain, but suffer from extreme climatic conditions in summer/winter in some regions. There are no adequate and energy efficient solutions. Some technologies are based on diesel generators, resulting in very high cost and energy footprint. As some goods are temperature sensitive, truck and sea shipment are the means of transporting them to final locations. As a consequence, those trucks and containers might undergo severe climatic conditions throughout the journey resulting in damage or loss of product integrity.

This paper presents simulations and tests of a novel device unit performed in the scope of the CORE project (Core, 2017). The device will be loaded in normal standard dry shipping sea containers and allow passive and on demand cooling capability to the transported goods. This new solution – called ICECUBE, commercial name ChillX – will demonstrate a much more efficient solution which will reduce both the cost and energy footprint related to guarantying product integrity by keeping mild temperature conditions (30 °C) in trucks and containers during shipments. This will ensure the entire integrity of the full load throughout the end to end supply chain. The new solution is expected to allow a 30-40% overall carbon footprint reduction with respect to commonly used diesel generators.

This paper describes the usage of the CORE Simulation Environment (CORE-SE), a simulation framework for supply chains developed within the EU project CORE, and its application for simulations supporting the development of the ICECUBE system. In detail, the P&G tradelane from Spain to South Africa was modeled using a multiagent-based simulation (MABS) approach.

2 CORE Simulation Environment

For the simulation of the P&G simulation scenario the CORE Simulation Environment (CORE-SE) is used, in particular providing a computer-aided model that calculates all relevant ambient conditions throughout a shipment as a function of the container's location and the time of year based on historical data. CORE-SE consists of a software agent platform that facilitates a multiagent-based simulation (MABS) approach and provides means for the simulation of logistics scenarios.

In MABS, the environment and the objects acting therein are modelled by a number of software agents. CORE-SE provides a platform to create and configure different simulation scenarios and finally “run” them by the emulation of the agents’ behaviours in a coordinated and controlled way. By usage of CORE-SE software developers are able to implement specific simulation scenarios of real operational conditions of secure supply chains with a special focus on resilience and controls in case of disturbances. The Scope of the simulation in the P&G demonstration is composed of:

— Assessment of the impact of weather conditions (e.g. temperature, solar radiation) on the temperature inside the container and the goods, cooled by the ICECUBE system

— Assessment of the impact of disturbances in the supply chain (e.g. strike in a port) on the temperature inside the container. In particular: what is the impact on the temperature of the goods if the container has been stopped due to a disturbance (e.g. strike in a port) for several days in an area with high temperature and high solar radiation impact?

— Overall goal is to simulate worst case situations in order to test the limits of the ICECUBE system, if it is capable of ensuring the product integrity even in worst case scenarios.

CORE-SE simulates the P&G tradelane including data on ambient temperature, wind speed and solar radiation incident during the transport of the container. In addition, during the transport events can occur which could lead to a delay. These events could be logistical delays, e.g. traffic jams during truck transport, Customs stops or other events (e.g. strike in a port). A delay could lead to a longer transportation time. Thus, longer exposure to higher temperature could be possible.

For each simulation run CORE-SE creates a CSV file which contains the following data:

— Hour

— Ambient air temperature

— Temperature of the surface below the container

— Solar radiation incident upon a horizontal surface

— Solar radiation incident upon the left wall of the container

— Solar radiation incident upon the right wall of the container
— The ambient wind speed relative to the container
— Geo-Position (latitude, longitude)

3 Climate data

The climate data used in the simulation is based on data from the ERA-Interim climate reanalysis (Dee, 2011) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF).

ERA-Interim is a still ongoing global data set describing the recent history of the atmosphere, land surface, and oceans, containing climate data from January 1979 to present. It is created by combining ECMWFs forecast models (IFS) and observations of many different sorts in an optimal way to produce a consistent, global best estimate of the various atmospheric, wave and oceanographic parameters.

The weather influencing the simulated container on the trade lane is based on the actual weather data on the location at the date in the year 2016. The year 2016 was used as base due to high temperatures in summer especially in Spain. To model the weather on the trade lane we use climate data for temperature, solar radiation, cloud coverage and wind speed. Especially ambient temperature, particularly solar effect, has significant influence on the container indoor temperature (Rodriguez-Bermejo, 2007). A similar methodology was applied by (Horak, 2016) to calculate the cabin air temperature of parked vehicles in summer conditions. In the following the data fields of the climate data are described, including limitations and restrictions for the current development phase of the simulation model.

Ambient air temperature The modelled temperature profile is based on the ERA-Interim climate data for temperature. A maximum, a minimum and an average temperature is calculated from the weather data of the actual day, the previous day and the next day. These values are used to adjust a typical daily temperature profile (sinus curve). The measure unit of this parameter is Degrees Celsius.

Temperature of the surface below the container The temperature of the surface below the container depends on the ambient air temperature at the location, how long that place was exposed to the sun before and heated up, and the time since the container was dropped. The simulation is partly based on results presented in (Jansson, 2006). The cooling off is assumed to be a steady function. The measure unit of this parameter is Degrees Celsius.

Solar radiation incident The solar radiation incident is calculated in total for three sides of the container:

— Top of the container

— Left side of the container

— Right side of the container

For each side the calculation uses the following parameters:

— Sun radiation at the location

— The sun position at that time of day

— The cloud coverage

— Direction the transport vehicle is heading

— Angle of the container side facing to the sun

From these values combined with the sun position at that time of day are calculated hourly incident solar radiation in W/m^2 for the top, left and right wall of the container. It is assumed that the container is always on the top row of the transport vehicle with nothing shadowing it left or right and orientated in the same direction as the vehicle. For example, if the transport vehicle is heading straight west, the front of the container is also facing westwards, the left side facing south, and the right side facing north. The measure unit of this parameter is W/m^2.

The ambient wind speed relative to the container The wind speed is calculated from the Zonal (eastward) wind value and Meridonal (northward) wind value provided by the ERA-Interim on that location and day in the year 2016. The speed and direction of the wind is assumed to reflect the worst case scenario that the container is fully exposed to the wind and not shielded by any obstacles. The measure unit of this parameter is m/s.

4 D3 heat transfer model

The D3 heat transfer model was created in order to predict the temperature conditions within a specific container under a broad range of input conditions and ambient conditions the system may experience while in transit, which are provided by the CORE-SE simulation. This in turn facilitates the evaluation of various design alternatives in order to develop an optimal design, and also the simulation of the limits to which this design is applicable. While the heat transfer model itself is sophisticated, the principle behind it is simple. The model receives user-defined inputs and performs necessary calculations to translate these inputs into useful outputs. In essence, these inputs are conditions we want to simulate, while the outputs serve to answer the question whether, based on the input conditions, the ICECUBE system will provide satisfactory control of the payload temperature, and if so, how much thermal storage medium in the ICECUBE thermal battery, which is analogous to the charge available in an electric battery system, is required.

5 Tradelane description

The tradelane in question starts at the P&G manufacturing site in Mataro, Spain. The containers are transported by truck to the container terminal in Barcelona, Spain, where they are loaded on a feeder vessel and shipped to the container terminal in Algeciras, Spain. From Algeciras the containers are transported by sea vessel to the container terminal in Durban, South Africa. The final part of the voyage is done by truck to the P&G warehouse in Durban. Locations, transport modes and durations are described in table 1. Six days is a typical transit time between Barcelona and Algeciras on some lines (Shortseaschedules, 2017).

Table 1: Location, transport modes and duration

From	Destination	Modality Type	Duration
Manufacturing Site - P&G, Mataro (Spain)	Terminal, Barcelona (Spain)	Road	50 min
Terminal, Barcelona (Spain)	Terminal, Algeciras (Spain)	Sea (Feeder)	6 d
Terminal, Algeciras (Spain)	Terminal, Durban (South Africa)	Sea	17 d
Terminal, Durban (South Africa)	P&G Warehouse, Durban (South Africa)	Road	35 min

6 Results of the simulation

The simulation model has been validated. In particular the weather data have been validated by the ERA-Interim climate data and the transport flow have been validated with schedules and routing algorithms.

In total 4 simulation runs have been made which are covering two different time periods and two different settings concerning the loading time. The different periods have been selected in order to have maximum temperatures in Spain resp. South Africa. The different loading times (2 days and 5 days) have been selected in order to model disturbance in ports (e.g. strike in port):

- Start on 2016-09-07 with 2 days loading time. Simulation run with maximum temperatures in Spain and short loading time.
- Start on 2016-09-07 with 5 days loading time. Simulation run with maximum temperatures in Spain and long loading time.
- Start on 2016-11-16 with 2 days loading time. Simulation run with maximum temperatures in South Africa and short loading time.
- Start on 2016-11-16 with 5 days loading time. Simulation run with maximum temperatures in South Africa and long loading time.

While multiple trials were conducted throughout this development, one scenario was chosen specifically for a deeper assessment, as is conducted below. In this scenario, a 40 foot dry container is shipped from Mataro, Spain to Durban, South Africa. The simulated shipment departs on July 9, 2016, and arrives on August 21, 2016. It is assumed that there are delays in the outbound port resulting in a relatively long duration of shipment. Figure 1 and Figure 2 show the results of CORE-SE simulation. Respectively, they are plots of the ambient temperatures and solar radiation incident on a horizontal surface versus time. Figure 3 and Figure 4 show the results of the D3 model. Respectively, they are a plot of the container and product temperatures and ICECUBE mass expiry versus time, and a map containing labelled positions indicating the thermal battery charge level for 5 specific days during the journey.

Figure 3 shows 3 data series. The series “T,product” refers to the temperature of the payload while “T,container” refers to the temperature of the shipping container itself as a result of heat exposition from the ambient. “m,Deepchill” refers to the mass of Deepchill, the thermal storage medium inside ICECUBE, that expires as a result of the ICECUBE system actively cooling the payload to prevent it from reaching 35 °C, the critical temperature of the payload.

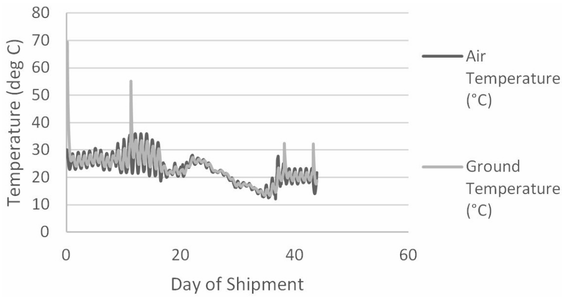

Figure 1: Plot of Ambient Temperatures versus Time

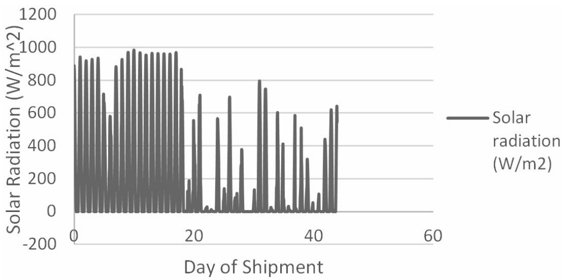

Figure 2: Plot of Solar Radiation Incident on Horizontal Surface versus Time

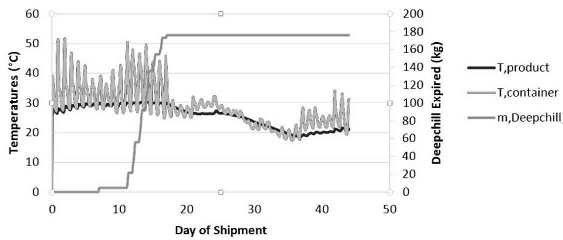

Figure 3: Plot of Container and Product Temperatures and Deepchill Expiry versus Time

7 Discussion of Results

Within the scope of this simulation, there are two objectives. The first is to develop a simulation tool that can reliably evaluate the performance of the ICECUBE system. This reliability starts from the use of realistic inputs (ambient conditions) and extends to an accurate evaluation of the system's performance based on these inputs. The second objective is to evaluate the system's performance for one specific case in which products are shipped on one of P&G's tradelanes. Both of these objectives will be discussed below.

The successful integration of CORE-SE with the D3 heat transfer model allows us to achieve the first objective. CORE-SE calculates ambient conditions based on real data recorded for recent years. The D3 model allows these inputs to be translated to useful outputs consistent with the trends observed in real test data. Concerning our second objective, we seek to answer two questions. These questions are:

1. does the ICECUBE system protect the payload from thermal damage, and
2. is there sufficient thermal energy available in the ICECUBE to do so during this shipment?

Referring to Figure 3, it is seen that the product temperature starts at 25 °C on the first day, and during the 7th day, this temperature has increased to 30 °C. At this point, the ICECUBE system begins actively using the stored thermal energy to cool the payload, as is visible from the increase in the data series "m,Deepchill". Over the course of the journey, roughly 180 kg of Deepchill are calculated to expire as a result of this active cooling. It can be seen that the products are successfully maintained below their critical temperature of 35 °C.

Figure 4 provides a visual representation of the thermal energy charge level available in the ICECUBE system. This figure accounts for Deepchill expired as a result of both active cooling and passive heat gained by the ICECUBE thermal battery. It is seen in Figure 4 that a substantial proportion of Deepchill expiry occurs by Day 23, which reflects the fact that the ICECUBE system is only active between the 7th and 17th days of the shipment. On the final day of shipment (Day 44), roughly 40% of the thermal energy is seen to remain. Therefore, we conclude that there is indeed sufficient thermal energy stored in the ICECUBE system to protect the payload from experiencing thermal damage.

Figure 4: Map of Shipment with Labelled Thermal Battery Charge Levels for Specific Days

8 Construction and first tests of a prototype

A half scale prototype of the ICECUBE device was designed, constructed and tested from both a thermodynamic and operability point of view. The first test validated the concept efficiency in cooling P&G loads over a long period of time. The second test focused on user case of operability and validated the “easy to use” concept of the prototype. Some improvements are needed to make the concept light and easier to use.

Figure 5 and 6 show a sketch and a picture of the ICECUBE prototype, which was used for demonstration and testing in order to prove the feasibility of the concept and validate the simulation results. Although first results are existing, a respective detailed analysis is not available to date. With regards to the lower carbon footprint emission, an initial estimate measurement of the baseline data for carbon footprint was performed. From the demonstration runs performed, the greenhouse gas reductions achieved have been projected to be reduced by 44% (from baseline of $71\,000\,\mathrm{kg\,a^{-1}}$ to $39\,000\,\mathrm{kg\,a^{-1}}$, based on an average of 250 trips per year). These promising first results need to be validated in further demonstration runs.

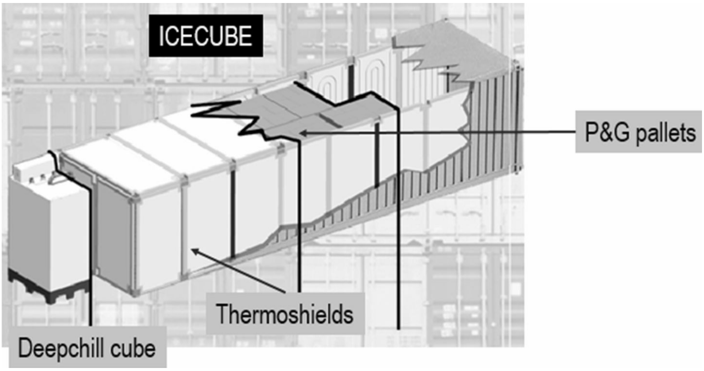

Figure 5: ICECUBE system

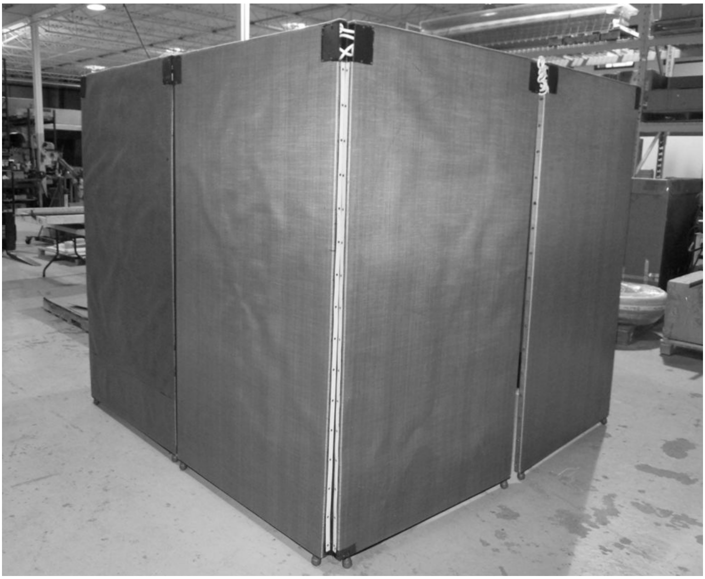

Figure 6: Half scale prototype of the ICECUBE system

9 Conclusions and outlook

The investigation presented in this paper has two objectives. The first was to develop a simulation tool that can reliably evaluate the performance of the ICE-CUBE system. This was accomplished by successfully performing an integration between the CORE Simulation Environment with the D3 heat transfer model. The second objective was to use this tool to perform one such evaluation for a shipment of products from Spain to South Africa. This was completed, and the ICECUBE system was concluded to successfully control the payload temperature, and to do so by using roughly 60% of its total thermal storage capacity. From first demonstration runs with a prototype, the greenhouse gas reductions have been estimated to be reduced by about 44%. These promising first results need to be validated in further demonstration runs.

In the current simulation model following assumptions have been made which have to be improved in next versions. By now disturbance can be modelled in terminals only on an abstract level. In detail, the loading time of the vessel can be set as parameter for each simulation run in order to test the impact of different events (like strike in a port). In later versions this will be fully integrated including random distribution for different events at different locations. In addition, climate data from 2016 only has been used. It has to be analysed if more realistic data could be retrieved if a longer time period would be used. Furthermore, in the current simulation the position of the container is on top of the vessel. Sun radiation and wind have impact from all sides, and the orientation of the container to the wind has not been identified, resulting in the simulation results to provide a worst case scenario. The simulation can be improved in future versions, possibly also taking into account effects by the coloring of the container, based on results presented in (Smith, 2003).

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References

Core (2017). www.core-project.eu.

Dee, D. P., S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M. A. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A. C. M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A. J. Geer, L. Haimberger, S. B. Healy, H. Hersbach, E. V. Hólm, L. Isaksen, P. Kållberg, M. Köhler, M. Matricardi, A. P. McNally, B. M. Monge-Sanz, J.-J. Morcrette, B.-K. Park, C. Peubey, P. de Rosnay, C. Tavolato, J.-N. Thépaut, and F. Vitart (2011). "The ERA-Interim reanalysis: configuration and performance of the data assimilation system". In: *Quarterly Journal of the Royal Meteorological Society*.

Horak, J., I. Schmerold, K. Wimmer, and G. Schauberger (2017). "Cabin air temperature of parked vehicles in summer conditions: life-threatening environment for children and pets calculated by a dynamic model". In: *Theoretical and Applied Climatology* 130.1, pp. 107–118.

Jansson, C. and E. Almkvist (2006). "Heat balance of an asphalt surface: observations and physically-based simulations".

Rodriguez-Bermejo, J., P. Barreiro, J. I. Robla, and L. Ruiz-Garcia (2007). "Thermal study of a transport container". In: *Journal of Food Engineering 80*, pp. 517–527.

Shortseaschedules (2017). http://www.shortseaschedules.com/Schedule/MapSearch?From=barcelona&To=algeciras.

Smith, G., A. Gentle, P. Swift, A. Earp, and N. Mronga (2003). "Coloured paints based on iron oxide and silicon oxide coated flakes of aluminium as the pig-ment, for energy efficient paint: optical and thermal experiments. Sol Energy Mater Sol Cell".

Part IV

City Logistics

Utility Evaluation of Battery Electric Vehicles in Urban Distribution

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*Utilizing battery electric vehicles in daily distribution operations of logistics service providers and freight forwarders goes along with major uncertainties for companies. There is no mechanism how to evaluate the technical and economical use of battery electric vehicles in companies use cases and processes in status quo in contrast to vehicles with an internal engine. This paper adopts an evaluation mechanism from literature, which is bases on a value benefit analysis with compensation factors, and applies this evaluation model to three real life use cases of a renowned logistics service provider with worldwide activities and strong business in road-bound transportation of palletized goods for B2B and B2C customers. The results of the evaluation showed that a substitution of vehicles with internal combustion engines with battery electric vehicles is not an applicable approach. The evaluation shows, that using battery electric vehicles in distribution generates only 41% (*3.5 t *vehicles) respectively 34% (*7.5 t *trucks) of the benefit value as using conventional vehicles with internal combustion engine. The results of the evaluation confirm, that not parameters of range and the operating costs, but parameters of payload and the vehicle asset costs are determining the utility evaluation in distribution use cases. In fact planning of distribution operations need to be adapted to the specific performance parameters of battery electric vehicles. The presented evaluation model in this paper can identify the fields of action, in which a company needs to adapt existing distribution activities.*

Keywords: Evaluation; Distribution; Electric Vehicle; Logistics

1 Evaluation of the utilization of electric vehicles in day-to-day operations of a logistic service provider

Demand and requirements for the distribution of goods, in particular in urban areas, are changing with increasing speed. Ongoing globalization, shorter product life cycles, urbanization and new technologies are drivers of this development. In addition, the growing importance of e-commerce, increased customer demand for fast, flexible and high quality delivery, as well as an increasing environmental awareness in the society is fostering current challenges in distribution. Increasing regulation in cities targeting the reduction of noise, CO_2 and fine dust emissions are completing the set of new circumstances for distribution operations in logistics. These frame conditions are creating an increasingly complex and dynamic environment in the transport sector. Against this background electric vehicles are considered to be a key technology for climate friendly mobility. The wide use of electric vehicles in the transport sector is seen as an instrument for reducing greenhouse gas emissions emitted by traffic, which have a current share of 14% on the global greenhouse gas emissions (IPCC, 2014). Given the continuous increase in freight traffic in Germany, which is estimated to increase by 38 percent by 2030, the importance of a reduction of greenhouse gas emissions is essential to meet national and international climate protection targets (BMVI, 2014). Hence, the utilization of electric vehicles in distribution operations has a significant for logistics service providers and freight forwarders to overcome the mentioned challenges, in particular in urban areas. But, using electric vehicles currently implies various uncertainties for companies in both, economic and technical terms. Logistic service providers and freight forwarders face the challenge to evaluate in which use cases in distribution operations the utilization electric vehicles goes along with economic and technical advantages or at least similar performance as vehicles with internal combustion engines.

2 Methodology

In order to evaluate the technical and economical impact of the usage of battery electric vehicles in distribution operations a model, tailored to access individual use cases, was developed. The theoretical foundation was taken from literature and adopted to consider all aspects of various use cases of a renowned logistics service provider with worldwide activities and strong business in road-bound transportation of palletized goods for B2B and B2C customers. The evaluation model is based on a value analysis which is extended by compensation factors (Schöder, 2017, p. 40 ff). The evaluation model of Schöder is the up-to-date approach in literature regarding a standardized procedure for evaluating the utilization of battery electric vehicles in individual use cases in distribution. Other publications are evaluating the benefit value of electric vehicles in regard to customer demand (Kreyenberg et.al., 2013; Hoffmann et.al., 2012), the benefit value of electric vehicles in regard to ancillary services (Rehtanz, Rohling, 2010), or have a narrow focus on economical aspects (Hacker et.al., 2015) or ecological aspects (Held et.al, 2016). Schöder's model is the only approach combining both, a technical and economical evaluation in regard to logistics operations in distribution. However, this existing approach for evaluation is a general model, applicable to various use cases in distribution logistics (including CEP). The model developed in this paper takes the approach from Schöder and adjusted it to the special use case of distribution of palletized goods.

The underlying method of the model is a vale benefit analysis according to Zangemeister (Zangemeister, 1971). In addition, the standard value benefit analysis approach was extended by compensation factors according to Bárdossy (Bárdossy et. al., 1985). The model produces a utility value for electric vehicles on the first target level. Conventional diesel powered vehicles were used as the reference standard for determining the benefits of battery electric vehicle use. On the second target level the model takes performance parameters, economic parameters and ecologic parameters into account. On the third target level performance parameters were divided into performance requirements and payload requirements of the battery electric vehicle. On the same level the economic parameters are divided into fixed and variable costs, as well as the ecologic parameters, which are divided into emissions and customer demand for sustainable transportation. For the last named parameters, there was no further breakdown into parameters on the fourth target level. However, all other mentioned parameters on the third level were broken down to final evaluation parameters on the fourth target level. Performance requirements were fragmented into range parameter and charging time parameter. For the payload no further fragmentation was done, too. The fixed costs on the third target level were subdivided into vehicle asset costs (costs of purchase for the vehicle) and infrastructure asset costs (charging respectively fueling infrastructure). The variable costs were subdivided in the same way into use case dependent operating costs (dependent on required range per day, fuel or kWh consumption and fuel respectively kWh costs) and vehicle dependent

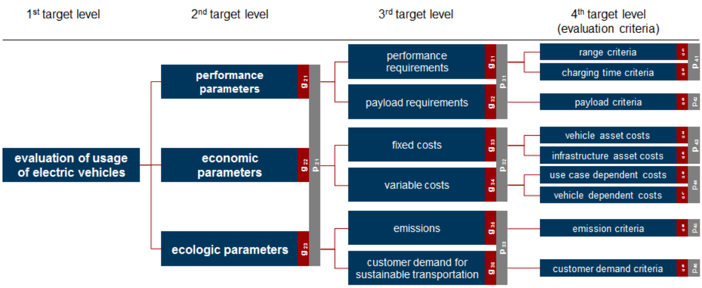

Figure 1: Target system of the value analysis model

operating costs (tax, insurance). Figure 1 visualizes the structural set up of the target system of the adjusted value analysis according to the literature.

The aggregation of values of each section is processed by using weighting factors (g) and compensation factors (p) on each target level. The weighting factors on the second target level are determined by the user of the model, as well as the weighting factors g_{31} and g_{32} on the third target level. The reason for that is that the weighting of these parameters in the target system depends on individual conditions of the use case and the company applying the model. All other weighting factors of the model are set as basic setting and are the same in every use case. All weighting factors in summation of one functional group of parameters have to be 1 (see formula 1; Schöder, 2017, p. 16, 44-47).

$$1 = \sum_{j=1}^{n} g_j \tag{1}$$

$g =$ weighting factor

$j =$ indicators

$n =$ total number of all considered criteria j

The settings of all weighting factors of the model are shown in table 1. All set values were validated with decision makers and managers from a renowned German

Table 1: Weighting factors

weighting factor	value	explanation
g_{21}	-	individual user input to the model
g_{22}	-	individual user input to the model
g_{23}	-	individual user input to the model
g_{31}	-	individual user input to the model
g_{32}	-	individual user input to the model
g_{33}	0,5	basic setting of the model
g_{34}	0,5	basic setting of the model
g_{35}	0,5	basic setting of the model
g_{35}	0,5	basic setting of the model
g_{41}	0,8	basic setting of the model
g_{42}	0,2	basic setting of the model
g_{43}	1	basic setting of the model
g_{44}	0,7	basic setting of the model
g_{45}	0,3	basic setting of the model
g_{46}	0,9	basic setting of the model
g_{47}	0,1	basic setting of the model
g_{48}	1	basic setting of the model
g_{49}	1	basic setting of the model

logistics service provider. The weighting factors of the second (and partially of the third) target level cannot be presented within this paper, due to the confidentiality of these information. Nevertheless, they were elevated and used for conducting the evaluation.

The purpose of the usage of compensation factors in the model is to countervail the major weakness of the value analysis. That disadvantage of a pure value analysis model is that – despite the use of weighting factors – the value of a parameter can be compromised in the course of aggregation of values between the target levels of the target system (Bárdossy et. al., 1985, p. 375 ff). An advantageous value of one factor can compensate a less advantageous value of a second factor, due to the given formula for aggregation in value analysis according to Zangemeister (Zangemeister, 1971; Schöder, 2017, p. 18).

$$N_{i-1} = \sum_{j=1}^{n} g_{ij} e_{ij} \tag{2}$$

$N =$ value of benefit
$e =$ value of evaluation
$g =$ weighting factor
$i =$ considered target level
$j =$ indicators
$n =$ total number of all considered criteria j

Thus, the compensation factor was introduced. One compensation factor applies for the entire functional group of parameters on a certain target level. A compensation factor with the value 1 has no effect and will result in the same outcome as formula 2. Every value of a compensation factor > 1 will defang the degree of compensation between the aggregated factors. A compensation factor > 6 will have the same mathematical outcome as a compensation factor of infinite value, meaning that in the aggregation of 1+x parameters the lowest value of evaluation of one factor will fully determine the value of benefit (Schöder, 2017, p. 60-65). Therefore the new formula for aggregation of value analysis with compensation factor can be described as seen in formula 3.

$$I_{i-1} = 1 - \sqrt[p]{\sum_{j=1}^{n} g_{ij} (1 - e_{ij})^p} \tag{3}$$

$I =$ value of indication (similar to value of benefit)
$e =$ value of evaluation
$g =$ weighting factor
$i =$ considered target level
$j =$ indicator
$n =$ total number of all considered criteria
$p =$ compensation factor of a functional group

Table 2: Compensation factors

compensation factor	value
p21	5
p31	5
p32	2
p33	1
p41	1,2
p42	1
p43	2
p44	1
p45	1
p46	1

The settings of all compensation factors of the model are shown in table 2. All set values were validated with decision makers and managers from a renowned German logistics service provider.

The value of evaluation, meaning the value of the evaluation criteria on target level four, is created by using target functions. Target functions can transform values with dimension (such as km, h, Euro etc.) into values without a dimension. A basic assumption of this model is that all target functions have a linear developing graph. All in course of the development of this model used target functions were linearly interval functions. Furthermore, the developed target functions were referencing to diesel technology vehicles. In addition the values of evaluation of diesel technology vehicles were fixed to a degree of performance of 70%. By doing so, evaluation results of electric vehicles can be above or under 70%. The theoretical concept of a target function is shown in figure 2 (Schöder, 2017, p. 17).

The detailed data for the individual target functions, which were developed for the evaluation of the utilization of electric vehicles in use cases of a renowned German logistics service provider were shown in table 3.

The value of the parameters range, charging time, payload and vehicle asset costs was researched by literature review and were presented in table 5 (Orten, 2017; Nissan, 2017, Forium, 2017; Mobile, 2017). Further input factors of the model, such as the requirements for the use cases and the assessment of the customer demand for sustainable transportation, were surveyed with representatives of

Table 3: Information of the individual target functions

target function	degree of performance (y-axis)	interval points value of the evaluation criterion (x-axis)
range	0	use-case minimum requirement * 0,9
	50	use-case minimum requirement
	100	use-case maximum requirement
charging time	0	duration diesel vehicle * 3,1
	50	duration diesel vehicle * 3
	100	duration diesel vehicle
payload	0	payload diesel vehicle * 0,5
	50	payload diesel vehicle * 0,75
	100	payload diesel vehicle
vehicle asset costs	0	asset costs diesel vehicle * 2
	75	asset costs diesel vehicle
	100	asset costs diesel vehicle * 0,5
infrastructure asset costs	0	infrastructure asset costs diesel vehicle * 3
	100	infrastructure asset costs diesel vehicle
use case dependent costs	0	use case dependent costs diesel vehicle * 2
	75	use case dependent costs diesel vehicle
	100	use case dependent costs diesel vehicle * 0,5
vehicle dependent costs	0	vehicle dependent costs diesel vehicle * 2
	75	vehicle dependent costs diesel vehicle
	100	vehicle dependent costs diesel vehicle * 0,5
emissions	0	Euro 4 norm
	75	Euro 5 norm
	100	Euro 6 norm
customer demand for sustainable transportation	0	1 on a Likert scale from 1 to 7
	100	7 on a Likert scale from 1 to 7

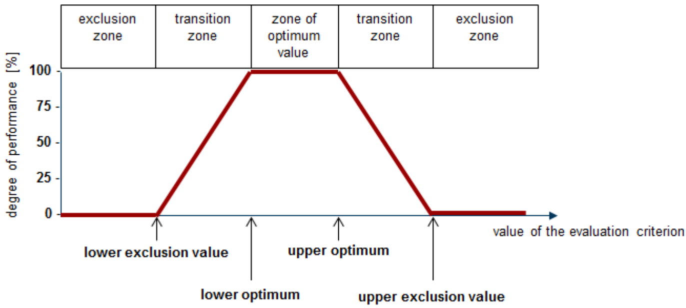

Figure 2: Theoretical concept of a target function

reowend German logistics service provider. Formulas for how to generate model input values for the parameters infrastructure costs, use case dependent costs, vehicle dependent costs and emissions were taken from literature (Schöder, 2017, p. 47-60).

3 Findings

Using the presented target system, formula for aggregation, weighting factors, compensation factors and target functions, the evaluation for the use cases of a …

- 3.5 t transporter in CEP local distribution
- 7.5 t truck in general goods rural distribution
- 7.5 t truck in general goods urban distribution

… was conducted.

The requirements of the evaluated use cases, which the surveyed logistics service provider sets, are shown in table 4. In addition, table 5 gives an overview over the used basic input parameters, needed for the used formulas. Moreover, table 6 informs about all additional information needed for the evaluation.

Table 4: Requirements of the use cases

requirement	value
range requirement CEP local distribution	150 km to 250 km
range requirement 7.5 t urban distribution	150 km to 200 km
range requirement 7.5 t rural distribution	300 km to 350 km
payload requirement CEP local distribution	1.8 t
payload requirement 7.5 t urban distribution	2.5 t
payload requirement 7.5 t rural distribution	2.5 t
charging time requirement CEP local distribution	10 min to 360 min
charging time requirement 7.5 t urban distribution	5 min to 360 min
charging time requirement 7.5 t rural distribution	5 min to 360 min

Table 5: Basic input parameters

parameter	3.5 t diesel vehicle	3.5 t battery electric vehicle	7.5 t diesel vehicle	7.5 t battery electric vehicle
vehicle asset costs	35 000 €	29 878 €	48 000 €	170 000 €
service life	36 month	36 month	36 month	36 month
value after service life	60%	30%	60%	30%
insurance costs	1500 €/a	1500 €/a	1800 €/a	1800 €/a
maintenance costs	5040 €/a	2400 €/a	5040 €/a	2400 €/a
range	1085 km/ 80 l	160 km/ full cycle	1500 km/ tank	100 km/ full cycle
charging time	2 min	330 min	5 min	360 min
consumption	7.3 l/ 100 km	16.5 kWh/ 100 km	15 l/ 100 km	72 kWh/ 100 km
vehicle tax	300 €/a	300 €/a	487 €/a	487 €/a
payload	1.2 t	695 kg	3 t	2.4 t

Table 6: Additional information for the evaluation

parameter	value
operation days per anno	250 days
average useful life	36 month
diesel price	1.12 €/l
electricity price	20 € – Cent/kWh
price per charging point	1500 €
Euro 4 emissions	0.45 kg CO2e/km
Euro 5 emissions	0.3 kg CO2e/km
Euro 6 emissions	0.2 kg CO2e/km
tax-free years for battery electric vehicles	5 a

The results of the evaluation model have shown, that the functional ability of using battery electric 3.5 t vehicles in CEP local distribution is 29 value point (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case). Primary reasons for this result can be found in the evaluation of performance parameters, which had a value of benefit on the second target level of 21 value points. In particular payload and charging time requirements are not fulfilled and are producing a quite low value of benefit on the fourth target level of the model. In contrast, the evaluation of the economic parameters on the second target level was 60 value points, which is close to the 70 value points of a comparable diesel vehicle. Drivers of this evaluation score are the comparable vehicle asset costs of battery electric vehicles and diesel vehicles within the 3.5 t vehicle category. Furthermore, have major advantages regarding the use case dependent and vehicle dependent costs, due to the significant lower price of kWh compared to liters of diesel and subventions of vehicle taxes by the governmental administration in Germany. Regarding the ecological parameters and their value benefit in the model, the lack of customer demand for sustainable transportation is the major driver for the result of 70 value points on the second target level. Hence, the model could not state an ecological benefit value above the evaluation of comparable diesel vehicles. In result for the evaluation of this use case, due to the set, and company individual, weighting factors along the target levels and the set compensation factors, a usage of battery electric vehicles in CEP local distribution is not beneficial for companies.

The evaluation of the use case of 7.5 t trucks in general goods urban distribution results in 24 value points (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case) for battery electric vehicles. Reasons for this evaluation result can be found in the evaluation of the performance and economic parameters. The evaluation result of performance parameters on the second target level was 21 value points, due to the fact that range and charging time requirements of the use case are not fulfilled (0 value points on the fourth target level each). Only payload requirements were partially matched with 53 value points on the fourth target level (compared to 70 value points of the diesel vehicle). Regarding the economic evaluation results the model clearly showed, that – due to the 3.5 times increased vehicle asset costs of an electric 7.5 t vehicle – only 28 value points could have been scored. The high gap between the purchasing costs of an electric vehicle and an diesel vehicle (0 value points on the third target level) negated the advantageous evaluation of operating costs of battery electric 7.5 t vehicles on the third target level (83 value points compared to 70 value points of comparable diesel vehicles). The ecological evaluation result of a battery electric 7.5 t vehicle is 70 value points, which was identical to the 70 value points of diesel vehicles. On the fourth target level the emission parameter of the battery electric 7.5 t truck were evaluated with 89 value points, due to the reduced emissions and a trend to longer ranges per tour of this use case. Nevertheless, customer demand is negating this high value over the aggregation over the target levels to the mentioned 70 value points.

The evaluation of the use case of 7.5 t trucks in general goods rural distribution results also in 24 value points (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case) for battery electric vehicles. Both evaluation results of the urban and rural use case differed only in the required range of the vehicle. With 300 km to 350 km the range requirement in rural distribution with this vehicle category is slightly higher than in the urban use case. But since the evaluation of the range parameter on the fourth target level in urban distribution was already zero value points, the result in the rural distribution case is also zero value points. The evaluation of all other parameters is nearly identical and due to the aggregation formula – using weighting and compensation factors – the result of the evaluation of both use cases shows no difference.

Since 12 t battery electric trucks are not available on the market at the moment, an evaluation of 12 t electric trucks would be pure theoretical with too many uncertainties (especially regarding the vehicle asset costs and parameters like range and payload). For this reason the evaluation was not conducted, but will be – once these battery electric vehicles are available on the market.

4 Conclusions

The results of all evaluated uses cases makes it evident, that a substitution of currently used diesel vehicles in distribution operations by battery electric vehicles goes along with no benefits in technical and economical terms. Quite the opposite is the case; a substitution of diesel vehicles goes along with significant disadvantages for the company, regarding performance and cost structure of their distribution activities in all evaluated use cases. Hence, further technological improvements of the current battery electric technology of electric vehicles are needed, especially in the direction of improves range, shorter charging time and higher possible payloads. The conclusion from literature, that payload requirements are more important to fulfill as range requirements and that vehicle asset costs have a more significant impact on the evaluation results as vehicle and use case dependent operating costs have been confirmed by these research results (Schöder, 2017). Nowadays the gap between vehicle asset costs of battery electric vehicles and comparable diesel vehicles of the same vehicle category is decreasing, resulting in a trend towards balanced cost structures of both vehicle technologies and even advantages for battery electric vehicles. Furthermore, changes in design of current logistics processes in operative distribution and distribution planning open the possibility to increase the value score and the utilization evaluation of battery electric vehicles in distribution. The evaluation was processed in status quo of operative process chains. The possibilities, to implement changes within operative distribution processes have a strong potential to increase the utilization of electric vehicles. Adjustments of that kind should focus on reducing the required payload and decrease the required range per tour, for instance by redesigning distribution areas and tours. In addition longer and more regular time slots at the logistics provider's facilities can help to overcome current challenges regarding long charging times of battery electric vehicles. In order to keep the number of deployed trucks on the same level, redesigning distribution processes by implementing multi-shift operations (two driver shifts per vehicle) could be an option. And last, but most important, increasing the customer demand for sustainable transportation – best if the customer is even willing to pay for it – is critical in order to utilize battery electric vehicles in distribution on a larger scale. Therefore, further research should focus on empirical evaluations on customers demand and expected changes in regulation by the authorities. This further research should focus to the question: How to turn the customer (B2B and B2C) into a pull-factor for sustainable transportation? Applying battery electric vehicles in distribution only makes sense, if the customer demands that kind of transportation or if basic circumstances of regulation by the authorities were making the use of battery electric technology mandatory for logistics service providers and freight forwarders.

References

Bárdossy, A., I. Bogardi, and L. Duckstein (1985). “Composite Programming as an extension of Compromise Programming”. In: *Mathematics of Multiple Objective Optimization*. Wien: Springer-Verlag.

BMVI (2014). “Verkehrsprognose 2030”.

C. Hoffmann et al. (2012). *Bewertung integrierter Mobilitäts- dienste mit Elektrofahrzeugen aus Nutzerperspektive - Ergebnisse der Begleitforschung im Projekt BeMobility*. Tech. rep. Berlin elektroMobil, Innovationszentrum für Mobilität und gesellschaftlichen Wandel (InnoZ) GmbH, Berlin.

Forium (2017). https://www.forium.de/kfz_steuer/.

Hacker et.al. (2015). *Wirtschaftlichkeit von Elektromobilität in gewerblichen Anwendungen – Betrachtung von Gesamtnutzungskosten, ökonomischen Potenzialen und möglicher CO2-Minderung*. Tech. rep. Öko-Institut e.V.

Held, M. et.al (2016). “Abschlussbericht: Bewertung der Praxistauglichkeit und Umweltwirkungen von Elektrofahrzeugen”. In: *BMVI – Bundesministerium f”ur Verkehr und digitale Infrastruktur, Berlin*.

IPCC (2014). “Climate Change 2014: Mitigation of Climate Change”.

Kreyenberg, D., J. Wind, J. Devries, and A. Fuljahn (2013). “Bewertung des Kundennutzens von Elektrofahrzeugen”. In: *ATZ Automobiltechnische Zeitschrift* 115.1, pp. 42–47.

Mobile.de (n.p.) (2017). https://suchen.mobile.de/fahrzeuge/search.html?s=Truck.

Nissan (2017). “NISSAN e-NV200 KASTENWAGEN UND KOMBI”.

Orten Electric Truck (2017). “ORTEN E 75 AT electrified by EFA-S”. In: 15.

Rehtanz, C. and J. Rolink (2010). “Bewertung des Einsatzes von Elektrofahrzeugen zur Erbringung von Netzdienstleistungen”. In: *Tagungsband VDE-Kongress 2010 - E-Mobility: Technologien - Infrastruktur – Märkte, VDE-Verlag, , 2010*. Berlin: VDE-Verlag.

Schöder, D. (2017). “Technisch-wirtschaftliche Bewertung des Einsatzes von batterieelektrischen Nutzfahrzeugen in der Distribution von Konsumgütern”. In: *Schriftreihe Logistik der Technischen Universität Berlin* 37.

Zangemeister, C. (1971). *Nutzwertanalyse in der Systemtechnik. Eine Methodik zur multidimensionalen Bewertung und Auswahl von Projektalternativen*. Vol. 2. 2. Auflage, München, 1971: Zangemeister & Partner.

Optimizing Distribution Logistics within Cities through Time-slot Deliveries

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Technological evolvement creates new business opportunities such as the optimization of distribution networks by using big data to calculate optimal delivery routes respecting individual time windows. The optimized network enhances firms to improve customer satisfaction, reduce delivery costs, and increase the utilization of the truck load by integrating reverse flows. Following the design science approach, we review and evaluate relevant data and scientific theories. Subsequently, requirements and system design are analyzed. On this basis we implement a prototypical information system to realize the optimized distribution network. The prototype consists of a mobile user-app and a back-office-system. Major functionalities of the prototype include the data analysis and the specification of settings for the desired delivery times and locations being actively influenced by the parcel recipients. The results of this research indicate that several tradeoffs have to be faced against the optimal use and analysis of available data, in order to provide a prototype that aims at improving customer satisfaction and reducing distribution costs at the same time. Hence, the focus has been laid on the analysis of dedicated, user-defined delivery time and location time windows by using a customized heuristic approach in order to decrease the complexity of the distribution process. We simulated the results, while a field study would enhance more insights. Practitioners can use the prototype to reduce their transportation costs to improve the utilization of the truck load or for new city services such as same day deliveries or as part of cyber-physical (distribution) systems (CPS).

Keywords: Distribution Logistics; Time-Slot Deliveries; City Logistics; Prototype

1 Introduction

Delivery of parcels has been part of everyday life of the population over the last decades. Especially due to the evolution of online retail activities over the last 15 year, millions of parcels are distributed worldwide (Fang and Zhang, 2005). However, it is commonly observed that there is a lack of coordination between the delivery schedules of the logistics companies and the schedules of the recipients (Engel, Sadovskyi et al., 2014). When a parcel is delivered, its recipient may sometimes not be present at the delivery location. This results from, either the recipient's unawareness about the delivery time in advance. However, even in a few cases, where logistics companies provide a 3-hour time range of estimated delivery in advance, the recipient may still not be able to be present at the delivery location and receive his parcel. In consequence, we have a need to optimize distribution networks (Shekhar, Gunturi et al., 2012, Valerio, D'Alconzo et al., 2009, Waller and Fawcett, 2013). This phenomenon is enhanced by the rapid increase of single-person households, as well as the amount of employed members in families (Nations, 2000).

This situation is primarily a problem for the logistics companies. Due to the heavy increase of parcels, ordered from online retailers, as well as the extra delivery attempts, the following problems have risen: Firstly, time and resources are wasted and distribution costs increase; trying to reach absent recipients and their neighbors subsequently. Additionally, the extra distribution routes lead to increased exhaust emissions, which are harmful for the environment. Furthermore, in order to decrease operational and distribution costs, the logistics companies provide their employees with insufficient working conditions and low salaries. Moreover, the most significant challenge for these companies, originating from the problematic situation described above, is, that their customer base lacks of customer satisfaction, as the current services that are offered do not meet their needs and requirements in the desired degree (Fang and Zhang, 2005, Weltevreden, 2008).

Despite all the problems, logistics companies have not made radical changes on their distribution processes. However, observing the evolution of online retail activities (Fang and Zhang, 2005) and the estimated increase of the internet users globally (Stats, 2013), these problems are expected to become more intense. Therefore, customer-oriented adjustments are needed. Customers need to have more delivery options considering their personal needs and schedule. They need high quality services, which let them choose whether their order is delivered at one of their addresses (work or home), at a parcel station, or even at a family member, a friend or a person of trust and moreover, the need to be able to combine those options for a single delivery, by specifying a time window for each one of them (Shekhar, Gunturi et al., 2012, Valerio, D'Alconzo et al., 2009, Waller and Fawcett, 2013). Such services would significantly contribute to the enhancement of customer satisfaction, which constitutes the major common goal of the supply chain partners, as well as to the optimization of distribution logistics processes.

Along with the evolvement of new technologies, such as real-time processing of huge data volumes new opportunities arise in the area of distribution logistics (Engel, Sadovskyi et al., 2014, Sadovskyi, Engel et al., 2014). The necessary data can be provided by the supply chain partners and originate from different sources (e.g. upstream and downstream inventory information, current and past geo-positions, traffic and weather information , historical data etc.). Moreover, focusing on the distribution logistics field, a customer-oriented approach is vital for any organization's success (Monczka, Handfield et al., 2008, Waller and Fawcett, 2013), considering the customer dynamism evolvement over the last years. Motivated by the steady increase of online retail activities (Fang and Zhang, 2005), we propose a novel approach as well as a prototypical solution to improve customer satisfaction avoiding unnecessary delivery attempts through real-time calculation of optimal delivery routes that take into account the current availability of the recipient.

The prototype allows firms to offer flexible, customer friendly, and effective services within the field of distribution logistics. Further, the optimization of distribution processes enhances firms to realize cost savings. Moreover, the prototype can be used as base for a distribution platform connecting various independent actors such as logistic distribution firms or taxis and smart things being equipped with sensors such as cyber-physical systems (CPS) creating a link to the Internet-of-Things. Using the prototype within a platform would enhance the society, e.g., to reduce gas emissions or improve the working conditions in the field of distribution logistics.

The paper is structured as follows: We briefly review related work as we base the prototype on an existing concept, followed by the conceptual approach – theoretical base for the prototype – and its development. In the fifth chapter we evaluate the prototype. Next we discuss the results, implications, and future research opportunities.

2 Related Work

A related concept has been described by Engel, Sadovskyi et al. (2014), proposing the development of a dedicated smartphone application, in order to use data from the customer's personal calendar and the GPS sensor, which operate on the smartphone, as source of his prospective location. Furthermore, the use of real-time information about weather, traffic and current location of the distribution vehicle is recommended (Waller and Fawcett, 2013). However, there is no optimization process until this last step of the supply chain, after the parcels have been loaded on the distribution vehicles. In order to provide a more effective solution for the problem described above, we have developed our prototype based on the work of Engel, Sadovskyi et al. (2014). The prototype aims at optimizing distribution logistics using big data, consisting of a dedicated smartphone application and a back-end system.

3 Conceptual Approach

Considering the proposed distribution process by Engel, Sadovskyi et al. (2014), the following data sources have to be used for smarter routing of distribution vehicles: Customer geo-location (current and past), distribution vehicle geo-location, schedule of the customer (smartphone calendar events), past purchases and deliveries historical data from customers, order priority data, and real–time weather and traffic data. For the development of the prototype, it is necessary to evaluate the data sources based on criteria like information security, complexity, and usability.

3.1 Customer current geo-location data

Customer current geo-location can be tracked from the app using the GPS sensor of the smartphone in the following format: a pair of decimal values, representing the current location's latitude and longitude. Considering that a user potentially faces privacy violation and information security issues by providing personal information and data, user's current geo-location should be optional and not be used in key functionalities like the initial route calculation or the creation of user's time windows.

However, the customer's geo-location can be used for the detection of a delivery plan divergence. The app will detect right before the delivery time, if the user is located further than a specified distance away from the delivery address, in case it would not be possible to cover this distance at the planned delivery time. Then the system will recalculate vehicle routes, as it is described in the concept and requirements of the prototype. In addition, customer current geo-location data should only be analyzed in the app, and not be stored or transferred to the server. Further, there are no data size or complexity issues that should be taken into consideration.

3.2 Customer past geo-location data

Distribution logistics could be further optimized by the analysis of customer past geo-location data. For example, the system can predict customer's future location, recognize patterns, and habits that could be used for route calculation along with user-defined time windows etc. using big data analysis techniques. While this allows firms to increase the efficiency, the complexity increases. In addition, customer past geo-location analysis would require permanent storage of this data raising the same information security issues as described above. As this would be in discrepancy with the decisions taken about customer current geo-location data, we neglected to use customer past geo-locations data at all.

3.3 Vehicle geo-location data

Geo-location data can be used for optimization being provided by the navigation system of the distribution vehicle's, e.g. its current location. This data can be analyzed in real time, as well as stored and aggregated for later analysis being beneficial for the estimation of the delivery time or route recalculation processes.

However, navigation systems are not provided in the context of this prototype, so there is no opportunity to integrate vehicle geo-location data. While the possibility of generating geo-location test data has been considered in order to integrate this functionality, it would be very difficult to assure that this data is realistic enough to meet evaluation requirements. In addition, it would make the testing phase too complicated, particularly in case of a real time geo-location analysis. That is the reason for our decision to exclude the vehicle geo-location data from the prototype. Despite that, the usage of geo-location data is recommended for the final product.

3.4 Smartphone calendar events data

In order to be able to create time windows for the route, the user's preferred delivery addresses and calendar events are needed being accessible via the customer's smartphone. However, there are plenty of reasons why smartphone calendar events' data do not meet evaluation criteria such as missing start and end time or the event's location. Finally, users are probably not willing to share their personal calendar events, due to information security and privacy violation issues. Therefore, we exclude the direct access to customer's calendar data from our prototype. Instead, we use a platform with an interface allowing firms to harmonize time-window wishes from customers with the distribution route. This allows us to ensure that every time window has a start and an end time, a delivery location is chosen, and the existence of uniform data format.

3.5 Customer past purchases and deliveries historical data

The next data category to be evaluated is order-specific data. Originating from their Data Warehouse and Customer Relationship Management (CRM) systems, companies in the distribution logistics branch have data available suitable for optimizing distribution logistic networks. As our prototype is not developed in collaboration with one of those companies, it is very complex to generate and analyze realistic such data in order to evaluate the effectiveness of the prototype.

As long as delivery time windows and addresses are exclusively created by the customers based on their schedule, there is no need for historical data integration in this process. In case of a delivery plan divergence, when the time windows data are not sufficient for a successful delivery, historical data will be used, regarding successful and unsuccessful deliveries in specific time slots in the past.

3.6 Order priority data

Due to mathematical constraints, there is a need for sorting the orders at several steps of the distribution algorithm (see chapter 4). Furthermore, orders that match certain situation-based criteria shall be given priority. For example, (1) the customer has paid an extra fee for an early/next day delivery service, (2) the order contains food, beverages, or medicines, (3) the order has already been unsuccessfully delivered, or (4) the order contains fragile products or products of high value. This allows firms to differentiate their business model according to their needs.

The values of this criteria are either Boolean or scalar integers and the total priority is calculated as a decimal number with the weighted arithmetic mean method. For the context of this research, decimal values between 0 and 5 where generated, with 5 indicating the highest priority and 0 the lowest.

3.7 Real–time weather and traffic data

Another idea for optimizing distribution logistics is to include real-time weather and traffic data into the route calculation process. By that, streets with high current traffic, due to bad weather conditions, accidents, or roads under construction, may be avoided; or at least delivery delays can be detected, estimated and taken into consideration. However, there is always the challenge to balance the need for computation power and needed complexity when using such data.

Google Maps API supports real-time weather and traffic data, but not in the free edition used for developing this prototype (Google, 2014). This fact prohibited the use of such data. However, if the prototype is further developed in the future in order to be launched in the market, there will be the need to use the commercial version of Google Maps API, where real–time weather and traffic data is fully integrated.

Table 1 1 provides and overview of used data and the source of the data proposing its relevance for the prototype.

3.8 Travelling Salesman Problem

For our distribution problem, we use the Travelling Salesman Problem (TSP) allowing us to optimize the route (Domschke and Scholl, 2010).

In our case, nodes represent the delivery address of the customer, while c_{ij} represent the travelling time between two addresses, as the overall goal of the

Table 1: Overview of type and source of data used for delivery optimization

Data	Source
Customer current geo-location data	Smartphone
Customer past geo-location data	Smartphone
Vehicle geo-location data	Navigation system
Smartphone calendar events data	Smartphone
Customer past purchases and deliveries historical data	CRM system
Order priority data	ERP system
Real–time weather and traffic data	External platform provider

prototype is maximization of customer satisfaction (if cost reduction through route optimization was the main goal of the prototype, then c_{ij} would represent the travelling distance between two addresses).

A more formal mathematical description of TSP is presented below:

Decision variables:

$$x_{ij}$$
$$(x_{ij} = 1 \quad \text{– if driving from i to j, 0 otherwise})$$

auxiliary variable:

$$z_i$$

Objective function:

$$\text{min } c = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$$

Constraints:

$$\text{drive to every location: } \sum_{i=1}^{n} x_{ij} = 1 \qquad j = 1, 2, ..., n$$

$$\text{leave from every location: } \sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1, 2, ..., n$$

$$\text{avoid short cycles:} z_i - z_j + n * x_{ij} \leq n - 1 \qquad i, j = 2..., n; i \neq j$$

However, the generalized TSP algorithm would violate the constraint of specific time windows for each delivery. Therefore, an extension of TSP algorithm is demanded, known as Traveling Salesman Problem with Time Windows (TSPTW). Additionally, a further extension is needed, as every customer has declared a set of delivery addresses, from which only one should be chosen. This extension is known in combinatorial optimization as set TSP, group TSP, One-of-a-Set TSP, Multiple Choice TSP or Covering Salesman Problem.

There has been an effort to combine algorithms proposed by Solomon (1987)), Dumas, Desrosiers et al. (1995)), Dumitrescu and Mitchell (2001)) and Focacci, Lodi et al. (2002)). However, every approach would result to at least non-deterministic, polynomial-time hard (NP-Hard) complexity class, which is unacceptable for this prototype. Furthermore, as the prototype's approach involves real-time responses to delivery schedule changes, it is very difficult for the exact methods, which were reviewed, to be integrated into this approach.

Therefore, it was decided to simplify the routing process and face the tradeoff between complexity and optimization by developing a custom heuristic approach: Every parcel is initially delivered to the depot, where the order address belongs. Then, parcels are assigned to vehicle routes, by focusing on the declared time windows, as well as the priority of the parcel. Finally, the optimal routes are computed using an external service, which, on a later iteration, was decided to be Google Maps API, that uses an implementation of a TSP algorithm (Google, 2014).

3.9 Clustering Algorithm

While developing the distribution-routing algorithm, there was the need to apply a clustering method. Given were a predefined set of distribution K vehicles and a set of n parcels, which have to be assigned to the vehicles in such way that, the vehicles cover the minimal distance to deliver them. Moreover, the capacity of the vehicles I, as well as the delivery address of each parcel is also known. After reviewing relative data mining literature, it was decided to proceed with k-means clustering algorithm (Hartigan and Wong, 1979). However, this algorithm does not compute clusters of predefined capacity, therefore it was slightly extended based on Lloyd's algorithm (Lloyd, 1982). The concept of the algorithm is explained below:

As the address of each order is represented by a pair of decimal values, corresponding to the address' latitude and longitude, they can be projected as nodes on a 2-dimensional coordinate system.

1. K nodes are selected randomly as each cluster's centroids.
2. Each one of the n nodes (parcels' address) is assigned to the nearest centroid, by calculating the distance between them as a Euclidean distance. If the centroid is full (due to capacity), the next nearest centroid is chosen.
3. For each cluster that has been formed, a new centroid is computed, by finding the node with the minimal average squared distance to the other nodes of its cluster.
4. Steps 3 and 4 are repeated, until there are no changes regarding the centroids, or after a predefined time of iterations.

4 Prototype

The purpose of the project is to develop a prototype that optimizes distribution logistics process using big data. The prototype will be used by the customers and employees of distribution logistics companies. The prototype consists of a smartphone application, allowing the users to get informed about, as well as to participate in the delivery procedure of their orders, by defining their desired delivery time windows and locations and managing their favorite parcel stations and trusted persons. Furthermore, a back-end system should be implemented, operating as a server and being responsible for routing calculations, and data storage. The objective of the prototype is to maximize customer satisfaction, by providing a flexible parcel distribution service, which is managed via a user-friendly smartphone application. Moreover, it aims to an efficient route computation process, also considering real-time changes in the distribution schedule, in order to minimize transportation costs. Beside customer satisfaction and user experience, the major quantitative success criterion is a high percentage of orders delivered within the user-defined time windows, at the desired location. The deployment model is visualized in figure 1

4.1 Actions if recipient is not present

If the recipient is not present at the delivery location, a popup message is displayed on his smartphone app. Then he can choose between the following four options: 1) his order will be instead delivered to another of his registered addresses, which has to be located in the service area of the delivery vehicle, 2) his order will be instead delivered to a selected trusted person, that has to be located in the service area of the delivery vehicle, 3) his order will be instead delivered to a favorite parcel station, that has to be located in the service area of the delivery vehicle, 4) his order will be returned to the depot. If the user does not respond to the new delivery location proposal, it is checked if there is a favorite parcel station of him, located in the delivery vehicles service area. If a suitable parcel station is found, the order is delivered to this parcel station, otherwise it is returned back to the depot.

A plan divergence is automatically recognized from the smartphone app. By checking the user's current or last known location, using the GPS sensor of the smartphone or his mobile network, the app should recognize whether he is located further than 1 km away of the delivery address, 30 minutes before the estimated delivery time. If a plan divergence is recognized, as described in the requirement "Plan divergence recognition", the smartphone app should display a popup message, asking the user, if the divergence automatically recognized is about to take place or not. If the user confirms the divergence, actions described in the requirement "Actions if recipient is not present" will be executed.

4.2 Distribution-routing algorithm

To face the complexity challenge of Travelling Salesman family of problems, there was the need to meet a trade-off between optimization and complexity. The core of the distribution-routing algorithm lays therefore on the user-defined time win dows, on order's priority, as well as on historical data from past purchases and

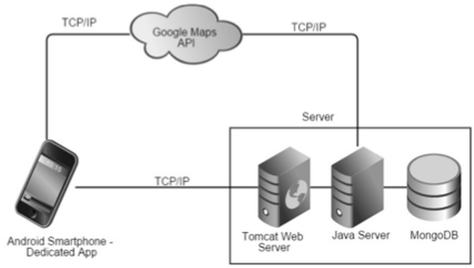

Figure 1: Deployment model

a clustering technique. The problem will be faced as a TSP, only at its last step, in order to calculate the optimal route for one particular vehicle. The algorithm is described in detail below, using natural language instead of code, in favor of comprehensibility. It is supposed to run the evening before the orders are delivered.

```
Preconditions
       Variable number of depots; Variable number of vehicles per
            depot
       Service time: 09:00 –19:00
       4 routes/time slots per vehicle per day: 09:00 –11:00,
            11:30 –13:30, 14:00 –16:00, 16:30 –19:00
       8 orders per route per vehicle (Limitation of Google Maps
            API free version)
       Algorithm runs for each depot in parallel
Step 1
       Separate orders without declared time windows
Step 2
       Sort orders by descending priority
       For each time slot:
              For each order:
                     For each order time window whose address be-
                          longs to the current ’depots service area
                            calculate time window midpoint: (end
                                 time + start time)/2
```

```
                    If midpoint is in this time slot,
                        assign order to this timeslot
                    Sort assigned orders by descending
                        priority
                    Keep only as much as can be loaded in
                        the existing vehicles according to
                         its capacity
```
Step 3
```
     Sort unassigned orders by descending priority
     For each unassigned order
          For each order time window
               Find the depot, in whose service area the time
                    window address belongs
               Calculate time window midpoint
               Choose the respective time slot for the
                   calculated midpoint
               If time slot is not full, assign order to that
                    timeslot
```
Step 4
```
     Sort orders by descending priority
     For each unassigned order (about 5–10 %)
          According to past purchases, find the best timeslot
              to deliver to order address
          If time slot is full, repeat step a and find the
              next better timeslot
```
Step 5
```
     Sort orders without declared time windows by descending
         priority
     For each order According to past purchases, find the best
         timeslot to deliver to order address. If time slot is
         full, repeat step a and find the next better timeslot
```
Step 6
```
     For each time slot: Assuming that the depot has K vehicles,
     use the extension of the K-means clustering algorithm,
         described in Chapter 2, in order to distribute the
         ordersassigned in this time slot, into K clusters of
         maximal size of 8 nodes
```
Step 7
```
     For each time slot: For each route/cluster:
     Optimize route with Google Maps API: Depot address is set
         as start point, as well as destination of the route
         and the maximal 8 orders are set as waypoints. Google
```

```
Maps API uses an implementation of TSP, described in
Chapter 2, in order to calculate the optimal route
```

4.3 Real-time re-computation

As described in the concept, routes should partially adapt real-time to changes in the distribution plan. However, considering customer satisfaction, as well as the nature and context of the service provided, there is no possibility to re-compute all the routes and constantly notify the customers about an updated delivery address and estimated delivery time. Therefore, it was decided to perform a real-time re-computation in the following 2 cases:

(1) Case recipient is not present, when an order is delivered.

If there is a trusted person with a shared address located in the service area of the depot, deliver the order to that person. If the trusted person is also not present, return order to the depot

Else if there is a customer's favorite parcel station located in the service area of the depot, deliver the order to that parcel station

Else, return order to the depot

(2) Case of detected plan divergence

In case it is detected, using the smartphone's GPS sensor, that the recipient is located further than 1km from the delivery address, 30 minutes before the estimated delivery time, display a popup message. This should ask him to verify, if there is a plan divergence or not.

If he confirms it, let him select an alternative delivery location, choosing between: i) an address of him, ii) a favorite parcel station iii) a trusted person's shared address iv) the depot. All of these option have to be filtered, by displaying only those, which are located within the depots service area

If he denies it, perform no action

If he does not respond, follow the steps of "case recipient is not present"

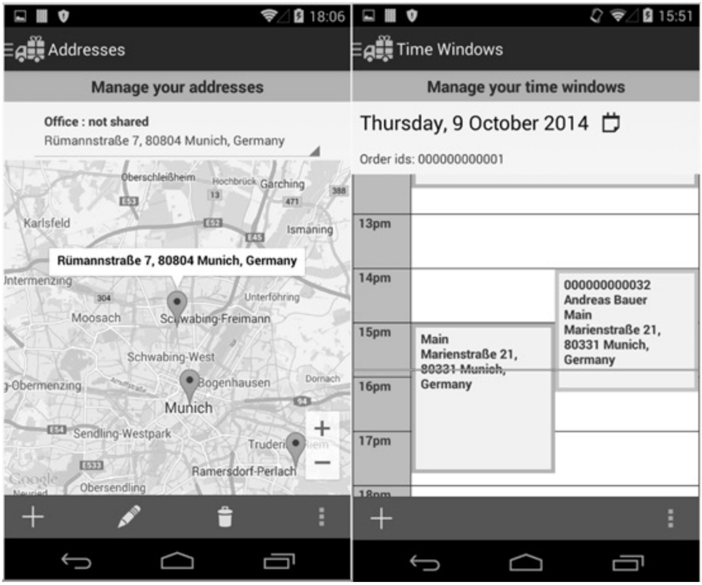

Figure 2: Screenshot of the Software Prototype

5 Evaluation

It was decided to assess customer satisfaction by calculating the following effectiveness metric: for each test run, the percentage of orders estimated to be delivered within a recipient-defined time window in comparison to the total number of order.

Test data

The evaluation of the prototype would be more accurate, if there was a big distribution logistics company available as business partner for this research. As long as no such partner is available, the test data had to be generated in case no suitable real data was available. However, the generated test data was as realistic as possible.

Service area

As service area, we chose the city of Munich, with a city population of 1.407.836 and an area of 310.43 km2 being a good example for medium-sized cities in the world.

Depots

In the service area, 74 different postal codes exist. Those postal codes where grouped by their first four digits, resulting in 19 groups. Some groups were merged with others to avoid groups covering very small area, which led to 17 groups/districts. The estimated population of the districts varies between 50.000 and 135.000 people. At the geographical center of each district a fictional depot was created, as well as the fictional customers. The number of customers of each district was calculated according to their population, also considering that at least 2 vehicles operate for each depot.

Customers

For each one of the 3000 customers, the following attributes were generated: A real main address (main addresses are distributed, corresponding to the demand for test customers of its depot)

- 0 to 5 further real addresses, randomly located within the whole service area
- 0 to 6 random favorite parcel stations
- 0 to 5 random trusted persons (randomly chosen between the rest customers)
- 0 to 1 pending order

Orders

For each one of the 150 orders (all estimated to be delivered at the same date) a random priority decimal value between 1 and 5 was generated, with intermediary steps of 0.1.

Parcel stations

47 parcel stations were created. Instead of randomly generating their locations, locations of actual parcel stations of DHL in Munich were used (DHL, 2014).

Purchase history

For each customer, a purchase history record was generated. It consists of a couple of integers for each one of the 4 delivery time slots, representing the sum of un-/successful delivery attempts in the past. The value of these integers varies between 0 and 10.

Time windows

Time windows were the most complex objects to generate. We used the following assumption: For each customer expecting an order at the specific day:

With probability of 10%, create no time windows at all

Starting with 9am, with probability of 15%, create a time window

Starting with minimum 2 hours duration, with probability of 80%, keep increasing its duration by 15 minutes.

With probability of 25%, choose randomly between the favorite parcel stations of the customer and set its address as the desired delivery address for that time window

With probability of 25%, choose randomly between the shared addresses of a randomly chosen trusted person of the customer and set this address as the desired delivery address for that time window, after checking that there is no conflict with the schedule of the trusted person.

With probability of 50%, choose randomly between the addresses of the customer and set it as the desired delivery address for that time window. A greater weight is given to the main address of the customer.

With probability of 85%, increase the time by 15 minutes and start over.

After several test runs, the metrics for assessing customer satisfaction corresponds to the average of those percentages, as well as average deviation between the defined time window and the estimated delivery time or time range. This is the factor that affects customer satisfaction the most, as the customers would expect of a service, supposed to optimize distribution logistics process, to deliver their orders at a time and location that fits to their schedule. However, when using that test scenario, it is not possible to integrate real time changes and route re-computations, which would probably slightly decrease the overall effectiveness metric, but at the same time providing a significant added satisfaction to the individual customers, whose schedule was changed.

Our evaluation results indicate that for 63.8% of the orders, the estimated delivery time concurs with a customer-defined time window. Regarding the rest orders, the average deviation between the estimated delivery time and a time window is 101.64 minutes. This value may seem quite high for the customer-oriented service, our prototypes aims to provide. However, in most cases this deviation is

Table 2: Results of the Evaluation

Metric	Value
orders, for which time windows are defined	86.2%
orders, for which time windows are not defined	13.7%
orders, for which the estimated delivery time concurs with a defined time window	63.8%
Average deviation between the estimated delivery time and the limits of a defined time window	101.64 minutes
orders, for which the estimated delivery time range concurs with a defined time window	48.4%
orders, for which the estimated delivery time range overlaps a defined time window	31.4%
orders, for which the estimated delivery range does not concur with a defined time window 20.2%	
Average deviation between estimated delivery time range and time window	33.67 minutes

no longer than 20 minutes, but the value is highly affected by extreme cases. On those cases, the total time of defined time windows for a particular order do not extend the minimum of two hours, which usually results in significantly higher deviation values.

This can be derived from the following set of metrics, regarding not the exact estimated delivery time, but the estimated delivery time range, with duration of 60 minutes. The estimated delivery time range of 48.4% of the orders concurs with a customer-defined time window, while another 31.4% of the delivery time ranges overlaps with a time window. These sums up to 79.8% of all orders, while only by 20.2% of the orders the delivery deed not meet a defined time window at all.

6 Discussion

The results indicate the availability of big data originating from different supply chain partners being relevant to improve distribution networks, e.g. processes or services. However, challenges such as information security, accuracy, complexity, optimization, or the user experience have to be regarded and tradeoffs have to be balanced between overall goals and the purpose of each service or product.

In the case of this prototype a lot of opportunities in the area of big data were applied to develop a prototype for optimizing distribution networks. The major component of the distribution logistics optimization process is the analysis of user-defined time windows, providing information about the desired delivery time and location of the customers. The prototype fulfills the majority of its initially defined functional and non-functional requirements providing a flexible, user friendly, and effective service. The prototype represents an effective solution considering customer needs, improving customer satisfaction, and providing firms with the opportunity to realized cost savings.

While our prototype does not use big data analysis techniques, the prototype has laid the technical foundations and relations between data for future distribution solution. Therefore, our prototype allows firms to offer customer-oriented delivery solutions plus being cost-effective and -efficient. Based on the evaluation results, the prototype could be used as an extension for existing distribution services or products. In addition, the prototype is being setup to integrate further data from other sources such as cyber-physical-systems or autonomous cars.

Using the prototype requires firms to adjust the prototype and adapt their supply chain strategy, especially from a pricing perspective. Firms need to define their planned margin, costs, and revenues. Firstly, in case of a new entry in the market, a niche player or a logistics company with considerable market share, which aims to extend its customer base, the offer of the service for free is recommended (as standard delivery option). Secondly, if the logistics company is not prepared for the full integration of this service as standard delivery, but simultaneously wants to face the margin pressure and not left behind by its competitors, a yearly or monthly subscription pricing strategy or a pay-per-use pricing strategy is recommended. Finally, a combination of the two previous pricing strategies is proposed, following a freemium model, by offering the service for free for some times monthly, but if the customer extends that limit, a pay-per-use model should be then used.

6.1 Implications

Regarding the implications of this research, the prototype is a practical application of a recent theoretical concept (Engel, Sadovskyi et al., 2014) and identified needs within the field of logistics (Waller and Fawcett, 2013), based on the latest technology evolvement representing a contribution in the field of information systems. Moreover, the heuristic distribution algorithm, which was developed to approach the set Traveling Salesman Problem with Time Windows and is explained in Chapter 2, constitutes a scientific contribution to the field of supply chain management. Rather than extending existing algorithms, in order to slightly decrease the complexity of this (at least) NP-Hard family or problems, the approach of this research focused on facing the tradeoff between optimization and complexity. The problem has been by notably simplified, using available data, and approach it as a TSP only, at one of its latest stages.

Furthermore, this prototype could serve as a model basis and be integrated in the delivery services currently offered by the logistics companies, which mostly do not take into consideration the schedule and needs of the recipient (Lienbacher, Waldegg-Lindl et al., 2013). This allows firms to increase service effectiveness by optimization of the routes, distribution costs will be reduced, and customer satisfaction will be on the foreground, constituting the major goal of distribution logistics companies. Such a customer-oriented approach of high quality is vital for any organization's success (Monczka, Handfield et al., 2008), considering the evolvement of customer dynamism over the last years. Finally, if this prototype is widely adapted in the future, it may also indirectly contribute to society, since it will affect gas emissions and working conditions in the field of distribution logistics.

6.2 Limitations

Considering the limitations of this research, all the analysis and development phases have been highly affected in several ways by the prototype's context, its planned duration and the available resources. Having set customer satisfaction, user experience and compliance with requirements of customers as major goals of the prototype, as well as the lack of a logistics company as business partner, prevented the analysis and use of data, which could be highly beneficial for the optimization of distribution logistics. There has also not been an opportunity to integrate actual distribution vehicles into the prototype, which could provide the optimization process with a considerable amount of big data, originating from their navigation systems or NFC sensors. Furthermore, the use of the free version of Google Maps API, prohibited the integration of real time weather and traffic information, the calculation of routes between more than 10 nodes, as well as the use of distribution vehicles of varying capacity. Regarding the smartphone application, the focus has been laid on implementing functionalities for managing a user's orders, time windows, addresses, parcel stations and trusted persons, as well as on creating a simple and friendly user interface. There is plenty of room for improvements, including, for example, a push notifications system and a more efficient data persistence management, before a future market launch. Finally, the most significant limitations of this research are observed at the testing phase. The real-time nature of the service provided by the prototype also demands a real-time and realistic testing environment, to be fully and properly tested. Considering the context and resources of this prototype, such a testing phase could not be realized, and therefore a different testing scenario was chosen. Using this scenario, customer satisfaction, which is the major goal of the prototype, is being assessed by calculating the percentage of orders being delivered with a customer-defined time window. However, as customer satisfaction is a qualitative metric, further evaluation actions are recommended.

7 Future Research

Besides facing the time-based and resource-based limitations, the focus should be firstly laid on further optimization of the distribution and routing algorithm, in terms of efficiency and accuracy. Furthermore, a partnership with a big distribution logistics company is highly recommended in order to access a large amount of big data. This allows researchers to make use of analytics for optimizing the distribution network. Moreover, the business partner could provide the appropriate testing environment and conditions, in order to face the major limitation of the current research. Finally, being in an era of rapid and continuous technological evolvement, new domain/related opportunities, as well as new customer requirements will arise. Their iterative review will be critical for future research in the field of distribution logistics optimization.

References

DHL (2014). *DHL Standorte*.

Domschke, W. and A. Scholl (2010). *Logistik: Rundreisen und Touren*. Oldenbourg Verlag.

Dumas, Y., J. Desrosiers, E. Gelinas, and M. M. Solomon (1995). "An optimal algorithm for the traveling salesman problem with time windows". In: *Operations research* 43.2, pp. 367–371.

Dumitrescu, A. and Joseph S. B. Mitchell (2001). "Approximation algorithms for TSP with neighborhoods in the plane". In: 365417: Society for Industrial and Applied Mathematics, pp. 38–46.

Engel, T., O. Sadovskyi, R. Heininger, M. Böhm, and H. Krcmar (2014). "A Conceptual Approach for optimizing Distribution Logistics using Big Data".

Fang, L. and C.-q. Zhang (2005). "The e-Logistics Framework in e-Commerce". In: *Proceedings of the 7th International Conference on Electronic Commerce*. ICEC '05. Xi'an, China: ACM, pp. 408–412.

Focacci, F., A. Lodi, and M. Milano (2002). "A Hybrid Exact Algorithm for the TSPTW". In: *INFORMS Journal on Computing* 14.4, pp. 403–417.

Google (2014). *Google Directions API*.

Hartigan, J. A. and M. A. Wong (1979). "Algorithm AS 136: A k-means clustering algorithm". In: *Applied statistics* 28.1, pp. 100–108.

Internet World Stats (2013). *Internet Usage Statistics - The Internet Big Picture*.

Lienbacher, E., M. B. Waldegg-Lindl, and M. M. Waldegg-Lindl, eds. (2013). *Last Mile: Die letzten–und teuersten–Meter zum Kunden im B2C ECommerce*. Handel in Theorie und Praxis. Berlin, Wiesbaden, and Heidelberg: Springer.

Lloyd, S. (1982). "Least squares quantization in PCM". In: *Information Theory, IEEE Transactions on* 28.2, pp. 129–137.

Monczka, R., R. Handfield, L. Giunipero, and J. Patterson, eds. (2008). *Purchasing and supply chain management*. Boston, MA and USA: Cengage Learning.

Sadovskyi, O., T. Engel, R. Heininger, M. Böhm, and H. Krcmar (2014). "Analysis of Big Data enabled Business Models using a Value Chain Perspective". In: *MKWI 2014 - Multikonferenz Wirtschaftsinformatik. Relativistic groups and analyticity*. Proceedings of the Eighth Nobel Symposium. (Feb. 26–28, 2014). Ed. by D. Kundisch, L. Suhl, and L. Beckmann. Paderborn, pp. 367–377.

Shekhar, S., V. Gunturi, M. R. Evans, and K. Yang (2012). "Spatial Big-data Challenges Intersecting Mobility and Cloud Computing". In: *Proceedings of the Eleventh ACM International Workshop on Data Engineering for Wireless and Mobile Access*. MobiDE '12. Scottsdale, Arizona: ACM, pp. 1–6.

SODA '01: Proceedings of the Twelfth Annual ACM-SIAM Symposium on Discrete Algorithms (2001). Washington, D.C., USA: Society for Industrial and Applied Mathematics.

Solomon, M. M. (1987). "Algorithms for the vehicle routing and scheduling problems with time window constraints". In: *Operations research* 35.2, pp. 254–265.

United Nations (2000). *The World's Women: 2000: Trends and Statistics*. United Nations Publications.

Valerio, D., A. D'Alconzo, F. Ricciato, and W. Wiedermann (2009). "Exploiting Cellular Networks for Road Traffic Estimation: A Survey and a Research Roadmap". In: *VTC Spring 2009 - IEEE 69th Vehicular Technology Conference*, pp. 1–5.

Waller, M. A. and S. E. Fawcett (2013). "Data science, predictive analytics, and big data: a revolution that will transform supply chain design and management". In: *Journal of Business Logistics* 34.2, pp. 77–84.

Weltevreden, J. W. J. (2008). "B2c e-commerce logistics: the rise of collection-and-delivery points in The Netherlands". In: *International Journal of Retail & Distribution Management* 36.8, pp. 638–660.

Smart Logistics of organic waste collection in cities

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Waste management is a growing problem all around the world with implications to society, environment, health and economy. In this context, the waste is considered as the last step in the consuming process. However, a smart waste management is possible by the generation of value from the garbage and the optimization of collection routes, landfills location and the determination of the transport fleet. This article addresses the problem of value generation from organic waste in cities, which is used for the compost generation, biofuels (as an alternative to fossil fuels) and specialized landfills.

The objective of this paper is to develop a conceptual decision support system (DSS) that allows efficient linkages between large organic garbage generators inside the cities (e.g. restaurants, health and educational institutions, food markets) with organic waste consumers, located outside the urban boundaries, who are responsible for recycling and generating value from the garbage (e.g. farms, special landfills, compost and biofuels). The DSS proposes both collection and delivery routes in combination with the fleet required where the information can be updated in order to reflect changes in supply and demand. Because of that, there is a benefit to the waste management and a reduction in the volume of organic waste in municipal landfills. The approach originality is based in the integration of suppliers, demands and transport services in a collaborative DSS that combines different techniques and theories.

The managerial implications are related with new waste value and its value chain, with new services in the decision process with impact in the sustainability.

Keywords: organic waste; smart logistics; decision support system; municipality waste management

1 Introduction

Each year the volume of garbage generated increases with the growth of the population and its centralization in the cities, which causes it territorial expansion and the known consequences (e.g. more time to move inside the city, impact on transport, new urban logistics, etc.). According to last sources, only half of the population has access to a controlled waste elimination system (Hoornweg & Bhada-Tata, 2012) and because of that, the waste management is a global problem with impacts in the society, cities, environment and economy. However, in the last decades there were some successful cases related with smart waste management, they have demonstrated to be a good business with important benefits as public saving, reduction in greenhouse gases, new jobs creation, contamination reduction, landfill longer life and better economic benefits.

The urban waste is classified in organic, recycle inorganic, non-recycle inorganic and special or dangerous garbage (Greco et al, 2015). In this paper, the object under study is the solid organic waste.

Even though traditional solutions to waste management have been implemented in landfills, many of them (in most of the Latin-American countries) are still uncontrolled in regard to the impact on the environment, society, and health, because they don't satisfy the technical requirements of polluting soil, water, and air.

In addition, the solid organic waste in landfills increase the negative effects because of the methane, deep-water pollution and smells; in other hand, there is more economics costs. This problem is more visible because the waste accumulation and overproduction, and the solid organic waste in landfills is not sustainable in time. Like the other kinds of waste, the solution is related to prevent its generation and its re-introduction to productive systems, which means that an intelligent waste management system could solve help in solving not only environment issues, but also promoting new jobs positions. This is a paradigm shift where the garbage is seen not as a burden but as an opportunity.

Reducing, reusing, recycling and recovering waste will reduce the demand for natural resources, but the base of this change is the education, information and awareness raising on the whole population.

The European community is the most advanced in programs and strategies related with the smart waste management, countries such as the Netherlands, Sweden, Norway, Germany and Austria. They have special programs characterized by being eco-cycle models where the basis is separation at source and facilities that generate energy by means of garbage, with a landfills reduction and incineration.

There are different works with approaches related to the waste usage and energy generation. Also, others works are related to some logistics aspects where new technology is introduced considering new aspects. In this paper, the approach is oriented with a decision support system to design the collection routes and the required fleet. This proposal has an impact in the organic waste management and generating value, combining different techniques and new technologies.

The Literature review is presented in the Section 2 detailing different works related with the smart waste management. In the Section 3, an approach for smart logistics in the urban area to smart waste management detailed. At the end, Conclusions and Future works are presented.

2 Literature Review

There is a vast literature related to the intelligent waste management, with focus in organic waste and generate energy (using incineration), compost or biofuel. Using the keywords ”organic waste” in Google scholar is possible to find 6230 articles and 272 papers only this year. The majority of this works use the organic waste to produce methane or other derivate (Frei-Baffoe et al, 2015; Banacu et al, 2016; Hierro, 2016; Cardavid and Bolaños, 2015; Chavez and Rodriguez, 2016). Other kind of works are related to urban logistics, specifically with the collection and disposition of the waste in landfills (Chen et al, 2016; Yusof et al, 2017; Brouko et al, 2017; Anagnostopoulos et al, 2015; Hua et al, 2016). On the other hand, the location and number of landfills or plants to process garbage are among other research topics (Kasliwal and Suryawanshi, 2016; Nelles et al, 2016; Amritha and Anilkumar, 2016; Simone et al, 2016; Hrebicak et al, 2016). With new technologies and new challenges, the smart organic waste management needs new development (Nelles et al, 2016).

Banacu et al. (2016) identify and analyze the concepts and strategies for waste recycling with the goal to reduce the negative impact on the environment, human health and natural resource. In this paper, they remark the requirement of creating a suitable channels collection and transport to locations where waste can be reused. In our work, this requirement is considered.

Chen et al. (2016) develop an approach with IoT (Internet of Things), cloud computing and a distributed architecture to the garbage truck fleet management. With the new technology is possible to monitor the different containers around the city, and use historical information to predict some behaviors, also the app can provide the immediate location of the garbage truck. In addition, an arrival time forecasting method is designed and implemented. This paper is related with the proposal considering the monitoring and control of the fleet and the real-time information to change the arrival time in the different collection points.

Anagnostropoulos et al. (2015) propose the fleet estimation and workout. The solution is based in using sensors, ubiquitous mobile communications and IoT to optimizing the garbage truck fleet size, collection routes and prioritized waste pick-up.

One of the main problems in this topic is the uncontrolled dumping in open landfills. Amritha and Anilkumar (2016) analyze how a directed landfill of organic and biodegradable waste can be a good option to reduce the environmental risks and simultaneously using the same land for green productive purpose, reducing the pollution.

A solution of the problem of the route calculation for garbage removal is presented in (Brouko et al, 2017). In this case, the solution includes route calculation and collaboration among the different actors. This idea is important for the solution developed in this work.

Yusof et al (2017) present a smart garbage monitoring system in a bin acting in real-time. The contribution is the possibility to improve the efficiency of the solid waste disposal management by using sensors in special bins to notify when some level is reached. Kasliwal and Suryawanshi (2016) develop other similar idea, where microcontroller, ultrasonic sensor, GSM and IoT are combined in a monitor system.

A DSS for a municipal waste collection and transportation is presented by Hua et al. (2016), where real-time data through smart devices to calculate the best path for each vehicle in the trucks fleet is integrated. In other hand, Shafray and Kim (2017) show sustainable strategies for municipal solid waste management, this idea can be integrated with the proposal of Bylot et al. (2016) where the waste is generated and treated in a consumption perspective. Thus, the waste is converted in economic resources (Fudala et al, 2016).

Analyzing the literature is possible to identify different research topics, in some of these works there are suggestions to combine different topics because they are related. One of this research areas is the logistic required to transport the waste from the different locations through the collection to other locations where the organic waste can be re-used like landfill, incineration, compost plants, biofuel plants, farms, etc.

3 An approach for organic waste smart logistics

In this section the proposal of a smart organic waste management is presented. In the section 3.1 the problem is detailed with focus in the advantages of intelligent waste management and the change in the paradigm where the garbage has an economic power. The conceptual model, presenting the main actors in the system with their activities and different requirement is shown in the section 3.2. The solution architecture is presented in the section 3.3, while some initial results are discussed in the section 3.4.

3.1 Organic waste: the power of the garbage

The waste management is a growing up problem with many different aspects and different impact levels. The problem is worst now because of the proliferation of big cities and the inexistence of political actions in many countries around the world. However, a new vision is emerging where the waste has a value. The 3R (reduce, re-use, recycle) and other proposals are oriented to this new vision about the waste. In this work, it is considered only the organic waste because is the source of many problems related with the sustainability, and providing a solution for this would be a good starting point that can be extended in order to tackle the problems related to other kinds of garbage.

The organic waste is produced in every home, institutions, food markets, commerce and streets. In general, there is not a regulatory law to determine responsibilities and there is not a conscience in the society about the volume of garbage per day each person produces. The organic waste management is important because the consequences have a social, environmental and economic impact, with pollution on soils, air, and water and in transition with health consequence.

The organic waste is special because it can be used in a next value process, for example, used to animal feeding, compost, vermiculture, biofuels (replacing fossil fuels), biofertilizers, etc. and there is a value in the waste that can be part of the production process. Some benefits of a good organic waste management are organic matter in degraded soils (and then organic agriculture), reducing the synthetic fertilizers and the new jobs positions. This new idea is an economic power element, for example with the fossil fuel reduction and the dangerous situation of the natural resources.

In this context, the scenario has some waste generators and other organizations using the garbage to produce value. Usually, among them there is distance (inside the urban boundaries and/or outside the boundaries) and a coordination problem because they don´t know each other. Because of that, a transport service is required, being an actor in the urban logistics with new functionalities. The coordination among them is necessary and in this paper, a new DSS is proposed.

3.2 A conceptual model: Actors, process and the relationships

The problem under studio is the coordination among the actors involved in the process of smart logistics related with the organic waste management. The different actors and the relations among them are represented in the Figure 1. The model is a simplification of the reality showing only the main roles involved in the process. Naturally, the DSS has many requirements, and it is related with the four different roles.

The producer or generator is the source of garbage, it has the responsibility to separate the organic waste from the other kind of waste. The producer informs to the DSS about the quantities available of every kind of garbage, and the information is sent manually or using sensors in the different bins. In this work the focus is only in large organic waste generators like hospitals, educational buildings (schools, universities, etc.), food markets, supermarkets, restaurants and others. In other hand, the DSS informs to the generator the planning of the organic waste collection, which is important because the uncertainty can be reduced.

/In some cases, it is necessary to establish a negotiation process between the producer, receptors and transporters according to the available capacity and requirements. This process is triggered when the collection planning is not able to meet all needs or when a real-time service demand occurs. In this process, the coordination becomes explicit between the different actors, being the DSS a key element that allows integration between them, In addition, with the stored information it is possible to generate movement and load generation profiles, which will allow in the future to create proactive collection protocols.

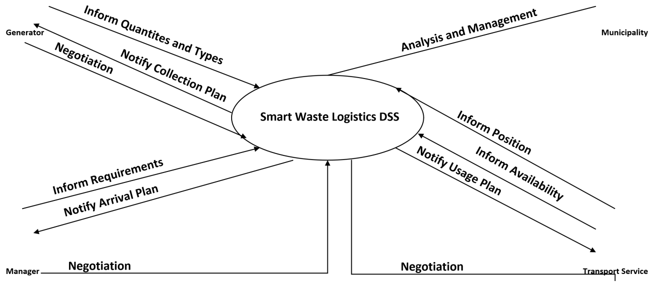

Figure 1: DSS Conceptual Model for organic waste smart logistics

One special kind of generator is the municipality itself through household waste collection. It this case, a separation process would be needed, and after it is completed the waste destination would depend on the service demand. If the waste is sent to the processing centers then the municipality would be considered as a regular producer but with higher volume of product; if it's sent to a specialized landfill, then this would allow the municipality to reclaim grounds.

The other actor relevant is the manager; this is the value generator from the garbage. Usually, this kind of actor is usually outside of city boundaries. Using the organic waste is possible to obtain energy (e.g. by incineration), biofuel, compost, etc. Alternatively, the waste can be used in a specialized landfill with only organic waste. This actor inform to the DSS the availability to process the garbage, and the system is responsible for informing the Manager that the trucks arrival planning. The manager can also participate in the negotiation process if he doesn't agree with the designed planning or because of the different needs originated by the other actors.

The municipality also performs this role of Manager but in a passive way, the surplus of the organic waste is destined to a sanitary specialized landfill only for the organic garbage and whose purpose is the recovery of land for its later use.

The relation among the generators and the managers moving the waste from the source to the destination is done through the transport service. The transport service can be outsourced or own, the goal is maximizing the own fleet. Each truck informs the availability of time and capacity, and the DSS informs the Usage Plan.

In addition, the truck informs the position with the GPS, which makes possible to monitor and control the fulfillment of the plans with the generators and receivers of the garbage.

The municipality is the other relevant actor, it can be generator and receiver, and the municipality needs to analyze how the process is doing and the benefits obtained. Also the municipality is responsible for the waste management policy in the city.

The DSS offers the coordination and integration between the different actors to planning the collection routes considering prioritized waste pickup, the truck fleet required, considering real-time data to change the plans dynamically, and the monitoring and control of the fleet. Furthermore, enables the municipality to conduct analyzes of the behavior of the different actors and their coordination. The next section details the main components of the proposed DSS.

3.3 DSS to the organic waste smart logistics

Considering the stakeholders defined in the previous section, the different the first conceptual components design of the DSS is presented. This version considers only the basic functions integrating different technologies. In the Figure 2 the main components are shown.

The first component is the Presentation Layer. Under this name, the components related to the presentation and interaction with the different users and other systems related. It is the top most level of the application.

For the problem under study, for each stakeholder there is a specialized component considering the requirements and activities to do in the system. For example, with the generators the information about the waste could be completing a form in the system or in automated way using IoT combined with specialized sensors in the bins, the stakeholders involved can receive the information about the collecting planning by means of messages, emails and/or using the DSS. In the transport stakeholder, the information is sent to the system using the platform directly in combination with the GPS system to inform the position during the service. The municipality and waste manager use the user interface in the system.

The second main component is the Logic Tier or Business Rules. In this level, the different elements of the systems are related to the application process and the coordination. These components make logical decisions, evaluations and perform

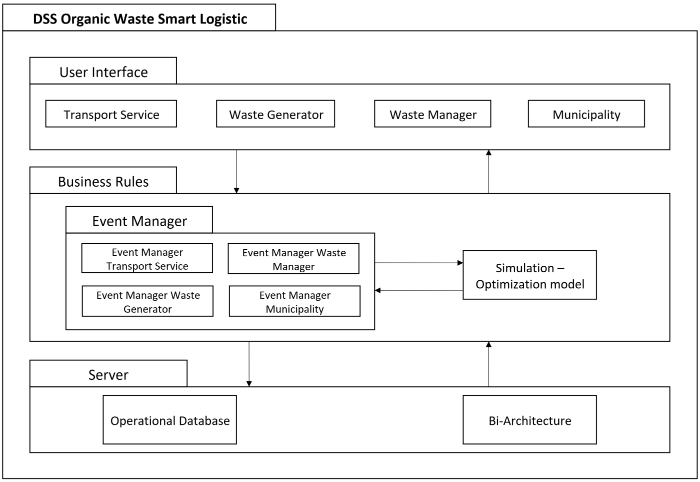

Figure 2: Conceptual Components in the DSS

different analysis. Also, it processes data between the surrounding layers. In this first approach, the main component in this level is the simulation-optimization model, taking the data from the generators and waste managers in combination with the transport service; this component produces the optimized garbage truck fleet and collection routes. In addition, with each change in the requirements, the component re-design the collection routes and it can the capacity to change the fleet to respond dynamically to the real-time information. Other components are related to the event management from the different stakeholders capturing and analyzing the changes in the original requirements or new requirements that can affect the planning.

In the next and last level we find the Data Tier. The function of this level is storing and retrieving the information. This level is in relation with the Application Tier sending data and receiving data in combination with requests.

The different elements of the architecture can be distributed between the different stakeholders. In the next version of this approach, the distribution of the components and its interactions will be under consideration

3.4 Desired results using the proposal

The organic waste management is a problem in every city around the world, and in most of the Latin-American countries, the normal process related with this kind of garbage is using landfills with a relative control with the consequences to the sustainability. With this proposal, there is a possibility to generate value using waste, in other words waste-to-value. Some of the desired results are The reduction in the uncertainty in each actors involved in the system and the ability to have a better reaction when something is out of the plan. Also, there is more flexibility, because there is information about when, how and what type of waste is being transported.

There is more information to develop new waste management policy. The municipality can redesign its policies considering this new information, thinking about the landfills location (e.g. specialized to only organic waste and then redesigning it) or the incineration plants.

The municipality and the garbage transport services enterprises should have better results, with an optimal trucks fleet according to the demand and optimized collection routes. The trucks should perform better and the usage is increased in time and capacity. Also, the urban logistic is affected with better routes and optimize fleet, especially if some restrictions are considered (e.g. to avoid the traffic jam in peak hours). In consequence, both the air pollution and the fuel oil consumption can be reduced.

Society should perceive less organic waste in the different sources of generation with the collection planning. Using IoT, sensors, and communication it is possible to have information in real-time, planning the waste collection when a point level is reached. Besides, it is possible to consider prioritized waste pickup.

Waste-to-value can be real, because the organic waste is not just garbage and can it be the input of a new process to add value and create new products like compost, energy or biofuel. Furthermore, there are new job positions related with this proposal, or a new conception from existing jobs. The transport is a key element linking the other actors.

The optimized garbage truck fleet and the optimization in the collection routes for each truck should be another important result, with the incorporation of real-time information, the routes can be changed to reflex the new requirement. This point is critical given that from a managerial point of view transport always takes a major role in the cost structure, and by taking care of this concept, system wide cost are optimized.

With this approach society should observe a reduction in the contamination in general, inside the city and in the landfills. With a better waste management, the pollution in air, soil and water is reduced. Moreover, this has an impact in the citizen satisfy level. This approach can be used in an educational program to the city, showing the benefits in the social, environmental and economic aspects. This potential benefits were developed in a round table with the different actors involved including the academy to model and design this approach.

According to the working table, the main contributions of the proposed DSS is the possibility to reduce uncertainty in the collection and delivery of waste, as well as having more certainty about the moving of it. Thus, facilitating the integration between different actors involving their processes in the decision making. However, for the acceptance and use of this platform, a technical training of the actors is required. Another critical point is the need to achieve the integration of different technologies and they heterogeneity, which must be respected considering the autonomy of the participants.

Currently a first proposal for the DSS has been awarded in an innovation and entrepreneurship contest with the co-participation of the Valparaíso City Hall (in

Chile). A conceptual test was analyzed in Brasil street (where the main buildings of educational institutions and markets are located) with the cooperation of the Facultad de Agronomía and Centro Biotecnológico. This concept test validated the main characteristics of the proposed system and the obtained results, laying the foundations to continue the development of this project to a larger scale.

4 Conclusions and Future Works

The organic waste is not a problem; it is a business opportunity and value added with the idea "waste-to-value". Furthermore, with a good organic waste management it is possible to have different benefits related with the sustainability and the use of natural resources.

The main result obtained with this proposal has been the possibility to work in a collaboratively in a round-table with the stakeholders involved in this process to value-added in the organic waste management. Because of that, the DSS for the smart logistics of organic waste collection emerges as a support to the collaboration and integration between the stakeholders. The DSS produce the optimized garbage truck fleet and collection routes for each truck, to move the organic waste from the generators to different plants and destination to produce other products like compost, energy or biofuel. Other destination can be specialized landfills controlled by the municipality.

This approach is the first step in a holistic intelligent waste management. Future works are required to consider the problem with its dimensions. The simulation-optimization model generates the optimized garbage truck fleet and collection routes, but only considering organic waste. It is necessary to increase the model including other kinds of waste, new garbage generators, and analyzing new restrictions. These restrictions are related to the hours (e.g. the collection routes are always out of rush hour); restrictions related to the type of trucks (i.e. different trucks for different kind of waste, or restrictions related with the circulation in the city), and other restrictions related to the urban logistics need to be considered.

From the municipality requirements, the approach can be extended considering the Business Intelligence. This extension permits the knowledge from the information in the system, and it is important for the analysis and evaluation of waste management policy. Evaluating the stakeholders' behavior to understand and discovery patterns and with this information re-design the simulation-optimization model. The information generated is key to have a better performance understanding and improving the process.

References

(N.d.).

Amritha, P. and P. Anilkumar (2016). “Development of Landscaped Landfills Using Organic Waste for Sustainable Urban Waste Management”. In: *Procedia Environmental Sciences* 35, pp. 368–376.

Anagnostopoulos, T., A. Zaslavsy, A. Medvedev, and S. Khoruzhnicov (2015). “Top–k Query Based Dynamic Scheduling for IoT-enabled Smart City Waste Collection”. In: *Mobile Data Management (MDM), 2015 16th IEEE International Conference on*. Vol. 2. IEEE, pp. 50–55.

Banacu, C. S., V. Zecheru, B. G. Olaru, et al. (2016). “Project Management In Organic Waste Recycling”. In: *Proceedings of the INTERNATIONAL MANAGEMENT CONFERENCE*. Vol. 10. 1. Faculty of Management, Academy of Economic Studies, Bucharest, Romania, pp. 101–106.

Beylot, A., B. Boitier, N. Lancesseur, and J. Villeneuve (2016). “A consumption approach to wastes from economic activities”. In: *Waste Management* 49, pp. 505–515.

Brovko, A., O. Dolinina, and V. Pechenkin (2017). “Method of the Management of Garbage Collection in the “Smart Clean City” Project”. In: *International Conference on Computer Networks*. Springer, pp. 432–443.

Cadavid-Rodríguez, L. S. and I. V. Bolaños-Valencia (2015). “Aprovechamiento de residuos orgánicos para la producción de energía renovable en una ciudad colombiana”. In: *Energética* 46.

Ceresia, F., R. M. M. Moreno, Á. S. Puchol, et al. (2017). “The Perception and Attitudes Towards City Garbage Management: A First Analysis”. In: *EJIS European Journal of Interdisciplinary Studies Articles* 7.

Chen, C.-H., Y.-T. Yang, C.-S. Chang, C.-M. Hsieh, T.-S. Kuan, and K.-R. Lo (2016). “The design and implementation of a garbage truck fleet management system”. In: *South African Journal of Industrial Engineering* 27.1, pp. 32–46.

Del Hierro Calvachi, A. G. (2016). “Solid Waste management in-ecuador: current practices and future challenges of anaerobic bioconversion of organic waste for agricultural purposes”. MA thesis. Australia/Universidad de Melbourne/2016.

Diao, M., M.-A. Cardin, S. Zhang, and E. Kuznetsova (2017). “Development of a Waste-to-Energy Decision Support System (WTEDSS)”. In: *IISE Annual Conference-Institute of Industrial and Systems Engineers*.

Fei-Baffoe, B., K. Osei, E. A. Agyapong, and E. A. Nyankson (2016). “Co-composting of organic solid waste and sewage sludge–a waste management option for University Campus”. In: *International Journal of Environment* 5.1, pp. 14–31.

Fudala-Ksiazek, S., M. Pierpaoli, E. Kulbat, and A. Luczkiewicz (2016). “A modern solid waste management strategy–the generation of new by-products”. In: *Waste Management* 49, pp. 516–529.

Hřebíček, J., J. Kalina, J. Soukopová, J. Valta, and J. Prášek (2016). “Decision support system for waste management”. In:

Hua, T. M., T. K. Nguyen, H. Van Dinh Thi, and N. A. N. Thi (2016). "Towards a decision support system for municipal waste collection by integrating geographical information system map, smart devices and agent-based model". In: *Proceedings of the Seventh Symposium on Information and Communication Technology*. ACM, pp. 139–146.

Jensen, M. B., J. Møller, and C. Scheutz (2016). "Comparison of the organic waste management systems in the Danish–German border region using life cycle assessment (LCA)". In: *Waste Management* 49, pp. 491–504.

Kasliwal Manasi, H. and B. Suryawanshi Smithkumar (2016). "A Novel approach to Garbage Management Using Internet of Things for smart cities". In: *International Journal of Current Trends in Engineering & Research* 2.5, pp. 348–353.

Liu, Y., Z. Ni, X. Kong, and J. Liu (2017). "Greenhouse gas emissions from municipal solid waste with a high organic fraction under different management scenarios". In: *Journal of Cleaner Production* 147, pp. 451–457.

Nelles, M., J. Grünes, and G. Morscheck (2016). "Waste Management in Germany–Development to a Sustainable Circular Economy?" In: *Procedia Environmental Sciences* 35, pp. 6–14.

Porras, Á. C. and A. R. González (2016). "Aprovechamiento de residuos orgánicos agrícolas y forestales en Iberoamérica". In: *Academia y Virtualidad* 9.2, pp. 90–107.

Shafray, E. and S. Kim (2017). "Residential Garbage Management from University Students Perception Though Case Study in South Korea". In: *International Journal of Engineering Innovations and Research* 6.1, p. 9.

Simeone, A., Y. Luo, E. Woolley, S. Rahimifard, and C. Boër (2016). "A decision support system for waste heat recovery in manufacturing". In: *CIRP Annals-Manufacturing Technology* 65.1, pp. 21–24.

Sisto, R., E. Sica, M. Lombardi, and M. Prosperi (2017). "Participatory Planning in Organic Solid Waste Management: A Backcasting Approach". In: *Food Waste Reduction and Valorisation*. Springer, pp. 261–278.

Yusof, N. M., A. Z. Jidin, and M. I. Rahim (2017). "Smart Garbage Monitoring System for Waste Management". In: *MATEC Web of Conferences*. Vol. 97. EDP Sciences, p. 01098.

Life Cycle Assessment for Frozen Food Distribution Schemes

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The online grocery market is facing big challenges. In addition to products for daily use, it is necessary to deliver fresh, chilled and frozen foods quickly and reliably to the customer. For decades frozen products have been delivered to the customers by using small cooling vans. Since some years, also normal parcel delivery services in combination with insulated shipping containers have been used. This article examines in a comparative analysis the environmental impact based on CO2 emissions of alternative distribution schemes (supermarket, cooling van, parcel delivery) by using a life cycle assessment (LCA) according to DIN EN ISO 14040. Thereby, the parcel delivery of insulated containers made of EPS (Expanded Polystyrene) was studied in detail, including recycling difficulties for the end customer. The LCA study showed that the transport scenario using small cooling vans lead to higher CO2 emissions, whereas the classical transport using high-capacity refrigerator trucks and refrigerated storage houses represented the scenario with less CO2 emissions. Additionally, recycling EPS-packaging in private households showed that reducing its volume is complicated and troublesome. The tests indicated that forces higher than 500 newtons were needed to break certain EPS-packaging.

Keywords: online grocery; life cycle assessment; city logistics; Expanded Polystyrene-Packaging

1 Introduction

The online food trade is facing great challenges in order to sustain the demanding clientele. In addition to items of daily use, it is also important to bring fresh, chilled or frozen food quickly and safely to the customer. Especially the amount of deep-frozen products has been growing steadily for years. With regard to the shipping business, frozen products are particularly convenient since they can be handled industrially and stored for longer periods than fresh foods. Enhanced manufacturing and freezing processes ensure higher qualities of the products, which now also meet higher requirements. The safe dispatch of deep-frozen foods requires compliance with hygienic standards, in particular, the adherence to the cold chain. In addition to stationary trading, frozen foods are delivered by direct distributors for decades by means of special deep-freeze vehicles. However, for some time now, competitors have been operating the classic online business as a full-range vendor and they are relying on the delivery of frozen products using standard CEP (Courier Express Parcels) service providers. In a comparative analysis, the present paper investigates the environmental sustainability of alternative shipping forms using a life cycle assessment according to DIN EN ISO 14040.

According to a study by the German Frozen Food Institute, more than 3.5 million tons of frozen foods were sold in Germany in 2015, which corresponds to an approximate per capita consumption of more than 43 kilograms and a sale plus of 3.7% compared to the previous year (Deutsches Tiefkühlinsitut e.V., 2015). In addition to ready-made meals such as pizza and buns, there are also vegetables, fish or meat.

Environmental sustainability is an issue in the context of consuming frozen foods since it is an indicator of how products or activities affect protective goods, such as soil, water, air or climate (Die Umweltdatenbank, 2017). The answer to this issue is of crucial importance since more and more people see the environmental sustainability of organic foods as a major factor for purchasing (Bundesvereinigung der Deutschen Ernährungsindustrie, 2013). The ECO-Institute Freiburg provides a comparative analysis of five selected foods and concludes that frozen products are not more climate-damaging than fresh products when all production and distribution stages are taken into account (Öko-Institut e.V., 2015). Industrial processing of fresh products results significantly less climate-costly than processing and storing in them in individual households. Due to the more complex distribution of frozen foods, this consideration is equalized but under certain assumptions it can lead to the statement that frozen products are as harmful to the environment as fresh products. This consideration is based on a customer's purchase in the supermarket. However, it can be observed that the online food trade is gaining in importance in comparison to stationary retail.

In his study for the 'Groceries Forum 2015' in Bremerhaven Professor Seeck mentions essentially three possibilities for logistics networks in e-commerce (Seeck, 2015).There are pure online players with central warehouse delivery, where deliveries are made from agglomeration-related central warehouse locations. To this pure online business also mixed forms from online and stationary trade are conceivable. Thus, the stationary trade can also offer an online sale, in which the customers are supplied from local branches. REWE is one of the German supermarket chains that uses this type of delivery. As alternative online sales and stationary trading may also be consolidated with agglomeration-related "online branches" where the delivery takes place as in stationary trading. In addition, it has to be decided whether the delivery is to take place through an own delivery organization or whether CEP service providers are used. For all considerations, it must be taken into account that the dispatch of foodstuffs and in particular of fresh and frozen foods imposes special requirements on transport. In particular, this concerns compliance with temperature corridors and hygiene regulations.

In addition to fast and safe delivery, ecological aspects are also of great importance to the consumers. Especially for organic food, it should be ensured that the ecological footprint is not impaired by expensive transports, as for example additional transports in low-wage countries for further processing. The distribution of frozen food as a section of the entire supply chain has several potentials for improvement, such as the design of the cold chain infrastructure (Manzini et al., 2013). Particularly the transport costs with heavy-goods-vehicles (HGV) and the accumulating packaging materials have to be analyzed critically, as these two aspects have the greatest impact potential on environmental sustainability (Hoang et al., 2016). One of the most relevant packaging material for frozen food delivery is Expanded Polystyrene (EPS), also known as Styrofoam, which requires thick sections to insulate the products and keep them at the desired temperature for longer periods. However, thicker packaging leads to bulky boxes. In the business-to-business sector, industrial disposal systems are available. For private costumers, storage and disposal from EPS-packaging is cumbersome. According to a study on online food commerce, packaging plays an important role since 36% of the online shoppers would buy groceries regularly online if they are sent using environmentally friendly packaging and generate fewer packaging waste (Fingerhut, 2015). In order to reduce the waste volume of EPS-packaging, it is necessary to break it, which might be a challenging task for some customers.

2 Methodology

The life cycle assessment technique was used to analyze the environmental impact of the considered transport scenarios for frozen food. Furthermore, since EPS-Packaging plays an important role in distributing frozen food without external cooling, a testbed was built to measure the force required to reduce the dimensions and disposal of such packaging.

2.1 Life cycle assessment of logistics processes

The life cycle assessment methodology is a way of determining the environmental sustainability of products or services. This is a standardized procedure, which is described in DIN EN ISO 14040 (Deutsches Institut für Normung, 2006). The goal is a holistic view of the entire way of life in order to be able to make a quantifiable and comparable statement about the resulting environmental effects. The obtained results are related to the functional unit with the intention of creating a comparability to other LCA results. According to the standard, an LCA is divided into four phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Evaluation/Interpretation. The process of accounting is described as an iterative procedure so that not only one-way connections exist between the individual phases. Therefore, it may happen that in a phase new knowledge or questions arise that require a return to the previous phase. This connection of the individual sections is shown, schematically in figure 1.

The first phase of the objective definition and definition of the study framework serves to define all the basic assumptions, describe the product system to be investigated and formulate the question, which is to be answered by the LCA. It is also necessary to determine the functional unit, which is the reference value for all results. In the phase of Inventory Analysis, all required materials and energies are determined and combined with their respective quantity necessary for the production of a product or the provision of the service. For this purpose, a distinction is made between input and output flows that either flow into the product from the environment or vice versa, from the product into the environment. At the end of this phase, an overview of all material and energy flows will be available.

The following step is the Impact Assessment where the previous results are used to calculate the values for different impact categories. This means that all substances or energies from the Inventory Analysis are assigned to the impact categories

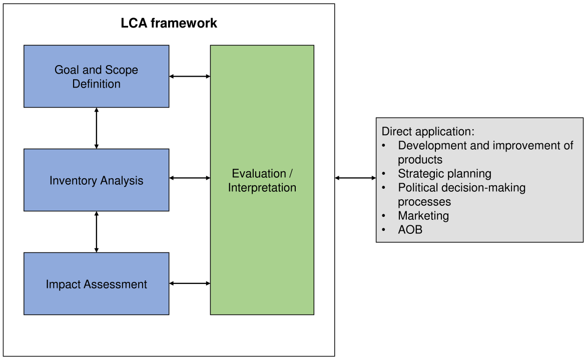

Figure 1: Life cycle assessment according to DIN EN ISO 14040

considered and then indicated by a specific characterization factor as a multiple of the respective basic unit. One of the possible categories is the climate change, characterized by the Global Warming Potential (GWP). For this category carbon dioxide (CO2) is the comparative value to which all results relate and are given in the form of kg CO2 equivalents (CO2e). As one example, methane (CH4) has a value of 23 kg CO2e and therefore the emission of 1 kg methane means 23 times more GWP compared to carbon dioxide.

The accounting is concluded with the Interpretation, where the results from the three previous sections are evaluated critically and conclusions are drawn. Changes in parameters of products or processes can be used to create different scenarios as possible future developments. The special challenges of LCAs occur in the procurement of directional and initial values for special materials or processes (Klöpfer, 2009). There are a number of databases (Ecoinvent, ProBas, ELCD, etc.) that may not contain all the values and in some cases, the present values are unsuitable for the specific application. As a rule, the values for transports are given as a mathematical product of mass and distance covered in the form of ton-kilometers. There are some scientific studies on the distribution of frozen foods that use these values, but therefore they are only partially comparable to other distribution scenarios (FRoSTA, 2009).

This is problematic when goods are transported that have a very low density but a high volume at the same time, such as Styrofoam packages. In order to obtain comparable results, there has to be a combined volume and weight-related determination of the transport costs. However, this requires a deeper consideration of the stowage and an estimation of cargo loading factor sections of the route. The cargo loading factor is an indicator of the utilization of the vehicles, which is calculated as the quotient of used and offered transport capacity (Gabler, 2017). The transport capacity can be either the weight of the maximum payload or the load volume. In the case of the latter, the ratio of volume and weight has to be observed in order not to exceed the permissible total weight. Since in most cases the weight is the limiting factor, in the following, the volume-related cargo-loading factor is used to show which volume reserves are still available.

In particular, in the case of round trips, the specific allocation of emissions is not trivial since the amount of cargo loading decreases dynamically. In the delivery process, the weight to be transported is gradually reduced, which is why theoretically the first delivered product would have to be allocated fewer emissions than the last product. However, since this cannot be resolved properly, an appropriate value for the average utilization or a cargo loading factor has to be found in order to evenly distribute the resulting emissions to all products of a delivery trip.

2.2 Testbed to study and analyze EPS-packaging disposal

With the purpose of measuring how complex it could be to break an EPS-box apart, a simple and logical procedure to break a box without special equipment at home is suggested. First, the box should be empty and without the lid. Then, it should be placed/against a solid wall and stepped on one of its sides with an angle of approximately 45° as shown in figure 2. This procedure should be repeated for each side.

In order to reproduce this scenario a simple testbed to apply discrete force steps was built as shown in figure 2. On top of the testbed, the weight could be gradually incremented, which is transferred to the box through a metal bar and a shoe fixed to it. A linear guide was used to allow the metal bar to displace perpendicular to the ground. The box is placed on an adjustable support, which was set to 45°. The force added to the box was calculated based on the weight of the metal bar plus shoe and the added weight on top. Friction force from the linear guide was neglected.

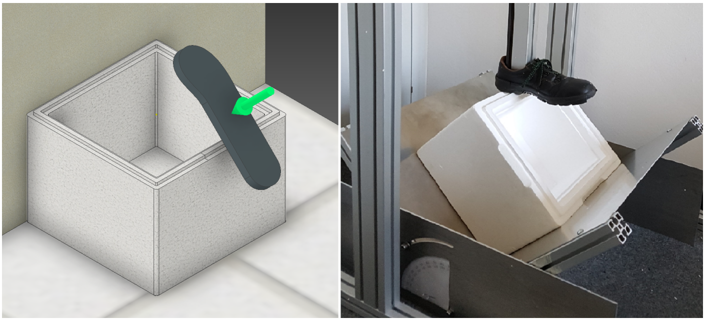

Figure 2: a. Representation of the procedure to break an EPS-Packaging
b. Testbed used to determine the breaking force for EPS-Packaging

3 Scenarios for distribution of frozen foods

The LCA analysis carried out is intended to answer the question of how many kilograms of CO2 equivalent emissions are generated when supplying the consumer with frozen foods. In order to get comparative results, the three most common scenarios are analyzed: delivery to the final consumer with refrigerated vehicles, delivery by CEP service providers with insulating containers as well as the final consumer's purchase journey to the stationary dealer. All calculated results refer to the functional unit transport and storage of "10 liters of frozen food with a total weight of 3.5 kilograms including packaging". This corresponds approximately to the volume/weight ratio of a deep-frozen ready-to-serve meal (e.g. chicken with fried potatoes, 500 grams by FRoSTA).

Within the scope of the following analysis a classical three-stage distribution is chosen with pre-run, main run and post-run (figure 3). Both the transport and the handling are considered. The pre-run describes the transport of frozen foods from the producer to the first transshipping point. The main run represents the section in which the goods are preferably transported by large heavy-goods-vehicles (HGV) over long distances to the second transshipping point. The phase of transport, in which the final consumer is exposed to the goods, is described with the post-run. The three scenarios differ significantly by their distribution network, whose distances chosen for this analysis are shown exemplary in figure 3.

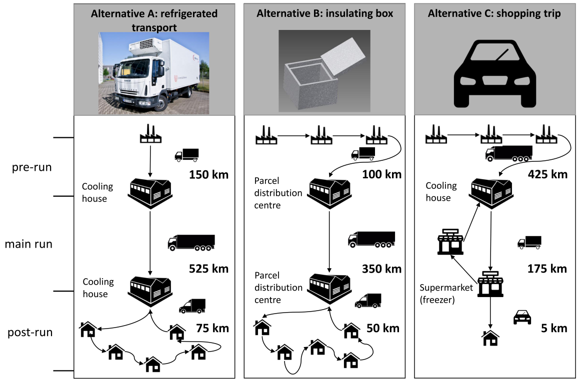

Figure 3: Scenarios for frozen food distribution (pictures: freepik, 2017)

The different distances between the cooling houses or the package distribution centers result from the assumption that there are ten times as many distribution centers for the standard parcel delivery as cooling houses for the handling of temperature-controlled goods. For all vehicle movements, the fuel consumption is an average value, which is calculated from the respective cargo loading factor and a consumption range for empty and full transports. The values are as far as possible based on the relevant literature values (ProBas, 2017).

3.1 Temperature-controlled distribution with refrigerated vehicles to the final consumer

For the pre-run of the temperature-controlled transports, it is assumed that there is a direct load transport between the producer and the cooling house with a 7.5-ton HGV, which has an estimated volume-related cargo-loading factor of 0.38. In this case, the volume-related cargo-loading factor is limited by the weight-related maximum load. There are CO2-equivalent emissions from fuel consumption that are generated by both the actual vehicle movement (18 l/100 km) and the use of the cooling units (3 l/h). In addition, coolant losses in the vehicles and the cooling houses cause emissions, which, however, are not included in the calculation by means of cut-off criteria. In order to be able to keep calculations comprehensively clear with all the complexity of the systems, one agreed on cut-off criteria. These determine the proportion from which an input is no longer relevant for the calculation. As a rule, the limit is 1% of the input of the total system in relation to mass, energy or environmental relevance since it is assumed that minor inputs below this limit have no appreciable influence on the overall result and therefore there is no need of further consideration (Klöpfer, 2009). Although the special vehicle bodies of the refrigerated vehicles and the construction of the cooling houses are made of materials that have high characterization values (e.g. 16.1 kg CO2e per 1 kg aluminum).

However, this may only be attributed to the individual functional unit on a pro rata basis. For a typical depreciation period of 9 years of vehicles with average use, the proportion of the emissions generated for the individual product is so low that this is not taken into account in the calculation. The energy consumption during transshipping is similar. It has to be pointed out, that the use of cooling houses causes emissions, but these also do not flow into the calculation because of the cut-off criteria (Klöpfer, 2009). In the main run, direct transports are carried out between cooling houses with 40-tonnes HGVs with an average volume-related cargo loading factor of 0.63. Here CO2e emissions are generated by fuel consumption for vehicle movement (31 l/100 km) and for the use of cooling units (5 l/h). The critical section of the three delivery phases is the post-run, where the calculations are based on round trips between cooling houses and final consumers. Deliveries are carried out with 3.5-tonnes HGV, which have an average volume-related cargo-loading factor of 0.28. Fuel consumption for the vehicle movement (10 l/100 km) and the use of the cooling units (4 l/h) generate CO2e emissions. The increased fuel consumption of the cooling units with respect to the loading volume is caused by the frequent opening of the cooling cell.

3.2 Delivery using EPS-Packaging by means of CEP service providers

In the online frozen food trade, the use of insulating containers made of EPS and dry ice as coolant is increasingly being used due to its good scalability. Such delivery solutions can be operated without external cooling, for example, the “NextGeneration Thermopack” from K+S over a period of 72 hours. Dry ice is solidified carbon dioxide (CO2) that sublimes under normal pressure at a temperature of around – 78.5 °C. Thus, a sufficiently low temperature is provided for the cooling and the solidified gas does not melt but passes directly into the gas phase without residue. The carbon dioxide used for the dry ice can be deposited as a by-product in combustion processes. After a multi-stage purification of the combustion gases, the pure carbon dioxide can be liquefied under pressure and low temperatures. Liquefied CO2 is optimal for transport and storage. Dry ice can be produced in different shapes and sizes. For the use as a coolant in insulated containers, a pellet shape is suitable, since these are easy to produce and to handle. In order to produce the pellets from the liquefied gas, the CO2 is suddenly expanded to normal pressure. The evaporation and adiabatic expansion result in a cooling that is large enough to produce dry ice snow, which can be compacted and pressed into the desired shape.

The subsequent release of the carbon dioxide can be regarded as CO2-neutral since existing combustion gases are used and the deposition only means a delayed release to the environment and no additional load. There are only a few more emissions from the deposition, the liquefaction, the pressing and if necessary the transport of the liquid carbon dioxide or of the dry ice to the place of application. The 10 kg dry ice are calculated with 1.39 kg CO2e and for the EPS-container with a useful load volume of 35.5 liters, there are 1.15 kg CO2e emissions. It can be assumed that there are a 27% material and a 40% thermal utilization of the insulating EPS-packaging.

The use of these EPS-packaging and dry ice allows the delivery by means of conventional CEP service providers, which have a very efficient distribution system. The analysis of this scenario is also based on a three-level distribution. The pre-run is carried out by means of 7.5-tonnes HGVs, which have a cargo loading factor of 0.63 and generate CO2e emissions by fuel consumption (20 l/100 km). In the main run, 40-tonnes HGVs (fuel consumption: 34 l/100 km) are used for the direct transports that have a cargo loading factor of 0.9. The post-run is realized through 3.5-HGVs (fuel consumption: 10 l/100 km) with a cargo-loading factor of 0.4. In order to evaluate EPS-packaging disposal, two standard EPS-Packaging solutions were tested. The packaging's dimensions were 48 cm x 48 cm x 38 cm and 26 cm x 21 cm x 18 cm (LxWxH), with a thick of 4 cm and 3 cm respectively.

3.3 Temperature-controlled distribution and final consumer's shopping trip

This scenario represents the classic distribution to the supermarket and the subsequent shopping trip of the final consumer. In this scenario, deliveries of larger quantities of frozen foods are exported from the producer to the cooling house of supermarket chains. For this purpose, consolidated transports are carried out with 40-tonnes HGV with a cargo-loading factor of 0.8. CO2e emissions are generated by the fuel consumption for vehicle movement (33 l/100 km) and the use of cooling units (5 l/h). The main run is represented by 7.5-tonnes HGV that supply the supermarkets and have a cargo-loading factor of 0.38, producing CO2e emission due to fuel consumption for vehicle movement (18 l/100 km) and use of cooling units (3 l/h). The transshipping and the storage in the supermarket take place in freezer cabinets with a load volume of 770 liters and a power of 300 watts (FRoSTA, 2009). In the post-run, the final consumer drives in its own car (fuel consumption: 8 l/100 km) an average distance of 5 km to the supermarket. Frozen foods take a proportion of 20%. Table 1 shows an overview of all three scenarios and their estimated values.

Table 1: Overview of scenario values

	Refrigerated	Transport	Shopping trip
Pre-run			
Vehicle	7.5-tonnes HGV	7.5-tonnes HGV	40-tonnes HGV
Distance	150 km	100 km	425 km
Fuel consumption for …			
Vehicle movement	18 l/100 km	20 l/100 km	33 l/100 km
Cooling unit	3 l/h	–	5 l/h
Cargo-loading factor	0.38	0.63	0.8
Main run			
Vehicle	40-tonnes HGV	40-tonnes HGV	7.5-tonnes HGV
Distance	525 km	350 km	175 km
Fuel consumption for …			
Vehicle movement	31 l/100 km	34 l/100 km	18 l/100 km
Cooling unit	5 l/h	–	3 l/h
Cargo-loading factor	0.61	0.9	0.38
Post-run			
Vehicle	3.5-tonnes HGV	3.5-tonnes HGV	car
Distance	75 km	50 km	5 km
Fuel consumption for …			
Vehicle movement	10 l/100 km	10 l/100 km	8 l/100 km
Cooling unit	4 l/h	–	–

4 Findings

4.1 Life cycle assessment

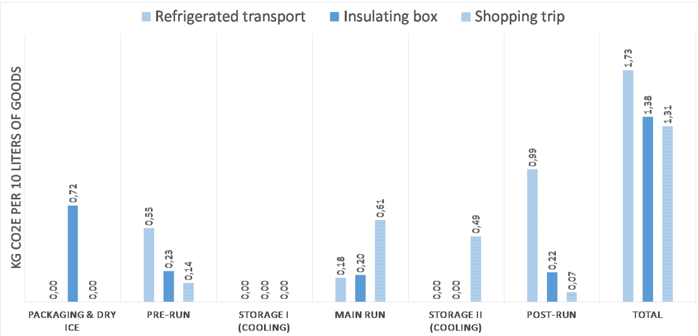

Figure 4: LCA results as kilograms of CO2e per 10 Liters of goods

The LCA is carried out using the above-mentioned parameters as well as the characteristic values known from the literature for the conversion of all emissions into carbon dioxide equivalent ones (ProBas, 2017). As described above, the emissions for dry ice are calculated based on the entire production chain, including transports from the source of the CO2 to the dry ice production. Figure 4 shows an overview of the results of the individual scenarios divided by phases. Therefore, the LCA shows a uniform picture. Having 1.31 kg CO2e, the "shopping trip" scenario is about 5 percent ahead of the scenario "insulating containers" with 1.38 kg CO2e. Only the scenario "temperature-controlled distribution" with 1.73 kg CO2e deviates by 32 percent from the "shopping trip" scenario. In the overview, it can be seen that the scenario "temperature-controlled distribution" has weaknesses in the post-run, whereas in the scenario "insulating container" the necessary packaging including dry ice leads to emissions independent of the actual distribution. The introduction of a deposit system, through which the insulating containers could be used several times, offers no ecological advantage in the case of the packaging considered here. In the case of a ten-time use of the insulating container, approximate 1.55 kg CO2e per 10-liter goods would be incurred per circulation. In order to improve this value, for example, foldable insulating containers would have to be used to save volume and thus to achieve a higher weight-related cargo loading factor.

The scenario "shopping trip" shows weaknesses both in the main run and in the necessary temporary storage in the supermarket. Here, the other two scenarios have corresponding advantages in the direct delivery to the final consumer, but these are fully equalized in the transport in particular in the "temperature-controlled distribution" scenario. In order to verify the calculation, reference should be made to 'Deutsche Post DHL's' experience values, which indicate less than 500 grams of CO2e for shipping an average package via its delivery system (Deutsche Post, 2011). In this calculation, 650 grams are omitted, which is probably due to the fact that there is a more efficient distribution in metropolitan areas that could not be taken into account and on the other hand, the fact that neither volume nor weight of an average package was specified by DHL. From the ecological point, this also shows that the online food trade with delivery via CEP service provider is also a clear alternative to traditional shopping trips. Even with a total range of 5 kilometers with a modern medium-sized class car, there are more CO2e emissions than for a parcel shipping (Deutsche Post, 2011). In this LCA, frozen foods only have a proportion of 20% of the total consumption, since no average values could be found in the literature.

4.2 EPS-packaging disposal tests

Due to the complications related with EPS-Packaging recycling for private users, two different packages sizes were destroyed systematically. The first side of the bigger box (48cmx48cmx38cm) required 514.5 newtons and broke irregularly as shown in figure5a. The opposite side required almost 10 newtons more to break. After the four sides broke, the edges of the box were almost intact as seen in figure 5b. For that reason, the testbed was also used to break the borders of the box as shown in figure 5. Since the shape of the rupture is uneven, the force required to break the edges varies from 328.3 newtons to up to 588 newtons. Finally, the remaining pieces longer than 30 cm were also crushed.

The same procedure was applied to the smaller box (26cmx21cmx18cm), which required an average force of 280 newtons to break its sides. For the smaller box, it was not necessary to continue breaking the remaining part of the box, since the edges were mostly damaged as seen in figure 6, proving to be easier to dispose

Table 2: Required force to reduce the volume and dimensions of two EPS-Packages.

	Force (Newton) for the …	
	Big box	Small Box
Side 1	514,5	291,06
Side 2	524,3	305,76
Side 3	504,7	276,36
Side 4	475,3	246,96
Edge 1	328,3	–
Edge 2	588	–
Edge 3	475,3	–
Edge 4	328,3	–
Piece 1	142,1	–
Piece 2	75,95	–
Piece 3	220,5	–
Piece 4	308,7	–

than the big box. A summary of the force required to break each EPS-Packaging solution using the before explained methodology is presented in table 2.

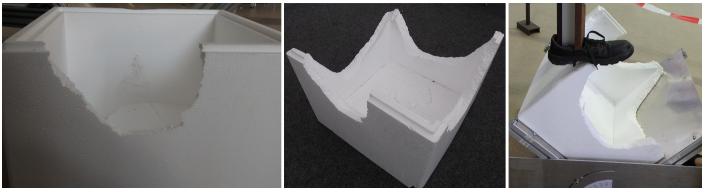

Figure 5: a. Rupture shape from the first side of the bigger box.
b. Remaining of the box, once all the sides are broken. c. Procedure to break the remain-ing edges of the box.

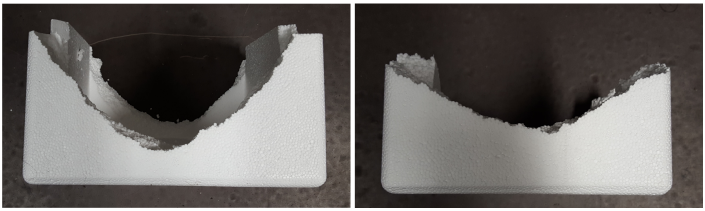

Figure 6: a. Rupture shape of the first and second side of the smaller box.
b. Remaining of the smaller box after breaking its sides.

5 Discussion and Conclusion

Distribution of frozen goods to the final consumer presents a special challenge for the online food trade in Germany. In addition to meeting hygienic standards, the safe dispatch of frozen foods requires compliance with the cold chain. Besides, these requirements, the final consumer is increasingly focusing on the environmental sustainability of the food, which also includes distribution.

In the present paper, three alternative scenarios of the distribution of frozen foods were examined from the ecological point of view: the classic shopping trip to the supermarket, the shipment by means of special refrigeration vehicles as well as the delivery CEP service providers with corresponding packaging solutions for deep frozen products. The LCA according to DIN EN ISO 14040 shows that none of the scenarios has clear advantages in ecological terms. The classical cooling transports are the worst performers, while the classic shopping trip causes the least greenhouse gas emissions. The shipping solution, which is preferred by many online grocers, by means of EPS-box and dry ice is scarcely inferior and benefits from the efficient distribution network of the CEP service providers. Additionally, it can be evidenced that breaking an EPS-Packaging requires a great effort from the private customers; especially for bigger EPS-Packaging. Considering that the average weight of an adult is 62 kg (Walpole et al., 2012), the required breaking force might be difficult to achieve without using fast and strong movements or impulse before stepping on the side of the box. This could even lead to dangerous situations or accidents. The big Package had to be hit 12 times to achieve a reasonable shape for disposal, which makes the process time consuming, where the time needed to clean the small pieces that are present after the process should also be considered.

In conclusion, although insulated containers' ecological impact is comparable to the impact of a classic shopping trip to the supermarket, disposing of EPS-packaging is a complicated, time consuming and possibly an unsafe process for private households.

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References

Birgit Grahl, W. K. und (2009). *Ökobilanz (LCA): ein Leitfaden für Ausbildung und Beruf*. Weinheim: WILEY-VCH.

Bundesvereinigung der Deutschen Ernährungsindustrie (2013). *Lebensmittel bewusst genießen darf mehr kosten*. Press release. Accessed: 12.06.2017.

Deutsche Post DHL (2011). *DHL transportiert alle Privatkundenpakete bundesweit CO2-neutral ohne Aufpreis*. press release: 27.06.2011.

Deutsches Tiefkühlinsitut e.V. (2015). *Tiefkühlkost-Absatzstatistik*. Accessed: 12/06/2017.

Die Umweltdatenbank (2017). *Keyword: Umweltverträglichkeit*. Accessed: 12.06.2017.

Fallstudie Tagliatelle Wildlachs (2009). Accessed: 12/06/2017.

Fingerhut, C. (2015). *Online-Kauf von Lebensmitteln: Knackpunkt Lieferung*. Accessed: 07/05/2017.

Freepik - free graphic resources for designers. Picture source: factory, truck (2017). Accessed: 12.06.2017.

Gabler Wirtschaftslexikon. Keyword: Ladefaktor (2017). Accessed: 12.06.2017.

Hoang, H., T. Brown, E. Indergard, D. Leducq, and G. Alvarez (2016). "Life cycle assessment of salmon cold chains: comparison between chilling and superchilling technologies". In: *Journal of Cleaner Production* 126, pp. 363–372.

Manzini, R. and R. Accorsi (2013). "The new conceptual framework for food supply chain assessment". In: *Journal of Food Engineering* 115.2, pp. 251–263.

Normung, D. I. für (2006). *Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen ISO 14040:2006*. Standard.

Öko-Institut e.V. (2015). *Klimabilanz Tiefkühlkost*. Accessed: 12/06/2017.

ProBas - Academic user Database v.1.5.3, 2017. Gütertransport-Dienstleistung (2017). Accessed: 12.06.2017.

Seeck, S. (2015). *Lebensmittel Online - Herausforderungen an die Handelslogistik*. Speech on Groceries Forum 2015. 4flow.

Walpole, S. C., D. Prieto-Merino, P. Edwards, J. Cleland, G. Stevens, and I. Roberts (2012). "The weight of nations: an estimation of adult human biomass". In: *BMC Public Health* 12.1.

Part V

Performance Modelling

Digitized VMI – Maturity Model for the FMCG Sector

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Optimized stocks and lean processes are prerequisites in order to keep up with the increasing consumption of goods and limited storage areas in cities due to urbanization. This paper, therefore, develops a maturity model to increase the dissemination rate of Digitized VMI to optimize supply chains in the FMCG sector. Firstly, criteria for successful VMI application are identified by literature research and expert interviews. Moreover, the respective target state descriptions are defined. Secondly, an assessment scheme is integrated. Finally, a procedure model to identify company-specific operational factors is developed. The research establishes requirements for successful VMI application in the FMCG sector within four generic categories and a specific one. It has been found that company-specific operational factors are particularly relevant in this context. Therefore, the specific fifth category is described by a procedure model to identify those factors. Current VMI models are generalistic and describe potential components of VMI, contract contents and relevant processes. However, a model addressing the barriers for VMI application ex ante and taking company-specific operational factors into account is pending. The VMI Maturity Model is practically applicable, since it has been tested at a company in the FMCG sector. It turned out, that assessing the VMI Maturity Level supports companies in identifying specific areas for improvements in advance of VMI implementation.

Keywords: FMCG; Vendor Managed Inventory

1 Digitized VMI in the FMCG sector

The megatrend of urbanization is driving consumption of goods in cities. Two-thirds of the world's population will live in cities in 2050 (United Nations, 2014), while in Germany, for example, it is already 75% (IW Köln, 2010). At the same time, storage areas in conurbations are limited and therefore it is expensive to increase stock capacities. Thus, optimized stock levels and lean processes are prerequisites in order to keep up with these developments.

Digitized Vendor Managed Inventory (VMI) is one effective solution to establish lean replenishment warehousing processes in a supply chain, while simultaneously increasing customer and vendor service levels. In VMI the customer is no longer responsible for inventory management and replenishment. Instead, the vendor becomes responsible for these processes. The customer has to offer current sales data and information regarding the inventory level continuously to the vendor (Schulte, 2013, p.506; Seeck, 2010, p.170). Especially in this case new digital technologies offer novel potentials regarding collecting, providing and analyzing data (Vogel-Heuser, 2014, p.36f). Therefore, the term "Digitized VMI" has been chosen to describe the subject matter. As a result of this reorganization of responsibilities, various improvements can be achieved (see table 1).

The table below has been developed based on the explanations of Draenert (2001), Schulte (2013), Werner (2008), Hellingrath et al. (2008) and Melzer-Ridinger (2007). It shows effects as well as examples that cause those effects and assigns them either to the vendor and/or to the customer, depending on which stakeholder rather benefits from the effect. This consideration makes the potential benefits of VMI obvious.

Particularly for companies in the Fast Moving Consumer Goods (FMCG) sector, which operate several stores in conurbations, VMI proves to be effective. However, VMI implementations are tentative in practice. Frequently, there is a lack of trust between supply chain partners and required data is not available. Thus, a model, which makes the success factors of VMI application transparent, could contribute to an increased dissemination rate of VMI.

The VMI models which currently exist are generalistic and describe potential components of VMI, contract contents and relevant VMI processes. Beckmann and Schmitz (2008) describe an extensive VMI model including components as strategy, processes, systems, benefits and costs cooperation controlling and contract design. In addition, Werner (2013) explains operational constraints. However,

Table 1: Potential VMI Benefits in the FMCG Sector

Potential Benefits	Effect	Cause (examples)	Stakeholder
Reduction of inventory costs	Reduced inventory levels	No double safety stocks	Vendor and Customer
	Reduced days inventory held	Lower safety stocks	Vendor and Customer
Reduction of production costs	Improved utilization of production capacity	Lower demand fluctuations	Vendor
Reduction of transport costs	Improved utilization of transport capacity	Optimized lot sizes	Vendor
Reduction of administrative costs	Reduced effort to satisfy volatile customer demands	Less ad-hoc customer requests	Vendor
	No effort for requirements planning and ordering	No demand planning and ordering processes	Customer
Reduction of Process costs	Reduced process lead time	Less feedback loops	Vendor and Customer
Sales growth	Improved goods availability	Less dependence on customer's processes	Vendor
		Less stock-outs	Customer
Improvement of service level	Improved customer retention	Responsibility for the customer's process	Vendor
	Improved end customer retention	Less stock-outs	Vendor and Customer
	Improved response speed	Transparent end customer demand in real time	Vendor and Customer
Improvement of supply reliability	Reduction of bottlenecks in supply	Continuous demand transparency	Customer

Werner (2013) further points out that social factors are often disregarded - even if, for instance, the experience and know-how of employees are critical for the success of VMI - and recommends to supplement VMI models with qualitative investigation in the company. The experts research has strengthened the fact, that considering social factors in terms of VMI is important, because traditionally evolved responsibilities are shifted from the customer's side to the vendor's side

A model that addresses the barriers of a VMI implementation in advance, takes company-specific and social factors into account and actively supports companies in determining targets and actions for a VMI collaboration does not exist yet. Therefore, this paper follows the scientific question: Which tool effectively supports companies in the planning process of VMI?

In order to answer this scientific question, a model which supports companies in defining concrete measures and corresponding goals to improve the organization is recommendable. In this context, maturity models are commonly applied (Feld, 2012, p.41ff). For this purpose, a VMI Maturity Model based on literature and experts research was developed. The research establishes requirements for successful VMI application in the FMCG sector. Furthermore, the model contains a procedure model to identify operational company-specific success factors and supports companies in identifying specific areas for improvements during a VMI planning process by assessing a Maturity Level.

2 Methodology of Model Creation

According to the example of two famous maturity models, the European Foundation for Quality Management (EFQM) model and the Process and Enterprise Maturity Model (PEMM) developed by Hammer (2007), two key aspects have been derived and adopted to develop the VMI Maturity Model:

1. Categories and criteria define the model's nature.
2. An Assessment Scheme objectifies the evaluation process including a Maturity Level for each criterion and a rating scale.

2.1 Categories and Criteria

The VMI Maturity Model aims at identifying VMI success factors to offer companies indications of the factors that have to be met in order to realize VMI opportunities optimally. Consequently, every success factor which is identified sets up a criterion for the VMI Maturity Model. This research has identified 24 factors by literature research. In order to facilitate the model's usability, the criteria have been logically clustered within the four categories Stakeholders, VMI Potential Utilization, Infrastructure and Planning System and complemented by the Procedure Model (chapter 4).

2.2 Assessment Scheme

The assessment scheme is composed of the Maturity Level and the Rating Scale. Regarding the Maturity Level, the model's approach is based on the PEMM. The reasons are the practical applicability and the transferability of its methodology. For this purpose, VMI target states have been derived in order to define the highest Maturity Level for each criterion. This highest Maturity Level is defined as the target state that is recommended to be achieved in the context of VMI. In order to determine an assessment scheme subsequently, statements have been formulated that can be checked by the assessing company.

The Rating Scale of the model is based on a qualitative assessment method, a ten-scale benefit-analysis, because the benefit-analysis is useful in making a decision if several non-monetary criteria are assessed. In order to assess the maturity of a company regarding the VMI criteria, the current overlap of the target state with the desired VMI business case is assessed. Therefore, zero means that the criterion does not apply to the underlying business case and ten means that the criterion does entirely apply. Thereby, the assessor has the possibility to assess that the criterion does not apply to the company at all (value 0), that the criterion does partly apply to the company (values 1 to 9) – hence, the assessor has nine gradations to self-evaluate to which extent the criterion is already implemented – and asses that the criterion does entirely apply (value 10).

3 VMI Maturity Model

The above mentioned categories Stakeholders, VMI Potential Utilization, Infrastructure and Planning System of the VMI Maturity Model and related criteria are described sequentially in the following. At first the basic criterion is always described. The target state is defined at the end of each paragraph within square brackets.

3.1 Stakeholders

The category Stakeholders includes criteria, which build the basis for the collaboration of two stakeholders following a joint SCM interest through VMI. Aspects which regulate the collaboration legally and structurally and express the stakeholders' competences and attitudes in terms of VMI are mapped.

3.1.1 Inventory Responsibility

The inventory responsibility has to be transferred from the customer to the vendor (Arndt, 2010, p.162; Zsifkovits, 2013, p.88f). The vendor is responsible for replenishment processes and the inventory levels of the customer. Consequently, this includes corresponding requirements planning processes. However, it has to be noted that not all products are suited to be managed by VMI. Therefore, the appropriate product range has to be identified and determined (Beckmann and Schmitz, 2008, p.274; Werner, 2008, p.107f).

The vendor is responsible for replenishment processes and consequently for the inventory levels of a specific pre-defined product range at the customer.

3.1.2 Know-how

In VMI, the vendor has to perform logistics activities significantly better and more cost-efficient than the customer. The customer, on the other hand, needs the know-how to influence the efficiency of the VMI processes in order to decrease transaction costs (Rajiv, 2009, p.20).

The vendor who is responsible for the replenishment processes has comprehensive expertise in the field of logistics. The customer is aware of possibilities to influence VMI processes.

3.1.3 Awareness & Commitment

The criterion Awareness has been taken from the PEMM and extended by Commitment. Awareness of the potential VMI benefits has to be created to convince the stakeholders to collaborate in an open and reliable way for self-interest reasons (Gudehus, 2010, p.974f). Committing the stakeholders to the agreed-upon goals is essential for collaborations (Arndt, 2010, p.187). Commitment makes the stakeholders acting goal-oriented and counter the threat of resistance against the impending changes (Pfetzing and Rohde, 2009, p.147; Neumann, 2012, p.253).

All stakeholders are, firstly, aware of the potential VMI benefits for the supply chain. Secondly, they are committed to the VMI implementation.

3.1.4 Behavior

This criterion has been borrowed from the PEMM, because even if stakeholders are aware of the VMI potentials and committed to the goals set, they may not behave in this way.

All stakeholders collaborate in the VMI process in order to fulfil defined and communicated VMI goals.

3.1.5 Contractual Agreements (SLAs)

Firstly, performance targets have to be determined for the vendor. Secondly, both stakeholders have to agree on the consequences if those targets are not met (delays in delivery, stock-outs…), since both the vendor (e.g. bad handling of products) and the customer (e.g. transfer of inconsistent data) may be the cause for errors. Those agreements are documented in Service Level Agreements ”SLAs” (Darwish and Odah, 2010, p.474; Beckmann and Schmitz, 2008, p.272ff). ECR Austria for instance published a model agreement for VMI within the results of a CPFR workgroup (ECR Austria, 2015).

The customer and vendor agree on VMI performance goals. Furthermore, they agree on the consequences in case these goals are not met. Those agreements are documented in SLAs.

3.1.6 Communication

Communication channels have to be defined to ensure the information flow between the customer and the vendor (Beckmann and Schmitz, 2008, p. 272f). Communication cannot merely be seen from a technical perspective. In SCM, face-to-face communication becomes more and more important whether digitally supported or not (Liebhart, Mödritscher and Blecker, 2007, p.173). Furthermore, knowledge-based uncertainties lead to deviations from standardized processes (Wildner, 2011, p.215ff). Therefore, for instance, process instructions have to be clear and mutually understandable.

The customer and vendor define clear communication channels. Furthermore, applied concepts and terms are clearly defined and known by the stakeholders.

3.2 VMI Potential Utilization

The category VMI Potential Utilization includes criteria which reveal the situation, whether stakeholders are willing to fully or partially exploit the potential of VMI. In order to create awareness for the full VMI potential and investigate the criteria where opportunities remain, this category maps the goal dimensions time, costs and quality.

3.2.1 Order Time

One of the most important VMI benefits is to eliminate double-work. Therefore, the customer does no longer invest time on ordering and requirements planning as the vendor becomes responsible for the corresponding operational activities (Darwish and Odah, 2010, p.473; Schulte 2013, p.506).

The customer does no longer spend time on requirements planning and ordering.

3.2.2 Order Process Lead Time

Neither the requirements planning nor the ordering process are eliminated, only the double-work is. Therefore, unless the customer and vendor are not able to reduce the total process lead time, no improvements are achieved for the supply chain (Alicke, 2005, p.175). Consequently, administrative effort has to be reduced via automation.

The administrative process lead time is reduced by process automation.

3.2.3 Inventory Costs

Inventory costs can be decreased due to the elimination of double efforts too. The customer, for instance, does no longer need safety stocks (Schulte, 2013, p.506; Seeck, 2010, p.170).

Inventory costs are decreased by reducing inventory levels.

3.2.4 Process Costs

The vendor has the opportunity to cut costs particularly in the procurement process, because requirements can be pooled based on a real time customer demand. Furthermore, improvements in the handling and order picking process may be realized, if ad-hoc requests are eliminated and a continuous replenishment process is implemented. Finally, transport capacities can be optimally utilized and tours to the stores can be improved, too (Alicke, 2005, p.147f; Hellingrath et al., 2008, p.468ff; Beckmann and Schmitz, 2008, p.271f).

The vendor reduces process costs based on better planning information.

3.2.5 Saleability

Reducing stock-outs and improving the saleability are main goals of VMI and, consequently, key success factors (Zsifkovits, 2013, p.89).

The customer’s saleability is increased and stock-outs are decreased.

3.2.6 Bullwhip-Effect

Due to the variety of other factors which are affected by the Bullwhip-Effect, it is included as a distinct criterion. Companies should evaluate if they have managed to eliminate distortions in the planning process (Melzer-Ridinger, 2007, p.141f; Yao, Evers and Dresner, 2007, p.664). Hence, it can be concluded that first successes have been achieved through VMI.

Distortions in the planning process through demand fluctuations of end customers are eliminated.

3.3 Infrastructure

This category depicts the resources which are required in order to run the VMI collaboration efficiently. Beckmann and Schmitz (2008) highlighted the importance of ICT technology and sensors to make data available and exchange it between functional units. Furthermore, Hammer (2007) has incorporated the dimension Infrastructure in his model in order to reflect information and management systems that support the process. These considerations and Hammers' wording have been adopted and expanded by adding additional criteria. The information processes, the ICT system and the use of technology are described.

3.3.1 Information Collection

In order to realize better planning information, the right information has to be collected in the process. Firstly, the automated collection of sales data at the POS is one key criterion in order to gain a better understanding of the end customer and future demands (Hellingrath et al., 2008, p.468f; Alicke, 2005, p.174). Secondly, information about the inventory levels has to be collected in order to determine net requirements. In the FMCG sector it is necessary that both sales data and inventory data are collected to check the true consumption of operational units (Zsifkovits, 2013, p.89). Therefore, the inventory process is important to check whether the inventory levels depicted in the system correspond to the true inventory levels on stock (Lux, 2012, p.179).

Sales data are collected at the POS and saved automatically. Inventory levels are measured by defined inventory processes.

3.3.2 Information Update

The vendor is only able to realize benefits through an improved information basis if the (correct) data is current data. For this purpose, data has to be transferred frequently - e.g. on a daily basis or much better in real time - and error-free - as inconsistent data distort the vendor's planning processes and may require reworks - from the customer to the vendor (Alicke, 2005, p.174; Hellingrath et al., 2008, p.468f).

The customer transfers current and correct data (sales and inventory information) daily and error-free to the vendor.

3.3.3 System Integration

The automated information exchange is one key criterion of VMI. For this purpose, the customer and vendor have to be connected by an electronic interface. Furthermore, standards for exchanging and identifying information unequivocally have to be defined (Beckmann and Schmitz, 2008, p.273; Draenert, 2001, p.51).

The IT systems of the customer and vendor are connected electronically and the data is transferred in a standardized way in order to enable an automated information exchange.

3.3.4 ICT Support

It is necessary that processes are carried out automatically to reduce manual work. These processes include determining net requirements, generating orders and sending the required information to the customer. The automation of those processes is supported by software systems (Draenert, 2001, p.81f).

The vendor's inventory management system determines the customer's net requirements and generates sales orders automatically.

3.3.5 Identification Technology

Identification technology should be implemented to streamline the process of identifying information and process the data automatically. In the context of VMI, mainly Barcode and RFID have proven to be effective (Hellingrath et al, 2008, p.471).

Identification technology supports the collection and processing of data.

3.3.6 Technical Equipment

In practice, inventory processes to identify inventory levels require manual work and are time-consuming (Lux, 2012, p.179). Therefore, technical equipment has to be used to make this process efficient (Beckmann and Schmitz, 2008, p.272f). If barcode or RFID technology has been implemented, technical equipment (e.g. scanners) has to be used anyway. In order to improve the process reliability of the picking process – which directly affects the inventory process – pick-by concepts can be deployed (Gudehus, 2010, p.693). Furthermore, several types of sensors can be used in order to automatically determine inventory levels (Schulte, 2013, p.506; Beckmann and Schmitz, 2008, p.272f).

Technical equipment supports the identification process of current inventory levels.

3.4 Planning System

High-quality planning processes are important in VMI (Beckmann and Schmitz, 2008, p.272). Therefore, aspects assigned to the VMI planning system as constraints, forecasting and control mechanisms have been summarized within this category.

3.4.1 Inventory Range

Firstly, a minimum inventory range at the customer has to be determined to ensure the saleability of the customer. In order to determine the right minimum inventory range, sales and required consumption quantities are considered. Furthermore, the lead time for the transport process has to be taken into account.

Additionally, potential lot size restrictions influence the minimum inventory range and safety stocks are considered. Usually the lead time for the production process is important too, however for FMCG usually a continuous demand in the market enables the suppliers to run the production continuously. Secondly, a maximum inventory range has to be determined in order to take the storage capacity at the store of the customer and warehousing cost aspects into account (Hellingrath et al., 2008, p.469f; Werner, 2008, p.108).

The customer and vendor agree on a minimum and a maximum inventory range.

3.4.2 Order Policy

If the delivery date is variable, the reorder point method is applicable (Schulte, 2013, p.412f). In case of a continuous customer demand, it is recommended that the vendor determines the delivery cycle in order to reduce process costs (Werner, 2008, p.109f; Draenert, 2001, p.89 and 93). This approach is in line with the order cycle method (Schulte, 2013, p.412f).

As FMCG are mainly handled continuously, determining order cycles is attractive. However, depending on the number of stores or on the products involved, the reorder point method can also be effective. Therefore, both order policy approaches are covered and the reference to take the cost/benefit ratio into account is explicitly given.

The customer and vendor decide on the ideal order policy by taking the respective cost/benefit ratio into account.

3.4.3 Forecasting Method

Traditional manual replenishment methods do not fulfil the contemporary requirements in terms of cost efficiency and service levels. In order to check the customer's inventory level, generate the forecast, determine the order quantity and submit it to the customer automatically, automated replenishment systems are implemented in the FMCG sector. In this context the forecasting system plays a vital role to forecast sales quantities of an operational unit for any desired time period. For this purpose, statistical methods are applied which, nowadays, deliver paramount predictive accuracy. Furthermore, those methods consider delivery times, minimum inventory levels and seasonal factors in the calculation (Draenert, 2001, p.48). Not least, Beckmann and Schmitz (2008) also highlighted the importance of forecasting.

Future requirements are determined objectively by means of a statistical forecasting method.

3.4.4 Planning Accuracy

FMCG companies usually run several stores in conurbations. Consequently, a variety of different factors individually influences the VMI collaboration and different persons manage different stores. This leads to a stronger heterogeneity in the system and increases complexity (Strunz and Dorsch, 2009, p.297). For example, if employees do not fully comply with standard processes, the process output may vary from store to store. Furthermore, the headquarters usually conduct promotions by means of voucher campaigns, which affect parts of the product range. Those voucher campaigns usually boost the sales of the advertised products (Jahn, 2003, p.147). Consequently, the sales vary considerably across the market since the consumers will react differently to a centrally organized campaign. The planning system has to deal with this complexity and take those customer (store) individual factors into account (Hellingrath et al., 2008, p.470f; Werner, 2008, p.109f).

The planning process considers defined customer individual influence factors as well as sales policy measures (promotions) across the market.

3.4.5 KPIs

It is difficult, but important to track the VMI performance (Zsifkovits, 2013, p.89; Gudehus 2010, p.976). For example, the delivery quality is applicable as a quantitative KPI by tracking the amount of additional deliveries due to impending stock outs (Beckmann and Schmitz, 2008, p.273). In terms of qualitative KPIs we propose to monitor the customer satisfaction as an integral part of the VMI collaboration (Wannenwetsch, 2004, p.217). As VMI is about collaboration in order to generate mutual benefits, the customer’s as well as the vendor’s cost/benefit ratio has to be critically and continuously assessed and deviations should cause tangible measures (Beckmann and Schmitz, 2008, p.272).

KPIs measure quantitatively and qualitatively if agreed VMI goals are achieved. Deviations in terms of the aimed win-win situation between the customer and vendor are analyzed and lead to tangible measures.

3.4.6 Plausibility Check

The Plausibility Check is explicitly incorporated into the model due to the enormous importance of the stakeholders' acceptance towards VMI. This insight was achieved during the expert interviews. Therefore, the plausibility of the quantity of each order position has to be checked automatically.

The plausibility of the planned replenishment requirements is checked automatically.

4 Procedure and Maturity Model

In order to create the VMI Maturity Model, the four categories are combined with the Procedure Model (see figure 1). The model is embedded into the Assessment Scheme in order to identify potential areas of improvement within the four generic categories and the fifth company-specific one, which is described by the Procedure Model. The four generic categories have been described above, therefore, before presenting the final results the integrated Procedure Model is described in the following.

4.1 Procedure Model

The aim of the integrated Procedure Model is to provide an approach to identify operational company-specific VMI factors. For this purpose, guided interviews with employees who have particular and specific know-how are recommended (Gläser and Laudel, 2006, p.36-41 and 140). Three steps are required to be carried out:

1. Preparation of the expert interviews
2. Implementation of the expert interviews
3. Analysis of the expert interviews

4.1.1 Preparation

Before the interview is conducted, the number of interviews and the right interviewees have to be defined. It is recommended to conduct several interviews, because firstly many people possess the required knowledge and secondly sources of error exist, which might lead to a loss of information. Furthermore, in terms of triangulation it is important to gather information from several points of view (Stake, 2010, p.123f). This model has been applied in practice by interviewing eleven managers. Six persons were operatively and two strategically engaged at the customer. In the case of the operational managers, care was taken that the persons manage stores with different requirements in terms of customer structure. Furthermore, three strategically involved persons of the vendor have been interviewed, whereby one has already maintained a VMI project in a different market and, therefore, was able to give insights in the learnings of a similar project.

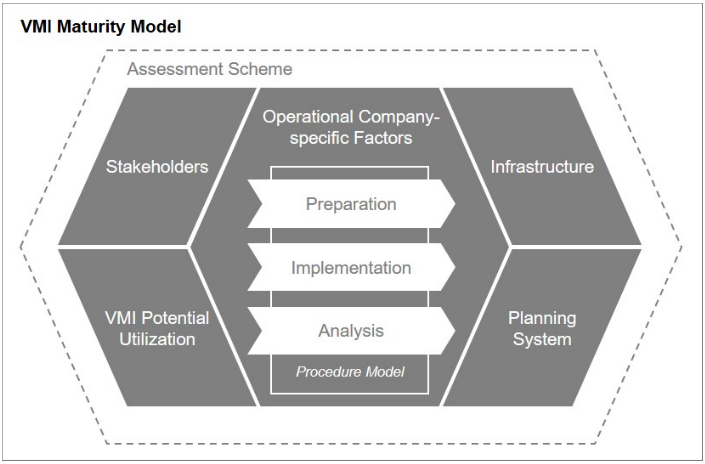

Figure 1: VMI Maturity Model for the FMCG Sector

As guideline interviews are the appropriate interview form for expert interviews, 8 to 15 questions including an introduction have to be prepared in advance. Binding rules do not exist for the development of an interview guide, however, the formulated questions should be open, neutral, simple and clear (Hopf, 1973, p99ff; Gläser and Laudel, 2006, p.36-41, 140 and 111; Patton, 1990, p.295). As in the model's test, we recommend to check the guiding questions with the stakeholders and apply the company-specific wording.

Before the interview is conducted the initial contact with the interviewees has to be established. We ensured that the management level explains the background of the expert interviews to the respective experts.

4.1.2 Implementation

At the beginning, we recommend to obtain the approval for recording the interview after the greeting. Then give the introduction about your background and explain the research goal as well as the contribution of the interview in achieving that goal to create a pleasant atmosphere. Further explain the anonymization process to protect the interviewee's privacy and make the interviewee aware of information which might had been gathered in advance. Finally, inform the interviewee that any questions may be skipped and the whole interview may be aborted anytime (Gläser and Laudel, 2006, p.153-161). After that start asking the questions prepared and be open to unforeseen topics as well.

After the interview the parts which are related to the research subject have to be transcribed (Meuser and Nagel, 2005, p.83). The texts created represent the raw data and are then further analyzed.

4.1.3 Analysis

The analysis of expert interviews follows the approach of the qualitative data analysis and aims at identifying the aspects the statements of the experts have in common (Meuser and Nagel, 2005, p.80-83). For this purpose, several different methods exist in theory. However, a standardized approach does not exist (Saunders, Lewis and Thornhill, 2012, p.556). In practice, hybrid forms between free interpretation and strict methods are commonly applied (Mayring, 2010, p.602; Gläser and Laudel, 2006, p.41f). We recommend to identify the characteristics in the raw data by using a category system, following a basic approach in qualitative analysis according to Mayring called "Structuring" (Diekmann, 2004; Gläser and Laudel, 2006).

In the first step, summarize the raw data in tabular form regarding the questions of the interview guide to present them clearly. In the second step, assign codes to the text passages and, thereby, structure the raw data. We recommend to derive the codes during the analysis. Assign a code to the first similarities identified in the content and create a category. The next text passage which is related to this code, is then assigned to this category as well. Whenever new definable text passages are identified, a new category is created.

4.2 Results and Outcome of the Application

The model has been applied in practice. In the following an example of a VMI Maturity Level evaluation is shown (see table 2).

After scoring the target states behind the criteria by applying the assessment scheme, the Maturity Level of each category is calculated in percent. Thereby, the assessing companies are able to define certain areas for improvements via radar chart (see figure 2). The continuous line shows the maximum value of 100% and the dashed line shows the current state.

According to this example, the assessing company will at first have to go deeper into the categories Infrastructure and VMI Potential Utilization. Within the category Infrastructure, especially the reasons for the low rating of System Integration and Technical Equipment have to be analyzed in a second step. In dependence of the results, it is above all necessary to take further measures in order to be able to implement VMI successfully. If, for instance, the topic of System Integration was left unsolved, this could lead to considerable efficiency losses in case of VMI application. Following this method, all potentials regarding VMI can be analyzed successively.

Table 2: Example of a VMI Maturity Level Rating

Category	Criteria	Score	Maturity Level [%]
Stakeholders	Inventory Responsibility	10	
	Know-how	8	
	Awareness and Commitment	6	
	Behavior	10	
	Contractual Agreements (SLAs)	8	
	Communication	6	
	Σ	48	80
VMI Potential Utilization	Order Time	10	
	Order Process Lead Time	4	
	Inventory Costs	2	
	Process Costs	10	
	Saleability	4	
	Bullwhip-Effect	2	
	Σ	32	53
Infrastructure	Information Collection	6	
	Information Update	4	
	System Integration	2	
	ICT Support	6	
	Identification Technology	4	
	Technical Equipment	2	
	Σ	24	40
Planning System	Inventory Range	9	
	Order Policy	3	
	Forecasting Method	6	
	Planning Accuracy	9	
	KPIs	3	
	Plausibility Check	6	
	Σ	36	60

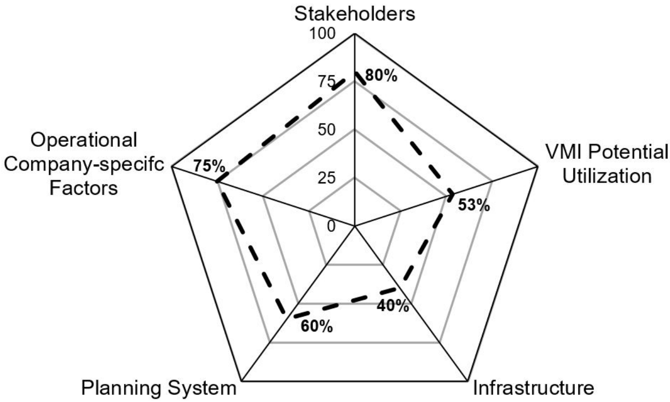

Figure 2: VMI Maturity Level - Areas of Improvements

5 Concluding Remarks

The VMI Maturity Model was applied to a company in the FMCG sector and supported the company in identifying weaknesses regarding VMI. Thereby, the company was able to solve the main problems, before finally daring to a test run. As a result, the functionality and applicability of the model could be reviewed and confirmed. Furthermore, the application of the model strengthened the point of view of Werner (2013), that social aspects should be considered in terms of VMI. Concluding, we recommend the VMI Maturity Model in three different states of a VMI implementation. During a VMI Feasibility Study, the model can be used as a checklist in order to make sure that relevant aspects are covered. If ”Digitized VMI” is implemented, companies are able to check to which extent the potentials are exploited by comparing actual values and target figures within the Monitoring Process. The monitoring process will become more and more real time with fully information out of the supply chain. This leads to improved data and as a consequence to better VMI processes in the supply chain. The benefits could only be realized with new and digital technologies.

However, the main benefit is in the Implementation Decision Process itself: Companies become able to check which aspects are covered by the desired VMI business case to which extent by comparing plan and target figures and, thus, defining concrete actions to optimize their intentions.

References

Alicke, K. (2005). *Planung und Betrieb von Logistiknetzwerken*. Berlin: Springer.

Arndt, H. (2010). *Supply Chain Management, Optimierung logistischer Prozesse*. Wiesbaden: Gabler.

Beckmann, H. and M. Schmitz (2008). "Logistikprozesse in Industrie und Handel". In: *Handbuch Logistik*. Ed. by D. Arnold, H. Isermann, A. Kuhn, H. Tempelmeier, and K. Furmans. Berlin: Springer.

Darwish, M.-A. and O.-M. Odah (2010). "Vendor managed inventory model for single-vendor multi-retailer supply chains". In: *In: European Journal of Operational Research* 204.3, pp. 473–484.

Diekmann, A. (2004). *Empirische Sozialforschung, Grundlagen, Methoden, Anwendungen*. Hamburg: Rowohlt.

Draenert, P. (2001). *Kooperative Absatzplanung*. Einführungsstrategie für den Prognoseaustausch. Wiesbaden: Springer.

Economic, U. N. D. of and S. A. P. Division (2014). *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER/352)*.

Ecr-austria.at (2016). "Workgroup results 2015".

Feld, T., M. Hoffmann, and R. Schmidt (2012). "Industrie 4.0 – Vom intelligenten Produkt zur intelligenten Produktion". In: *IM Information Management und Consulting* 03, pp. 38–42.

Gläser, J. and G. Laudel (2006). *Experteninterviews und qualitative Inhaltsanalyse*. Wiesbaden: Verlag für Sozialwissenschaften.

Gudehus, T. (2010). *Logistik 1, Grundlagen, Verfahren und Strategien*. Berlin: Springer.

Hammer, M. (2007). "The Process Audit". In: *A new framework, as comprehensive as it is easy to apply, is helping companies plan and execute process-based transfor-mations. In: Harvard Business Review* 85.4, pp. 111–123.

Hellingrath, B., T. Hegmanns, J.-C. Maaß, and M. Toth (2008). "Logistikprozesse in Industrie und Handel". In: *Handbuch Logistik*. Ed. by D. Arnold, A. Isermann H.and Kuhn, H. Tempelmeier, and K. Furmans. Berlin: Springer.

Hopf, C. (1978). "Die Pseudo-Exploration – Überlegungen zur Technik qualitativer Interviews in der Sozialforschung/Pseudo-exploration – Thoughts on the techniques of qualitative interviews in social research". In: *Zeitschrift für Soziologie* 7.2, pp. 97–115.

Jahn, M. (2003). "Status des Couponing in Österreich". In: *Handbuch Couponing*. Ed. by W. Hartmann, R.-T. Kreutzer, and H. Kuhfuß. W., Kreutzer, R.-T., Kuhfuß, H., 2003. . Wiesbaden: Gabler.

Liebhart, U., G. Mödritscher, and T. Blecker (2007). "Supply Chain Management als Herausforderung für die Organisations- und Personalentwicklung". In: *Nachhaltiges Change Management: Interdisziplinäre Fallbeispiele und Perspektiven.* Ed. by F. Keuper and H. Groten. Wiesbaden: Gabler.

Lux, W. (2012). *Innovationen im Handel. Verpassen wir die Megatrends der Zukunft?* Heidelberg: Springer.

Mayring, P. (2010). “Qualitative Inhaltsanalyse”. In: *Handbuch Qualitative Forschung in der Psychologie*. Ed. by G. Mey and K. Mruck. Wiesbaden: Verlag für Sozialwissenschaften.
Melzer-Ridinger, R. (2007). *Supply Chain Management. Prozess- und unternehmensübergreifendes Management von Qualität, Kosten und Liefertreue*. Wiesbaden: Oldenbourg.
Meuser, M. and U. Nagel (2005). “Experteninterviews – vielfach erprobt, wenig bedacht. Ein Beitrag zur qualitativen Methodendiskussion”. In: *Das Experteninterview. Theorie, Methode, Anwendung*. Ed. by A. Bogner, B. Littig, and W. Menz. Wiesbaden: Verlag für Sozialwissenschaften.
Neumann, M. (2012). *Projekt Safari*. Frankfurt: Campus.
Patton, M.-q. (1990). *Qualitative Evaluation and Research Methods*. Newbury Park: Sage.
Pfetzing, K. and A. Rohde (2009). *Ganzheitliches Projektmanagement*. Gießen: Dr. Götz Schmidt.
Rajiv, S. (2009). “Vendor managed inventory”. In: *Industrial engineer* 41.7, pp. 20–21.
Saunders, M., P. Lewis, and A. Thornhill (2012). *Research Methods for Business Students*. Edinburgh: Pearson.
Schulte, C. (2013). *Logistik, Wege zur Optimierung der Supply Chain*. München: Vahlen.
Seeck, S. (2010). *Erfolgsfaktor Logistik. Klassische Fehler erkennen und vermeiden*. Wiesbaden: Gabler.
Stake, R.-e. (2010). *Qualitative Research. Studying how things work*. New York: Guilford.
Statista (n.d.). “Anteil der in Städten lebenden Bevölkerung in Deutschland und weltweit von 1950 bis 2030”. [Accessed 04 July 2017].
Strunz, H. and M. Dorsch (2009). *Management im internationalen Kontext*. München: Oldenbourg.
Vogel-Heuser, B. (2014). “Herausforderungen und Anforderungen aus Sicht der IT und der Automatisierungstechnik”. In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by Wiesbaden. Bauernhansl, T. and ten Hompel, M.: Springer.
Wannenwetsch, H. and S. Nicolai (2004). *E-Supply-Chain-Management. Grundlagen – Strategien – Praxisanwendungen*. Wiesbaden: Gabler.
Werner, H. (2008). *Supply Chain Management. Grundlagen, Strategien, Instrumente und Controlling*. Wiesbaden: Springer Gabler.
Werner, H. (2013). *Supply Chain Management, Grundlagen, Strategien, Instrumente und Controlling*. Wiesbaden: Springer Gabler.
Wildner, S. (2011). “Problemorientiertes Wissensmanagement. Eine Neukonzeption des Wissensmanagements aus konstruktivistischer Sicht”. In: *Wirtschaftsinformatik*. Ed. by D. Seibt, H.-G. Kemper, G. Herzwurm, D. Stelzer, and D. Schoder. Köln: EUL.
Yao, Y., P.-T. Evers, and M.-E. Dresner (2007). “Supply chain integration in vendor-managed inventory”. In: *Decision support systems* 43.2, pp. 663–674.
Zsifkovits, H.-E. (2013). *Logistik*. München: UVK.

Production Flow valuation through VSM modeling: An industry case study

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A special combination of lean methodologies and modeling of industrial processes has been increasingly used in the last decade between University and Industry. With lower costs, knowledge in lean tools and innovation in simulation packages, manufacturing has improved its practices in the flow of their processes detecting aggregate value. The research team describes a case in which a glove manufacturing production line and its Value Stream Mapping are simulated at the same time. The purpose of this work is to identify potential benefits such as reducing waste, improving lead time, resource optimization, reduced WIP and increasing throughput by simulation, applied to a real case industry. The modeling of the process and its VSM as a visual tool, highlight waste and hidden sources of the same through the variables and their behavior in the development of the simulation. Via a first simulation, the current process status is diagnosed. Then, using LEAN-manufacturing tools, a proposed VSM model is designed, which, through indicators and plots, shows the elimination of the causes of waste and improvements of this process.

Keywords: Lean; Lean logistics; CONWIP; Little law

1 Introduction

During this time, specifically in the industrial sector, there has been an interest in greater efficiency in all processes, such as operative, logistic, or administrative processes, focused on adopting the best practices in order for the proposed option to be feasible. To achieve the main goal, which is to obtain high efficiency in processes, the organizations have adopted methodologies that allow for the visualization and control of all the necessary steps or processes in order to carry out certain tasks, and among these is the LEAN methodology. It allows us to reduce or eliminate waste or activities that do not generate value for the organizations (Abdul Malek and Rajgopal, 2007).

The LEAN methodology is being adopted by organizations, on a global scale, in order to enable them to increase their competitiveness in a national or global market. The promoter for this methodology was TOYOTA, and was championed by different associates within the administration and handling of the quality department in the organization, such as Toyoda, Taiichi Ohno, and Juran. As the first tool, it began with TQM initiated by Deming which has promoted from its beginnings waste disposal and activities that do not generate value in the processes of the company. During this time other tools appeared, such as the TPM, VSM, SMED, and JIT(Muhammad al-Ashraf, 2012), (Jones, Hines and Rich, 2001), (Wu, 2002).

In the event simulation area, they have raised analytical, but not graphical simulations, focusing on algorithms and visualizations of its processes and how they are being carried out, a simulation definition can be the approach to a real event by means of visual methods, combining it with statistical and mathematical tools. By using hardware, such as the PROMODEL, it can offer us a more detailed approach of the reality and therefore promote action plans to improve the identified activities that do not generate value (Harrel Gosh, 2000).

This work has the goal of using PROMODEL, in order to carry out a latex glove production process simulation case study, applying LEAN through value stream mapping tool. The purpose of combining the previously mentioned software was to analyze all the productive stages from raw material requisition until product delivery to the final client.

2 Methodology

2.1 Data Collection

In order to improve the process and cause significant impact on the financial indicators, the research group identified the product to evaluate, through a Pareto assessment. From the annual income, 18% corresponds to the "C25 bicolor Industrial Glove", a high turnover product. Keeping the selected product in line, the process was assessed in close observation for three weeks, in order to identify the practices and identify potential waste. In this same period, transportation, flow and delay data was collected. Additionally, procedures, formats and standard working methods were reviewed. Statistics associated with process were compiled in the production planning and control stages, with a record of 4 months between their respective analyses.

2.2 The VSM Tool

In order to use the LEAN methodology, 5 principles must be taken into consideration, which were proposed by Womack (2003) in order to apply the philosophy, which are:

1. To define value in the eyes of the consumer
2. To identify the flow or the chain of value
3. To generate a continuous and smooth flow from the provider to the consumer
4. To allow the client to pull the product (PULL)
5. Continuous improvement in order to achieve perfection.

These 5 principles describe a short definition of the VSM mapping, but the essence of the VSM is about eliminating all the waste and non-value operations that influence the costs of the organization (Lasa, Laburu and Vila, 2008). This can help us to identify and solve the different problems of the supply chain, or another process being analyzed (Hines and Rich, 1997).

These 5 principles shortly describe VSM, but its essence lies in eliminating waste and non-value operations which affect the costs of the organization ((Lasa, Laburu and Vila, 2008). This can help us identify and solve different problems within the supply chain or other analyzed processes ((Hines and Rich, 1997).

3 Case Study: The Process

3.1 Company and Progress Background

The company being analyzed is part of the Confederacion Cauchera Colombiana (CCC for its Spanish acronym), which has been recognized by the Colombian Ministry of Agriculture and Rural Development as the national organization for the rubber and latex manufacturers since 2002. In 2015, with about 58 thousand hectares planted with natural rubber, only 20% corresponds to productive sections, which means about 5 thousand tons per year, with 25 thousand tons being consumed by the productive sector of the country; the other 20 thousand tons are imported from Brazil and Guatemala (CCC, 2016). Although crop growth has increased exponentially at a rate of 10% per year, production has fallen by 19% per year, due to price problems on an international level (MINAGRICULTURA, 2016).

The industry, and in general all its subsections exhibited a total growth of 2 %, as presented by the ANDI at the end of 2016. During 2016 the sector has had to face different problems such as the supply of raw material, infrastructure and logistics cost, contraband and tributary expenses.

The increase of these problems has affected the logistic competitiveness of the sector, and has caused an uncertainty regarding what could happen to the market. In order to change alternatives, there is a tool that allows us to visualize and identify each of the links that compose the supply chain and how they individually influence the identified problems or the chain in general.

Given the shortage of domestic raw materials, the complexity of importing materials and low price products from China, management has chosen lower costs associated with glove manufacturing in Colombia.

With 7 productions systems, the industry in evaluation obtained a turnover in 2015 of close to US $ 1.2 million. According to management, it was decided to study the system 1 given that it employs the latest equipment and with better speeds. To select the product to be evaluated, a Pareto was constructed on 15 product references that were currently processed. Within the gloves there are different calibers, colors and destinations of use. The Caliber 25 two-color industrial glove was the first product of the type A family, representing 17.8% of the income with US $ 186,000 per year. Of this product 5 sizes are produced: Size 7 with a 5% participation, size 8 with 24%, Size 8.5 with 5%, size 9 with a 52% participation and size 10 with a 14% participation. According to these percentages in the monthly production, proportional inventories of the molds are maintained.

Management found the LEAN philosophy to be the strategy to generate greater added value to its consumers with a rational use of resources, improving planning and control of the operation in coherence with prices and market demand. This research, through process simulation and VSM, will allow management to compare productivity of the current system and a system under LEAN parameters (Calva, 2014).

One of the tools that enable us to realize what we propose is the VSM, or Value Stream Mapping, this tool allows us to graphically visualize all the links that compose the supply chain and allows us to identify the individual bankruptcies (Lovelle, 2001).

Due to the help that this tool can offer, it is possible to apply to the industries of the sector and this way to diminish the suspense of the market and to match its needs more appropriately or to improve the processes that are carried out to obtain a few minimal logistic and financial cost savings.

3.2 Process Flow

In order to achieve the VSM, one emphasized the production of latex gloves, for which the production process fulfills the following steps:

The process begins with an operator preparing the mixture, this process takes about 8 minutes, once the mixture is finished, an operator from the immerse area, pours the mixture in the molds and another operator places the molds in the immerse machine. This process has 3 stages with a total duration time of 21 minutes, including adjustment after immersion, then the gloves are bordered by one operator in 18,7 minutes including the disposal of the gloves in a bin. This bin is the work in process of the process and then it passes to a conveyer belt in order to vulcanize the gloves in a FIFO line. Once this process has finished, the gloves move on to the de-mold process before being processed in extraction and chlorination operations. Finally, after they have been chlorinated in the bins, they are dried in a machine.

Process Flow Diagram				
Location	Plant of Gloves		**Summary**	
Activity	Manufacturing Glove Black-Green C25		**Activity**	**Actual**
date	18/08/2016		**Operation**	118,5
Operator		**Analyst:** A.C.	**Transport**	37,2
Method	Actual X Propose		**Delay**	22,4
Type	Operator Material X Machine		**inspection**	-
Comments:			**Storage**	-
Batch = 48 Gloves Black-Green C25= 224 min. / 4,7 min per Glove			**Time (min.)**	178,1
			Distance(mts)	32,2

Activity	Symbol	Times (minutes)	Distance (m)
1. Immerse in immersion system; tank black latex		6,5	
2. Lift molds and rotate system to the right		0,5	1,5
3. Immerse in immersion system; coagulant tank		7	
4. Lift molds and rotate system to the right		0,5	1,5
5. Immerse in immersion system; tank green latex		6,5	
6. Lift molds, remove covered molds		12,4	
7. Carrying molds to the conveyor belt		8,5	2,7
8. Take uncovered molds and take to the immersion system		6,8	2,7
9. Install bare molds in system		16,2	
10. Transport of molds covered towards the furnace through conveyor belt		15,4	12,0
11. Bordered gloves		18,7	
12. Vulcanizate the gloves in the molds		25	
13. Unmold gloves and turn		8,6	
14. Put gloves on bins		3,4	
15. Transport to the Extraction area		1,6	4,7
16. Gloves on bins, wait for extraction		22,4	
17. Extraction		5,6	
18. Transport to the area of chlorination		1,1	1,4
19. Chlorination		3,8	
20. Transport to the Drying area		1,5	4,1
21. Drying		8,2	
22. Transportation to the Cooling Area		1,3	1,6

Figure 1: Process flow diagramn

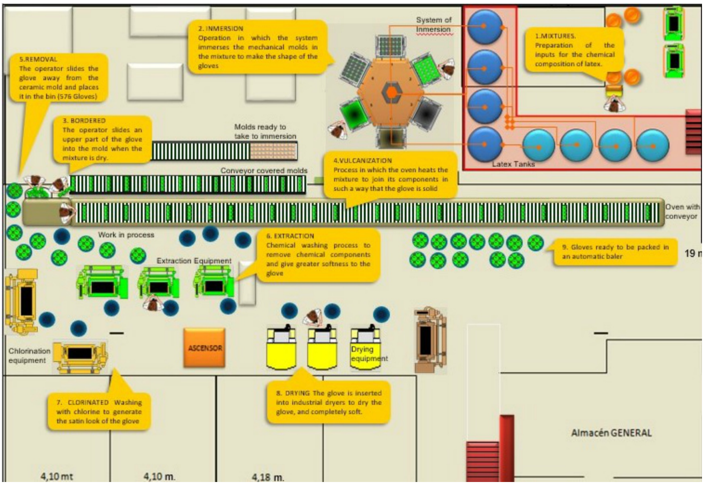

Figure 2: Layout and process

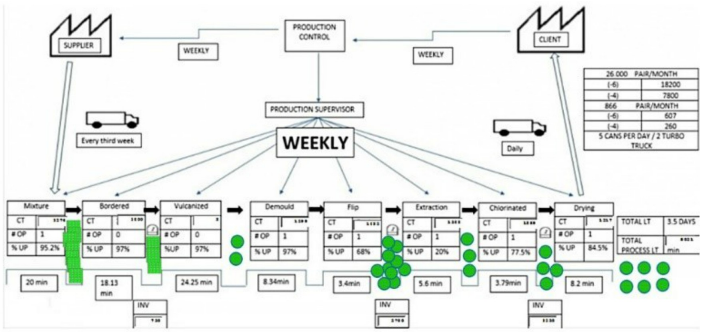

Figure 3: Actual VSM

3.3 The Actual VSM

Thanks to the data retrieved from the times and movements study, a simple flow of production line 1 has been made, which refers to the C-25 latex gloves, with the starting point being the reception of the raw material that is suggested for the product.

4 Simulation

Over time, simulation has become a helpful tool in order to study the different problems related with constraints and tails theory, helping us analyze problems in real-time series, by assuring the identification of possible problems, for them to be submitted.

The simulation is interpreted as the imitation of a moving object, ie a system. From its continuous research, multiple authors personify its definition according to its application in different fields:

— Representation of a system operated by a simulator, subject to manipulations, that if used in the real system, would be expensive or impractical, in order to know its operating properties (Shubik, 1960).

— Numerical or graphical description of the time trajectory of the variables involved in the development of the system using a digital or analog computer (Kalman, 1960).

— Tool that manages experiments in a PC, which requires logical and mathematical models that describe the behavior of a system in assumptions of real time (Naylor, 1969).

— The objective of generating a simulation is to understand its behavior, so that possible strategies can be evaluated to achieve its control and operation (Shannon, 1988).

It is possible to conclude that the simulation is an instrument that, through a PC, approximates to imitate the dynamics of a real model interpreted with logic, mathematics and complexity, having as object the knowledge of its reaction to deliberate events to improve the quality of the decision.

4.1 Buliding The Model

As mentioned in the introduction, the simulation of the production process of the ”Industrial C25 industrial glove” was scheduled for an 8-hour work shift, starting at 6 a.m. and ending at 2 pm.

This model was simulated in the Pro-Model Software version 8.6. The construction was undoubtedly complex, since in the immersion operation, the system worked in parallel with 6 latex tanks and 6 hydraulic arms that immersed the molds (24 Units) in the mixtures, respecting the sequencing of the sub-process.

To design the simulation model, the following constructors were used:

4.1.1 Layout

In this model, the floor plan was designed on a scale of 1: 100.

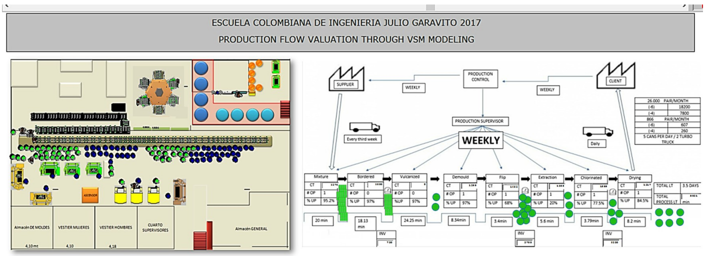

Figure 4: Layout Simulation

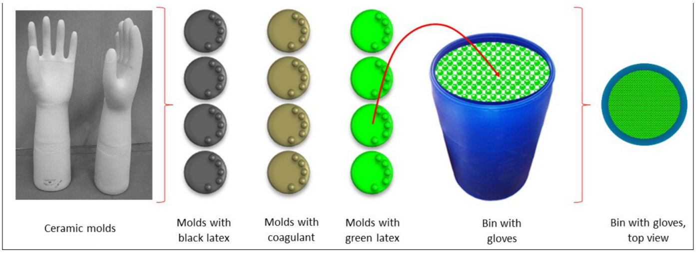

Figure 5: Model Entities

4.1.2 Locations

Those spaces in which there is a transformation or where the product is stored during the process (Entities) . This information, with its respective times, transports and delays was standardized in a flow diagram.

4.1.3 Entities

These are the elements that move within the model. The simulation used different representations to describe the work in process, all these are in top view:

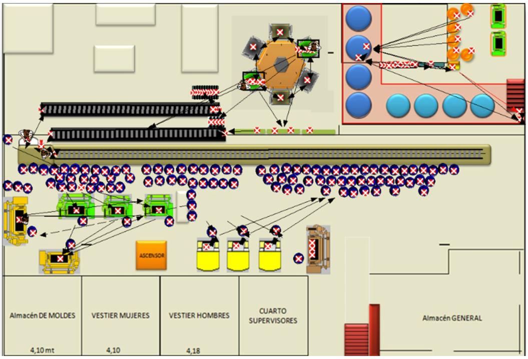

Figure 6: Process Configuration

4.1.4 Processing

This part of the simulation defines the routing of entities through the system and the operations that take place at each location they enter. Each operator has its process above its path network.

4.1.5 Arrivals

An arrival record is defined by specifying the following information: Number of entities, Frequency, time of the first arrival and total occurrences of the arrival. 3 arrivals were worked on for this model; the first arrival of material corresponds to the preparation of the mixture, in which the operator weighs and prepares the mixture in the tanks feeding the immersion system. Considering the proportion of latex consuming the molds in the system, the second material inlet, which is recorded in the immersion system, according to the way the immersion times were set up. Finally, a third material entrance is evident in the de-mold of the glove, next to the vulcanizing furnace, since the de-molded gloves are placed in blue bins, around 576 gloves.

Processing

		Process			Routing	
Entity	Location	Operation	Blk	Output	Destination	Rule
Bombeo	Bascula		1	Bombeo	Mangeras	FIRST 1
Bombeo	Mangeras	wait 0.5	1	Bombeo	Llaves_de_apertura	FIRST 1
Bombeo	Llaves_de_apertura		1	Bombeo	EXIT	FIRST 1
MPGN_0034	Materiales		1	MPGN_0034	Bascula	FIRST 1
MPGN_0034	Bascula	wait 0.4	1	MPGN_0034	Tanque_14	FIRST 1
Bombeo_2	Bascula		1	Bombeo_2	Llaves_de_apertura	FIRST 1
Bombeo_2	Llaves_de_apertura	wait 2	1	Bombeo_2	Agitadores	FIRST 1
Bombeo_2	Agitadores	wait 0.4	1	Bombeo_2	Tanque_14	FIRST 1
Bombeo_3	Bascula		1	Bombeo_3	Llaves_de_apertura	FIRST 1
Bombeo_3	Llaves_de_apertura	wait 1	1	Bombeo_3	Mangeras	FIRST 1
Bombeo_3	Mangeras		1	Bombeo_3	EXIT	FIRST 1
Bombeo_4	Bascula		1	Bombeo_4	Agitadores	FIRST 1
Bombeo_4	Agitadores	wait 0.6	1	Bombeo_4	Tanque_14	FIRST 1
MPGS_0010	Materiales		1	MPGS_0010	Bascula	FIRST 1
MPGS_0010	Bascula	wait 0.4	1	MPGS_0010	Tanque_14	FIRST 1
MPGS_0012	Materiales		1	MPGS_0012	Bascula	FIRST 1
MPGS_0012	Bascula	wait 0.4	1	MPGS_0012	Tanque_14	FIRST 1
Plastificante	Materiales		1	Plastificante	Preparacion_	FIRST 1
Plastificante	Preparacion_	wait 1	1	Plastificante	Tanque_14	FIRST 1
MPGS_0001	Dispersion_1	wait 0.3	1	MPGS_0001	Tanque_14	FIRST 1
MPGS_0002	Dispersion_2	wait 0.3	1	MPGS_0002	Tanque_14	FIRST 1
MPGS_0004	Disp_3	wait 0.5	1	MPGS_0004	Tanque_14	FIRST 1
MPGS_0005	Disp_4	wait 0.3	1	MPGS_0005	Tanque_14	FIRST 1
MPGS_0003	Materiales		1	MPGS_0003	Bascula	FIRST 1
MPGS_0003	Bascula	wait 0.3	1	MPGS_0003	Tanque_14	FIRST 1
MPGS_0003	Materiales		1	MPGS_0003	Bascula	FIRST 1
MPGS_0003	Bascula	wait 0.2	1	MPGS_0003	Tanque_14	FIRST 1
MPGS_0133	Materiales		1	MPGS_0133	Bascula	FIRST 1

Figure 7: Process Algorithm

5 Acknowledgements for the Future Mapping

To transform the current process into a LEAN-type flow by eliminating or reducing waste, the research group met with management to explore the feasibility of a change in purpose of outlining the future map. Regarding the current map, with the help of the simulation, the following improvement points were found:

— A critical bottleneck is evidenced in the Extraction operation (Attended around 3 cups per hour, however, the cups arrive at a rate of 8 per hour)

— There is permanent inventory between operations with a very high WIP (7158 units/day)

— No transport or systemic manipulation.

— The supply of the material is not balanced with the demand.

After this meeting with the managers, it was possible to work with those directly involved, in order to sketch a future map considering the characteristics of a lean chain, such as:

— Produce according to the rhythm of demand (Takt time)

— The construction of a continuous flow.

- Identification of the block within the process
- Perform a balance of loads on the line

6 Lean Thinking

6.1 Takt time

By understanding the Takt time as the rate at which customers consume the product, and considering the information and calculations performed to assemble the current VSM (Hines and Rich, 1997), it is possible to plot the Takt time cycle graph. This graph shows the individual cycles of the operations versus the Takt time of the total system. There is an established demand of 0.36 hours/48 gloves. This operation can be considered a bottleneck, however the company programs more resources without having the immediate need to do so. A balancing and reprogramming line of the work shifts of both the operators and teams is evident. The speed at which all resources are working is less than the Takt speed, which indicates that the efficiencies gained in the process are being lost in the finished product inventory. When the demand does not pull, the company lowers prices to lower the inventory level, but the saved cost is wasted.

6.2 Little Law

Thanks to the VSM, since the first option already proceeds to analyze the yield of the finished chain or of the process that was analyzed previously.

This yield is given by John Little's law, basing on the tails theory since our main problem identified in the VSM is related to the work in process (WIP), cycle time (CT) and throughput (TH)(Hopp and Spearman, 1996), the relation of the 3 variables allow us to identify the problems in the system, as follows:

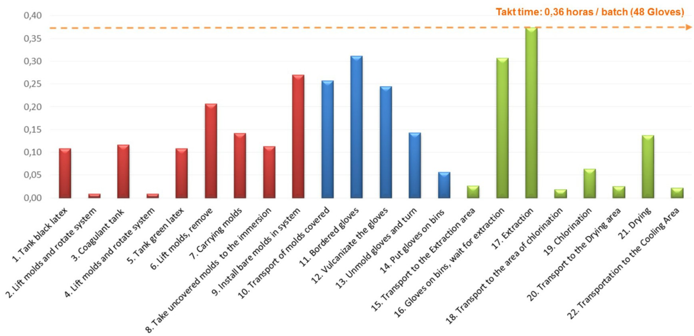

Figure 8: Balance workloads

6.2.1 Cycle Time (CT)

Proceeds according to the time that takes every operation in extracting the batch defined previously:

$$\begin{aligned} CT_{total} = {} & CT_{OP1} + CT_{OP2} + CT_{OP3} + CT_{OP4} \\ & + CT_{OP5} + CT_{OP6} + CT_{OP7} + CT_{OP8} \end{aligned} \tag{1}$$

$$CT_{TOTAL} = 120,9\,minutes \tag{2}$$

6.2.2 Work in Process (WIP)

Proceeds as follows, bearing in mind the inventories that were appearing between processes

$$\begin{aligned} WIP_{total} = {} & WIP_{OP1-OP2} + WIP_{OP2-OP3} + WIP_{OP3-OP4} \\ & + WIP_{OP4-OP5} + WIP_{OP5-OP6} + WIP_{OP6-OP7} + WIP_{OP7-OP8} \end{aligned} \tag{3}$$

$$WIP_{TOTAL} = 7158\,units \tag{4}$$

6.2.3 Throughput

Having calculated our CT and entire WIP, with the following relation we can look at the following yields (Jirsák and Holman, 2012):

Yield of the process

This yield is given by the relation of the cycle time found in the whole process and the WIP of the same:

$$TH = \frac{WIP}{CT} = 98,08\,\frac{units}{minute} \tag{5}$$

Yield of the chain

To find the yield of the finished chain, the Cycle Time was calculated from the arrival of raw material up to delivery to the different clients, taking as the same for all, likewise our WIP is the same that of the previous process:

$$TH_{CHAIN} = \frac{WIP_{PROCESS}}{CT_{CHAIN}} = 2,35\,\frac{units}{minute} \tag{6}$$

In conclusion, according to the calculations, it was found that the value given by the TH is relatively high regarding the cost for the processed inventory.

In order to diminish this value and for the cost yield to be ideal, it is proven that the option to locally apply the LEAN tool, 5S Kaizen. To improve the yield, it might implement a line swinging, bearing in mind the whole finished chain and so, to unify the whole process from the requisition of raw material up to the delivery of the product to the final client (Blank, 2013).

operation	immersion	bordered	vulcanized	demould	flip	extract	chlorinated	drying		
machine time	21	18,7	25	8,6	5	28	4,9	9,7	120,9	minutes
takt time	0,006045	minutes/pair								

Figure 9: Calculation of Takt Time

6.3 CONWIP

As the second measurement, WIP is found that allows us to minimize the incurred costs (Blanco, Motta, 2006), for it we proceed to find our inventory in the process allowed by the line, as follows:

Calculating the takt time, allow us to identify the frequency and the rhythm of the process, therefore, it proceeds to be compared with the time that it takes each operations to produce the batch defined in the VSM, this allows us to identify the specific bottleneck of the process:

$$takt\, time = \frac{time\, avalaible\, per\, operation}{demand\, of\, de\, chain} \tag{7}$$

$$takt\, time = 0.006045\, \frac{minutes}{pair} \tag{8}$$

Having identified the bottleneck, its valuation proceeds with the following equation:

$$r_b = 1,71\, \frac{units}{min} \tag{9}$$

Knowing our raw process time:

$$T_0 = 91,73\, minutes \tag{10}$$

We proceed as with the first measurement to calculate the critical WIP:

$$W_0 = r_b * T_0 W_0 = 157,25\, units \tag{11}$$

(12)

Finally, the CONWIP is:

$$CONWIP = 160\, units \tag{12}$$

It is possible to infer, with the calculations, that the inventory in an ideal process is of 160 units, this in relation to the inventory in the current process (7158 units), it shows that it is necessary to reconsider the distribution of the process, defining so, minimal distances to be covered, minimal dead times, with the studied CONWIP.

On the other hand, considering the balance of the process flow against the takt time, it is evident that the demand (2.78 Batch/hour) of this product is much lower than the supply. Although the appearances of the process show the opposite, in the sense the bottleneck determines the speed of supply (2.68 batch/hour). The analysis shows that the bottleneck is aligned with demand, something appropriate, however, the other operations have a much higher speed than the restriction, which means that these resources are being programmed without meaning. If in the future map, the speed of all the operations is aligned to the takt time, that is to say, to the bottleneck, a saving of 0.40 Batch/hour in the process would be achieved.

7 Improvements

The purpose of the VSM methodology is based on the diagramming of the current situation of the process in order to understand the dynamics, needs and spaces for improvement. After this balance, points are identified to modify or deepen their research, to be developed the future VSM so that waste is reduced and the flow increases responding more effectively, lower cost and added value recognized by the customer.

In the present case the current VSM was diagrammed through the simulation in Promodel, able to identify the following improvements to design the future VSM:

1. It was possible to identify the bottleneck of the system with the simple observation of the model. With a proper line balancing synchronized with the operations shifts of the operations will achieve a continuous flow with a much greater throughput (Process speed), reducing operating costs.

2. Throughout the process was a high level of inventory in process, a result of the bottleneck and regular planning for the market. This opportunity for improvement was exploited through three practices:

   — By measuring takt time, the speed of the process will be matched to market demand, which will be amortized through proper inventory planning.

   — Through plant physics, understanding Little's law will further increase throughput, balancing cycle time and product in process, defining the CONWIP to use in the future VSM.

   — Bearing in mind that the market has been in the last decade emerging with the 15 references that the company produces, for the future VSM will be realized the planning through the Heinjunka philosophy, that is, to level the variety and quantity of the products with the market Creating a continuous flow with an initial pull.

8 Relevance for the Sector

Combining lean thinking (VSM) with discrete modeling waste is evident at first glance. Through this visual tool, the management of the organization will observe the behavior of the industrial process against its VSM in detail through a simulator with graphs and real-time indicators of the simulation. The reactions are immediate and the decision making occurs in the short term. With this tool the entrepreneurs of the sector will be aware that waiting to build an action plan will take time. Waste is synonymous with loss of capital, so that industries will evolve their thinking against the instruments of continuous improvement.

In this sense, this application will help close the gap between the role of the university and industry in this sector. Unfortunately, in the domestic industry, the thought of an application technology unusual for continuous improvement as discrete simulation, it becomes an investment, which is ineffective in the reality of its operation (Eslava, 2017) (Sánchez, 2015).

9 Conclusions

By using the VSM, it was possible to identify the different operations that do not add value to the process, in this way diagnosing the different progress options that could occur by applying the LEAN tool, focused locally in the operations.

The application of this tools locally allows us to fit the times of every process, in order to minimize the incurred cost for inventory in process or in dead times regarding personnel.

When using the VSM tool with the help of the PROMODEL software, it is observed that thanks to this tool combination real-time information is obtained in relation with prosecution times of the raw material, inventories simulated at the date of the situation, waste generated in each of the operations and analysis of the efficiency and yield of the system.

This helps us to control and improve the economic impacts that could be generated by changes in production planning, changes in distribution times and reception of materials, helping minimize the variability to generate different restrictions of the system.

References

Abdulmalek, F. A. and J. Rajgopal (2007). "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study". In: *International Journal of Production Economics* 107.1, pp. 223–236.

Blank, S. (2013). *Why the lean start-up changes everything*.

Calva, R. C. C. (2014). *TPS Americanizado: Manual de Manufactura Esbelta*. Rafael Carlos Cabrera Calva.

Ernesto, B. R. L. (2001). *Simulación con Promodel, Casos de Producción y Logística*. 2nd ed. Escuela Colombiana de Ingeniería Julio Garavito.

Harrel Gosh, B. (2000). *Simulation using Promodel*. McGraw Hill.

Hines, P. and N. Rich (1997). "The seven value stream mapping tools". In: *International Journal of Operations & Production Management* 17.1, pp. 46–64.

Hopp, W. and M. Spearman (1996). *Basic Factory Dynamics*.

Jirsák, P. and D. Holman (2012). "Productivity of Lean Logistics System". In: *Journal of Logistics & Sustainable Transport* 13.1, pp. 30–40.

Jones, D. T., P. Hines, and N. Rich (2001). "Lean Logistics". In: *International Journal of Physical Distribution & Logistics Management* 27.3/4, pp. 153–173.

Lasa, I. S., C. O. Laburu, and R. D. C. Vila (2008). "An evaluation of the value stream mapping tool". In: *Business Process Management Journal* 14.1, pp. 39–52.

Lovelle, J. (2001). *Mapping the value stream*.

Luis Ernesto Blanco Rivero Enrique Romero Motta, J. A. P. R. (2006). "CONWIP UN SISTEMA DE CONTROL DE PRODUCCIÓN". In: *Fourth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCET 2006)*, p. 7.

Muhammad al-Ashraf, R. A. R. (2012). "Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study". In: *ElSevier*, pp. 1727–1734.

Wu, Y.-C. J. (2002). "Effective Lean Logistics Strategy for the Auto Industry". In: *The International Journal of Logistics Management* 13.2, pp. 19–38.

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