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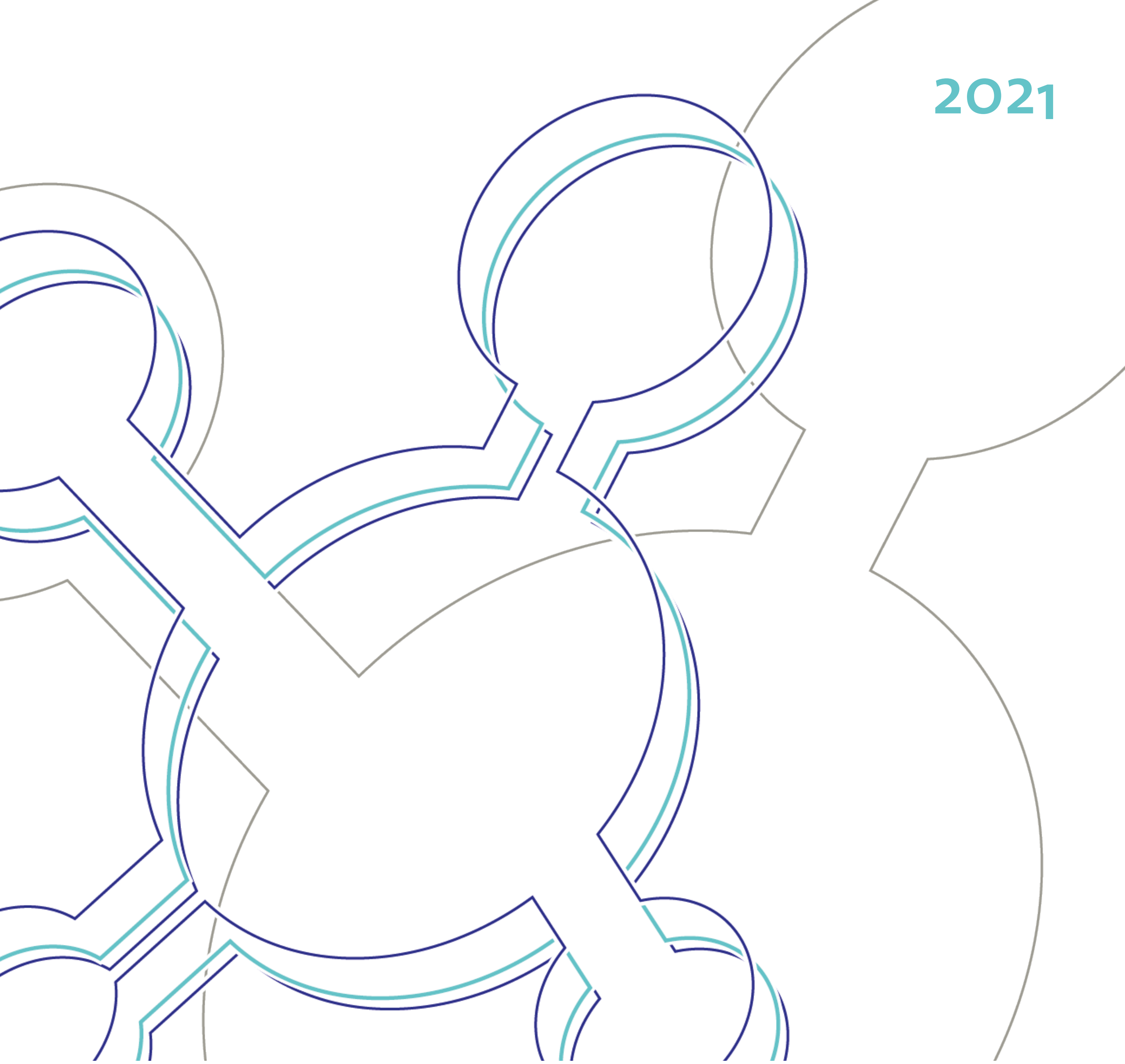

BVL

International Scientific Symposium on Logistics

June 15, 2021

Conference Volume

Digital Event

INTERNATIONAL SCIENTIFIC SYMPOSIUM ON LOGISTICS
June 15, 2021

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Conference Volume

edited by

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Preface of the Editors

Thorsten Schmidt, Institute of Material Handling and Industrial Engineering,
Technische Universität Dresden

Kai Furmans, Institute for Material Handling and Logistics
Karlsruhe Institute of Technology

Dear researchers in logistics,

the pandemic influences our life to an extent, which we knew from disaster movies only. Yet, in the meantime we somehow managed to adjust our professional life and working habits to these circumstances. The (advanced) mastering of any video meeting tool is part of that, but merely worth mentioning. In our distinct communities we moved "into virtuality" and often perform surprisingly efficient.

However, there is one element that certainly was not cultivated in its proper form. This is the cross view into other logistical disciplines, the interaction with the fields just outside of our core expertises. The International Scientific Symposium in Logistics (ISSL – in 2021 meanwhile the 10th) stands from its beginning for exactly this: a scientific meeting covering the entire spectrum in logistics in its broadest form.

The contributions to the 2021 ISSL address the current challenges to logistics from various perspectives and deliver a valuable contribution to any logistics scientist with a unique look at the interaction between economic aspects, technology and humans and how these impact on the shape of tomorrow's supply chains.

Dresden, in May 2021

Thorsten Schmidt
Kai Furmans

Preface of Bundesvereinigung Logistik (BVL)

Christoph Meyer, Managing Director, Bundesvereinigung Logistik,

Susanne Grosskopf-Nehls, Senior Project Manager, Bundesvereinigung Logistik

Dear participants of this year's ISSL,
Dear readers of this congress volume,

Under the title "Logistics for a Sustainable Future – Contributions from Science", the International Scientific Symposium on Logistics (ISSL) was originally scheduled to take place in Dresden in June 2020. It would have been the tenth symposium. Preparations for the content had already begun in 2019. The program committee includes Professors Kai Furmans, Michael Freitag, Bernd Hellingrath, René de Koster, Anne Lange and Thorsten Schmidt.

Now we are one year on, the Corona pandemic has changed the world. In 2020, the ISSL finally had to be cancelled due to the pandemic. But the logistics science event is alive and well – and the "sustainability" theme chosen for 2020 still strikes a chord. Thus, all those who assumed that this was just a short-term "hype topic" were wrong. Moreover, logistics experts have been dealing with the topic for a much longer time already: Green Logistics had already been discussed scientifically in the BVL environment ten years ago. In terms of society as a whole and the economy as a whole, various factors have contributed to an intensification of the discourse. Consequently, the ISSL program committee had the submissions updated. In light of digital-only implementation, the program has been streamlined.

On June 15, 2021, participants will be able to join this "anniversary" and first-ever all-digital ISSL with just one click. Researchers and practitioners alike will find inspiration, insights, and knowledge – real "take away value": three keynotes and 18 technical presentations in 6 sessions, as well as reading this congress volume, offer first-hand information and knowledge. Sincere thanks are due to all contributors and to the members of the program committee who also edited this volume.

The symposium was made possible by the joint efforts of TU Dresden, Fraunhofer IML in Dortmund and BVL. We would like to thank all participants as well as the members of the Scientific Advisory Board of BVL for their great commitment and perseverance in continuing the event series against all odds. The BVL wishes all participants of the ISSL 2021 and all readers of the congress proceedings lasting inspiration and impulses.

Bremen, in June 2021

Christoph Meyer
Susanne Grosskopf-Nehls

Solving Sustainability Problems: Lessons Learned in Transport and Logistics

Dirk Helbing, Computational Social Science, ETH Zürich, Switzerland

Keynote

Summary. Our economy and the underlying supply chains are complex dynamical systems, which may show features of self-organization and emergence. As a consequence, disruptions as well as control attempts, can have unexpected side effects, feedback effects and cascading effects. Instabilities, as reflected by bull-whip effects and business cycles, are common as well. The question is, therefore, how these flows can be organized efficiently.

In case of conflicting traffic flows, e.g. at intersections of an urban road network, centralized optimization and synchronized cyclical control have been common approaches over many decades. In this talk, however, I will present a new approach called "self-control", which is based on a self-organization of the flows in the network based on short-term anticipation and local coordination. This turns out to be a superior solution approach. I will argue that these principles can be used to better distribute perishable goods such as food, and introduce a socio-ecological finance system, called Finance 4.0, which can support the co-evolution towards a more sustainable circular and sharing economy.

Behavioral Issues in Automated Warehouses: Unifying Framework and Research Agenda

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Fabian Lorson, Supply & Value Chain Management, Technical University of Munich

Andreas Fügener, Digital Supply Chain Management, University of Cologne

Extended Abstract

Summary. We identify and analyze relevant behavioral issues of human interactions with automated and robotized warehousing systems for operational activities. By developing and applying a unifying framework, we structurally discuss interaction setup, targeted operational activity, associated human factors and behavior, as well as the impact on system performance. Using expert interviews with practitioners, we identify the most relevant interactions and behavioral issues, while a structured literature review allows us to develop future research questions.

1. Introduction and Motivation

Over decades, warehouse operations have relied on manual processes as human operators had been more efficient in many aspects, such as picking a large variety of products. Enabled by advances in Internet of Things devices and artificial intelligence coupled with the advent of new system providers and more cost-efficient solutions, warehousing has been revolutionized during the last decade: Human operators found themselves next to new robotized and automated teammates (Olsen and Tomlin, 2020). The size of the warehouse automation industry has been growing by 12% annually between 2014 and 2019, and is predicted to double its size from USD 15 billion to USD 30 billion in the next six years (IFR, 2020; Statista, 2020; The Logistics iQ, 2020). The resulting development and utilization of novel automated and robotized systems are boosting the transformation of warehousing from a cost center to a central component in the value proposition of firms. For instance, Amazon is currently employing more than 200,000 warehouse robots to accelerate its growth in online retail and logistics (IHCI, 2020). There are many other examples which show that innovations in warehouse automation play a crucial part in delivering products efficiently and effectively throughout supply chains (Swisslog, 2020).

Despite the growing and ubiquitous presence of automated and robotized systems, manual labor will be needed simultaneously with such machines in many warehouses in the future due to distinctive human capabilities and economic advantages. To manage resulting human-machine interactions efficiently, new frameworks and concepts are needed (Olsen and Tomlin, 2020). As human actions and decisions in such interactions may deviate from traditional assumptions and thus impact operations management metrics in both positive and negative directions (Boudreau et al., 2003; Bendoly et al., 2006; Croson et al., 2013), it is imperative to account for human factors of workers in operational activities, and to consider behavioral methodologies since they provide the opportunity to resolve emerging issues in human-machine interactions (Kumar et al., 2018). Hence, this is the first paper that structurally analyzes human-machine interactions in the warehouse by building and applying a unifying framework. Additionally, we identify the most relevant behavioral issues for these interactions. Ultimately, we establish a research agenda to improve operational decision-making for human interactions with automated and robotized systems.

2. Research Methodology

We want to generate a holistic and accurate understanding for the emerging research area of human-machine interactions in warehousing, while we need to cope with the scarcity of existing contributions. Multi-method approaches are imperative in such cases (see Boyer and Swink (2008); DeHoratius and Rabinovich (2011); Flick et al. (2004); Singhal et al. (2008) for examples). We follow well-established guidelines for emerging topics (Webster and Watson, 2002) and first develop the theoretical foundation by analyzing seminal literature in operations management of warehouses, behavioral science and human-machine interaction theory. Secondly, we conduct semi-structured expert interviews to identify the most relevant human-machine interactions and capture the associated behavioral issues as recommended by Edmondson and Mcmanus (2007). Finally, we perform a systematic literature analysis for the issues identified. This is a pivotal step to deepen links among managerial relevant issues and existing work, and necessary to identify current gaps in literature (DeHoratius and Rabinovich, 2011). The theoretical foundation is the input to develop the unifying, conceptual framework (see Section 3). The expert interviews are conducted to identify the most relevant interactions and corresponding behavioral issues, while the systematic literature analysis allows us to develop resulting open research questions. We discuss each behavioral issue along our unifying framework, ensuring a structured approach to investigate and enrich the issue analysis (see Section 4). In this way, we provide insights by complementing and characterizing the behavioral issues with theory on associated human factors and potential impact on system performance. To enhance the confidence in our findings, only the continuous and comprehensive triangulation of all these sources provides the opportunity to validate the proposed framework, systematically identify and analyze relevant issues, and ultimately create a comprehensive research agenda.

3. Unifying Framework for Human-Machine Interactions in Warehouses

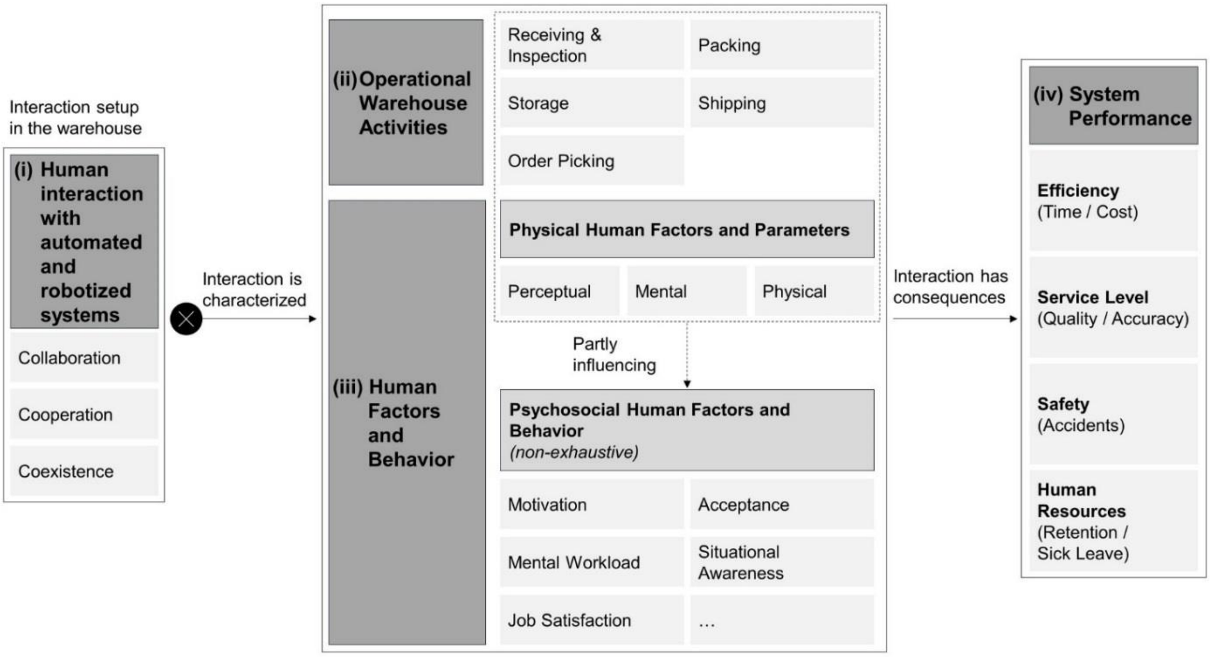

Figure 1. Unifying framework to discuss behavioral issues of human-machine interactions

The framework developed links human-machine interactions with the respective operational warehouse activities and human factors and behavior, and elaborates consequences on system performance. This serves to identify a set of potential interactions and issues that may exist. We utilized theories from related fields to rely on existing definitions and relationships for our framework (Ramasesh and Browning, 2014). Using our framework allows us to structurally discuss the following identified issues.

4. Relevant Behavioral Issues of Human-Machine Interactions

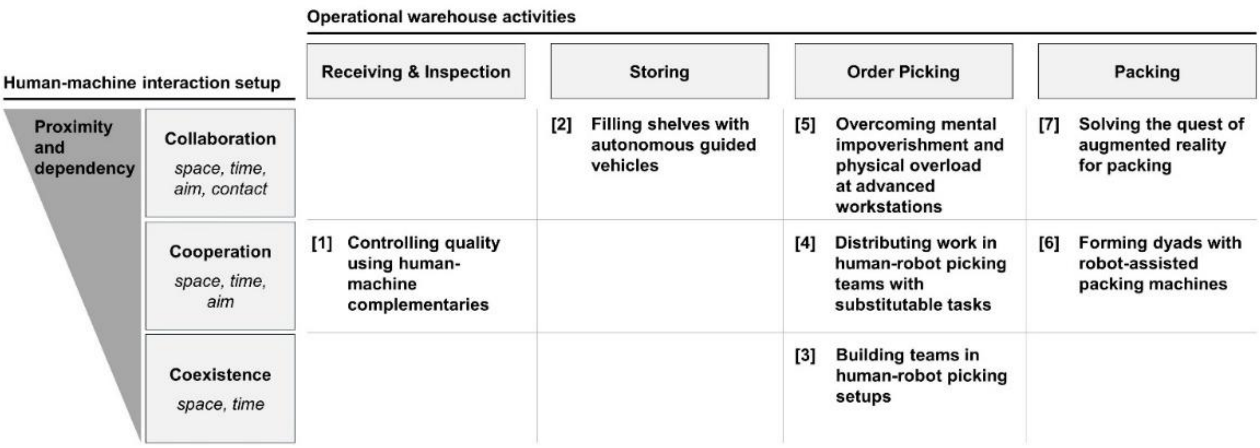

Figure 2. Overview of the seven issues identified along operational activity and interaction setup

Issue identification and description. One key challenge revealed in our expert interviews is determining the team structure, that is, how many humans and how many autonomous picking robots to employ for a given picking zone during the same shift: "*I will have to form new teams, and this will change the human dynamics significantly depending on how many robots I will include,*" to cite a warehouse operator. In mixed teams, humans will see the autonomous robots, hear their noises, and maybe even smell their robotic odor. Humans may think about robots as team mates, their role within the team, and how to deal with them. They need to move around them to both ensure human safety and robot productivity. Many experts have also reported different ways employees have of coping with such close human-machine coexistence, with one warehouse manager pointing to unknown consequences: "*We do not know yet what the short- and long-term influence on human social components will be when we employ more and more robots.*"

Implications on human behavior. The physical human factors mentioned influence psychosocial factors and behavior in many ways. The perception of a robot working at a different speed might alter the human motivation to work efficiently, the human may have to cope with the fact that a robot has replaced their human team mate, or the human may experience a lack of team spirit. Outside the warehousing literature, a plethora of theories exist on behavioral issues regarding team composition in general and for human-machine interactions in particular. One key aspect of managing teams is to deal with interpersonal processes such as conflict and affect management or collective motivation building to avoid performance problems (Marks et al., 2001). Employees care about human relationships and identify with colleagues (Urda and Loch, 2013), and these social interactions have a large impact on motivation and performance (Cantor and Jin, 2019). In line with that, Stein and Scholz (2019) encourage automation-oriented diversity management when building groups and Gombolay et al. (2015) establish that people value humans more than robots as team members. Hence, psychosocial factors such as motivation, job satisfaction or loyalty of employees may vary depending on the team structure in warehouse operations, too. Additionally, findings about peer effects (Tan and Netessine, 2019) may also exist for such human-machine teaming and impact optimal operating policies. The physical presence of autonomous picking robots may further influence trust and actions, depending on the individual human being (Glikson and Woolley, 2020). Consequently, this requires a thorough understanding of which personalities, behavioral traits or skills prove to enhance performance criteria.

Related literature and gap. As humans and robots have formed teams only recently for picking activities, this constitutes a new area of research including the following questions:

- How does the share of robots impact the efficiency and retention of human operators, why does it differ (e.g., human-robot peer effects, individual motivation and trust), and what is the optimal share and policy in which constellations?
- Which behavioral traits and skills impact performance when teaming with autonomous robots, what behavioral aspects may explain differences (e.g., satisfaction, stress), and why?

5. Conclusion

Interactions among human operators and automated or robotized systems in the warehouse are developing into a multi-disciplinary field of research, and has recently evolved and gained momentum due to the rapid growth of automation in logistics. This raises new issues related to the role of workers in warehousing and in operations of the future. As such, it has become essential to investigate and optimize human-machine interactions in operational warehouse activities. This paper develops the pathway to upcoming research within this context by identifying key human-machine interactions and corresponding behavioral issues. We first contributed to theory building and developed a unifying framework to structurally analyze issues in such interactions to tackle this nascent research area. We presented our empirical findings from expert discussions and combined those with relevant behavioral theory and existing warehousing literature that revealed significant gaps. The research agenda developed unfolds interesting and relevant research propositions.

The managerial implications of this paper contribute to design aspects for warehouse systems providers, the decision-making processes of warehouse managers, and the awareness for project managers on behavioral issues in warehouse automation projects. The unifying framework can additionally applied in other contexts, particularly towards human-machine interactions of both different activity levels and related operations management fields.

Future interdisciplinary research can leverage the findings to apply a variety of methods to address the research questions proposed, and to inform operations management models, theories and principles.

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Method for the Evaluation of An Autonomous Handling System For Improving the Process Efficiency of Container Unloading

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Summary. Rising trade volume creates an increasing need for automatic unloading solutions for containers. Some systems are already on the market but not widely used due to lack of robustness and difficult-to-predict performance. We present the first approach towards a universal estimation of unloading performance and apply it to a new system. We divide the unloading process into five steps, made up of six individual tasks, and present the ten parameters affecting these tasks. We show how the total unloading time and performance can be calculated based on the task times, reducing the number of necessary tests. Using this method, we calculate the unloading performance of a system gripping multiple cartons. The estimated performance ranges from 341 to 3,252 cartons per hour. This shows that for many systems, the unloading performance depends on multiple parameters. We anticipate this contribution to serve as the first step towards a standardized calculation of unloading performance for containers.

1. Introduction

International trade volume is steadily rising (World Trade Organization 2020, 12). The majority of this cargo is transported in containers, mainly by ship, and packed and emptied in the hinterland (United Nations 2020, 9). To increase transport efficiency, both on ship and truck, cargo in containers are loaded with individual cartons instead of pallets, complicating the emptying of containers (Bortfeldt and Wäscher 2013; Zhao et al. 2016).

Several automatic handling solutions for unloading containers are available on the market but are not economical, as fully autonomous solutions often fail due to the varying loading patterns (Wilhelm, Beinke, and Freitag 2020). Existing solutions either pick items individually, limiting the potential throughput, or handle cartons in bulk, potentially damaging fragile goods. In this contribution, we present an overview of available systems for container unloading and provide a first evaluate of the unloading performance of a newly developed solution for the container unloading. We propose a process segmentation of unloading-tasks for an objective calculation of unloading performance and robustness in different scenarios. We evaluate this method on a newly developed system for the autonomous unloading of containers.

The remainder of this work is organized as follows. Section 2 reviews currently available container-unloading systems and describes a semi-autonomous system recently developed by the authors. The method for evaluating the unloading system and its performance is presented in Section 3. In Section 4 we describe the test-bed and experiments and present the resulting task time and unloading performance. Section 5 concludes this article and presents both future work and further perspectives.

2. State of the Art and System Description

2.1 State of the Art

Recent overviews of autonomous unloading systems for stacked cartons in containers are presented in Wilhelm, Beinke, and Freitag (2020) and Freitag et al. (2020). Despite the large number of unloading systems for containers or trucks, none of these solutions have achieved widespread use yet (Wilhelm, Beinke, and Freitag 2020). Reasons are the high variability of packing patterns and short process times, which is currently hard to achieve for fully autonomous systems (Petzoldt et al. 2020). Especially in complex scenarios this leads to system downtimes and costly manual interventions (Freitag et al. 2020).

The available solutions can be classified by various characteristics (Petzoldt et al. 2020; Freitag et al. 2020). One feature that directly affects the process time is the type of unloading. Techniques are the individual picking of items (Boston Dynamics 2021; Bastian Solutions 2018; Stoyanov et al. 2016), gripping of multiple cartons stored in a row (Honeywell Intelligrated 2019), and bulk-unloading of the entire content of the container on conveyor belts (Siemens Logistics GmbH 2019; Honeywell Intelligrated 2019). In the bulk-unloading scenario, the system does not pick up individual items, but unloads the entire cargo of the container via conveyor technology in the floor, potentially damaging the cartons due to falls. The unloading speed ranges from 500 (Echelmeyer, Bonini, and Rohde 2014) to 1,000 cartons per hour (Bastian Solutions 2018) for individually picked items to 25,000 cartons per hour in the bulk unloading scenario (Siemens Logistics GmbH 2019). The unloading performance of human operators ranges from 420 to 840 cartons per hour (Petzoldt et al. 2020). The unloading speed for all systems presented are extracted from commercial publications and therefore not reviewed. An independent evaluation or methods for calculating the unloading speeds are not available.

Unloading Type	Unloading speed in cartons/h	
Manual	420 .. 840	Petzoldt et al. 2020
Individual picking	500	Echelmeyer, Bonini, and Rohde 2014;
	1,000	Bastian Solutions 2018
Multi-grip	1,500	* Krantz 2021
Bulk	1,500	* Krantz 2021;
	25,000	Siemens Logistics GmbH 2019

Table 1. Performance of different unloading methods
** values given as the upper bound for a system*
that can perform both multi-grip and bulk-unloading

2.2 System for Multi-Grip Unloading

The method for the calculation of unloading times will be evaluated on a newly developed system for unloading loose-loaded containers in which the cargo is stacked in multiple layers (Petzoldt et al. 2020). To improve the throughput over unloading systems that pick items one at a time, the authors proposed a solution the unloading multiple items packed in a row (Petzoldt et al. 2020). This increases the unloading performance without high impact-loads on the items as in the bulk-unloading scenario.

The systems consists of a omnidirectional mobile chassis, a vertically moveable platform with tilt-adjustment, and three individually movable gripping-modules with vacuum suction cups to grip and pull cartons. The platform and center of the robot are equipped with conveyors to move the unloaded items to external material-handling technology at the back of the system. Figure 1 highlights the controllable parts of the system.

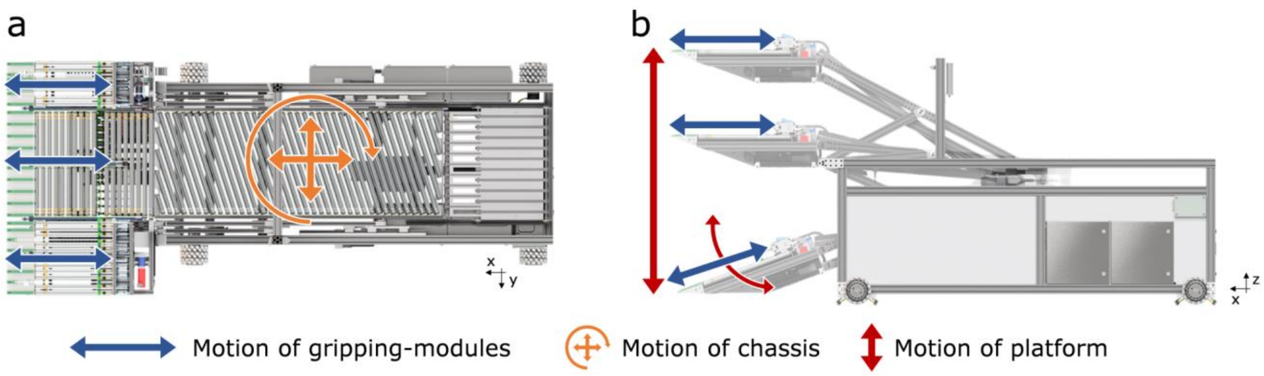

Figure 1. Unloading system with its degrees of freedom modules
(in accordance with Petzoldt et al. 2020)

The system is equipped with an array of four RGB-D cameras, placed at the top and bottom, left and right corners of the vehicle. To increase robustness, the detection process runs independently on the four individual camera frames. After the detection of the box corners in the 3D color-frames, the positions of the corners are transformed into the common coordinate system of the robot. For carton identification we adapted a methodology based on deep neural networks (DNNs) which has been very successful in 2D Multi-Person Skeleton Estimation (Gong et al. 2016; Chen, Tian, and He 2020; Xiao, Wu, and Wei 2018; Cao et al. 2021). In this scenario, the four front-facing corners of the cartons present the skeleton to be detected. The key advantage of this concept over traditional computer vision methods is the long-term sustainability. This approach allows for a quick re-training in case the type of cargo changes, compared to traditional methods, in which an expert would have to adjust or even re-develop the algorithms.

2.3 Unloading Process

The unloading process performed by the robot consists of multiple steps, each built from unique tasks (Hoppe et al. 2020). Table 2 presents the list of process steps and their corresponding tasks. First, an array of four depth-cameras scans the area in front of the robot. A carton detection algorithm identifies the individual cartons in each of these four images and creates a skeleton representation of all identified objects. After merging this array of four skeletal images, the cartons for the next grip are chosen based on their reachability and the optimal unloading pose of the robot is calculated. Second, the robot approaches the cartons by moving its chassis and platform concurrently. To grab the cartons, the robot moves the gripping-modules to the front of the platform and starts the vacuum once the carton-front is in proximity of the suction cups. The vacuum is individually monitored and controlled so that the robot can distinguish between failed and successful grips. Once either all packages have been successfully grabbed or non-gripping suction cups are deactivated, the gripping-modules move to the rear. The robot switches off the vacuum and moves the gripper modules to their rest position, with the center module sinking below the conveyor belts. Finally, the conveyor modules unload all cartons pulled onto the platform.

s	Step	Tasks (T)	Conc.$^{+}$
1	Identify	Carton detection (1), Carton selection*, Pose calculation*	
2	Approach	Chassis motion (2), Platform motion (3)	yes
3	Grab	Gripper motion (4), Vacuum effect (5)	
4	Pull	Gripper motion (4), Vacuum effect (5)	
5	Convey	Conveyor motion (6)	

Table 2. Individual tasks of the system to be tested based on the unloading process
* task time and robustness independent of parameters, negligible impact on unloading time
$^{+}$ Tasks in this step are performed concurrently

3. Method

3.1 Experimental Design

Before the performance of the system is determined under real conditions in a field-test, integration and laboratory tests are performed to provide an initial estimate. We place particular emphasis on the coverage of as many potential scenarios as possible and the determination of the robustness of the solution.

To minimize testing and create universally valid results, we propose a modular design of experiments. The separation of the overall process into individual steps and their basic tasks allows to specifically test each task T with a reduced number of parameters. For each step s only the relevant parameters of the tasks need to be adapted. The unloading time t_r for one row of cartons is the sum of the times t_s of the different steps based on the individual parameters p of their underlying tasks T. In first approximation, each step is performed once for each row, since we assume that all cartons of a row are unloaded at once.

$$t_r(p_1, \dots, p_n) = \sum_{s \in S} t_s(p_1, \dots, p_n) \tag{1}$$

with

$$t_s(p_1, \dots, p_n) = \sum_{T \in T_s} t_T(p_1, \dots, p_n) \;\; \forall \;\; s \notin S_{conc} \tag{2a}$$

$$t_s(p_1, \dots, p_n) = \max_{T \in T_s} t_T(p_1, \dots, p_n) \;\; \forall \; s \in S_{conc} \tag{2b}$$

S_{seq} is the set of all steps s with sequential subtasks (see Table 2).

Due to the multi-grip performed by the system, the total unloading time for a given container is unloading time t of an individual row times the total number of rows in a container. Assuming homogeneously stacked cartons, the number of rows in a container is the number of layers n_x in length times the number of layers n_z in height. Therefore, the total unloading time t is

$$t = n_x \, n_z \, t_r \tag{3}$$

3.2 Parameter Identification

In a first step, we identified the external parameters of influence for each task by interviewing system and process experts. For each task, we deducted their elementary parameters from first-order principles and the expert evaluations. Thus, we can vary only task-relevant parameters, drastically reducing the number of tests necessary for each task. By combining the individual times with parameters of the unloading process (e.g., carton size), we can estimate the overall unloading time for varying conditions. Table 3 shows the relevant parameters affecting unloading performance and robustness for each task.

T	Task	Performance factors
1	Carton Detection	object size (carton width, carton height), lightning (brightness, contrast), refractions, reflection (carton surface)
2	Chassis motion	distance (carton depth), resistance (floor inclination)
3	Platform Motion	distance (carton height), resistance (carton mass)
4	Gripper Motion	resistance (carton mass, platform inclination)
5	Control Vacuum	resistance (carton surface: porosity, carton mass, platform inclination)
6	Control Conveyor	distance, resistance (carton mass)

Table 3. Parameters affecting unloading performance and robustness of tasks T

In the second step, we designed individual tests to analyze the effect of the corresponding parameters. For each parameter, we created discrete variations described in Table 4.

p	Parameter	Parameter value
1	Carton surface	matte; laminated
2	Brightness	no ambient lighting; bright ambient lightning
3	Contrast	equally distributed light; mixed lighting (spots)
4	Atmosphere	no fog/dust (clean laboratory); Reduced visibility (fog)
5	Floor inclination	-4%; 4%
6	Platform inclination	0%; 40%
7	Carton width	200 mm; 800 mm
8	Carton depth	200 mm; 800 mm
9	Carton height	200 mm; 800 mm
10	Carton mass	0 kg; 35 kg

Table 4. Range of values for the parameters

4 Experiments and results

For this contribution, we identified the times of the tasks that significantly affect the unloading time (tasks 2, 3, 4, 6). Each task was performed ten times for each combination of parameters. Since all controllers are velocity controller, we only changed the parameters affecting the distance. The task time for the conveyor motion was determined on theoretical grounds. The total distance of $3.9\,m$ can be covered in $5.6\,s$ assuming a conveyor speed of $0.7\ \frac{m}{s}$. We performed all tests in a laboratory test-bed with a container of cartons of different sizes.

4.1 Preliminary Task Times

Table 5 lists the results of the experiments performed. It presents the mean time and its deviation for the slowest and fastest combination of parameters for each task. The total unloading time is given by the sum of all steps s of the unloading process (Eq. 1). The time t_s of each step is defined by the total time or maximum time of all tasks $T \in s$ as given in Table 2 (Eq. 2). Table 5 gives the minimal and maximal time of step task.

T	Task	$\bar{t}_{T,min}$ in s	$\bar{t}_{T,max}$ in s
2	Chassis motion	4.0	12.0
3	Platform Motion	4.9	13.3
4	Gripper Motion	6.4	6.4
6	Control Conveyor	5.6	5.6

Table 5. Preliminary results of the unloading task times. The time for the conveyor motion was determined theoretically

4.2 Performance Evaluation

The unloading performance is defined as the number of cartons per time (Table 1). The number of cartons per container depends on the size of the cartons. The size of conventional cartons are between 300×200×100 mm (small) and 800×640×600 mm (large). Therefore, the maximum number of cartons in a 1AA 40-feet container[1] is 9,009 with the long side oriented to the back. The maximum number of large cartons is 126 also with the long side oriented to the back.

Table 6 presents the different scenarios and the stacking pattern for these scenarios and the estimated unloading performance. The total unloading time is calculated with Eq. (3). It should be noted that chassis and platform motion are performed concurrently and the gripper motion is performed twice, both when gripping and unloading.

Carton size	Number of cartons in length n_x	Number of cartons in width n_y	Number of cartons in height n_z	Total number of cartons	Unloading time t_{row} per row in s	Unloading performance in carton/h
Small	39	21	11	9,009	23.2	3,252
Large	14	3	3	126	31.7	341

Table 6. Carton pattern for standard sized containers and the preliminary unloading performance

4.3 Limitations

The aforementioned test-setup allows for a flexible test of multiple criteria with a reduced overhead due to the evaluation of individual tasks. With equations (1–3), the final unloading time can be evaluated for a wide range of scenarios. This flexibility comes at the cost of lacking full-service evaluations. The estimated times are the result of distinct tests and present only an expected value for the total unloading time under various conditions. Since we did not perform full factorial tests and so far only tested for parcel size and mass, potential correlation between the parameters might affect the unloading performance. Additionally, the conveyor time was estimated based on conveyor velocity.

Additional effects will be evaluated in a field-test. There, actual 40ft-containers in the receiving area of a large logistics service provider will serve as the testbed for the system. With this test, we will evaluate the robustness over longer periods of time as well as the systems approach to unforeseen situations.

5. Summary

This paper presents a list of available solutions and their performance as well as a first approach towards a standardized evaluation of unloading throughput for automatic unloading solutions. In the presented method for throughput estimation, the process is divided into multiple steps and the tasks in each steps are evaluated in terms of performance and robustness. We propose

[1] internal dimensions of 11.998 × 2.330 × 2.350 m (International Organization for Standardization 2020)

distinct tests for each task under variation of all parameters affecting performance and robustness and evaluate this division on a new unloading system, resulting in a setup with five different tasks and ten parameters.

In a first test, we estimate the unloading performance of the system to range from 341 cartons per hour for very large items to over 3,200 cartons per hour for small items. Next, we will evaluate all parameters affecting robustness in a laboratory environment. In field-tests we will evaluate the robustness and performance of the system under varying conditions.

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Planning and Optimization
Of Internal Transport Systems

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Summary. The digital transformation is increasingly affecting the field of intralogistics. In order to develop corresponding concepts in logistics planning in a short time, software tools should profitably transfer the theoretical knowledge into practice and support the user in the best possible way. This article gives insight in particular into the typical tasks involved in the planning and optimization of internal transport processes and how LOGSOL addresses these with the help of the RoutMan planning tool.

1. Introduction

Jeff Bezos, founder of the online sales company Amazon, described the current digital transformation of society with the emphatic phrase "There is no alternative to digital transformation" – transformation which now seems to us to be not only fundamental but also irreversible. In this context, the fourth industrial revolution encompasses all those structural changes that occur in the course of digital transformation in logistics and production (ten Hompel and Henke 2020).

And indeed, it is hardly surprising that logistics – with its algorithmic and deterministic nature – is one of the earliest areas of application for new technologies such as artificial intelligence or the Internet of Things (ten Hompel and Henke 2020). At the same time, it represents the link between companies in the value creation network and the interface between internal company functions, and thus proves to be a predestined playing field for continuous improvement (Hofmann and Nothardt 2009). Within this overall supply chain, intralogistics represents only one logistics task, but its role – as the process stage that determines the type and timing of material supply – can certainly be described as central (Miebach and Müller 2006). It, too, is subject to constant optimization initiatives. In this context and due to the fact that they are often still manually operated, internal floor-based transport systems in particular have a high potential for improvement (Wehking 2020).

Lean design in intralogistics has been a primary objective of logistics planning at least since the worldwide establishment of the Toyota Production System. The challenge here is not only to realize high quality and efficiency with low lead times, but also to simultaneously optimize space utilization, personnel deployment, and inventory reduction (Liebetruth and Merkl, 2018). Even today, digital solutions such as automated guided vehicles, indoor tracking, E-KANBAN and many more already offer versatile possibilities for optimally exploiting the potential of internal transport concepts and their control. LOGSOL encounters such developments daily in the practical environment of logistics planning. In order to contribute to the growth of digitalization and the ongoing need for optimization in the planning of internal transport systems, LOGSOL developed a software-aided planning tool in the last few years.[1] In this context, LOGSOL also cooperates with scientific facilities and institutes, such as the Chair of Material Handling at the Technical University of Dresden.

2. Planning of internal transport processes

Planning internal transport processes is undoubtedly an extensive undertaking that depends on many factors. Although every project in this context is individual, established planning methods can be applied in almost every case and the complexity of the planning task can be reduced by a standardized procedure. The first stage of the planning process usually begins with the identification of potential transport concepts.

Over the past 30 years, both the technologies used in in-plant transportation and the associated processes have changed. In the course of time, highly complex and mostly partially digitalized conveyor systems have been created, the dimensioning and optimization of which requires considerable effort. A wide variety of transport concepts are available. Most widespread and relevant in terms of planning is the classification of these according to their underlying application concept. The most elementary distinction should be made between continuous conveyors – used to create a continuous transport flow through stationary line connections – and discontinuous conveyors – used to create an interrupted material flow (Jünemann and Schmidt 2000). The latter are used in particular for direct supply of materials to production (Wehking 2020).

Floor-bound non-continuous conveyors are characterized not only by the intense planning and control efforts associated with them. They also represent the group of conveyor technology that has experienced massive automation in recent years. The most common technologies include tugger trains, forklifts and automated guided vehicles (AGVs). Although they all come under the same classification, these conveyor systems differ from each other in many ways. Among the critical criteria to consider for their planning are (Wehking 2020):

- Flexibility in the event of changes to the layout, infrastructure or material flows
- Technical parameters, such as the conveying direction, load capacity and the turning radius
- Degree of automation as a factor influencing personnel costs and controllability
- Interactions among themselves and with each other and with adjacent processes
- Control effort
- Investment requirement

[1] The planning and control of internal transport systems are closely interlinked. However, in practice, the focus is usually on digitalization in operational areas and not in planning (i.e., the design and dimensioning of flexible internal transport processes).

The selection of a suitable transport concept depends on a large number of contributing factors. One of these factors is the preexisting, internal company requirements for the transport system being planned. Three planning paradigms play a decisive role here, regardless of the conveyor technology (see following figure).

Figure 1. Planning paradigms

The *spatial dimension* includes conditions within which transport processes are to be conceptualized. They refer to all storage, picking, transport and handling arrangements that constitute the framework for the transport of goods. The first step of their analysis starts with the visual recording and graphic mapping of abstract, mostly geometric basic structures of the company facilities (Martin 2016). Based on these planning fundamentals, initial considerations can then be made regarding the design of the transport system. Relevant here is the definition of sources – delivery points where materials are made available – and sinks – receiving points where materials are required (Liebetruth and Merkl 2018). The transport task to be performed, such as production supply, disposal, or transport between storage points, determines both the number and type of sources and sinks. With the help of this spatial visualization, organizational principles can be determined in the next step. If sinks are in a linear arrangement, flow production can be assumed. Much higher planning efforts result from a station or island-like arrangement (Lieb et al. 2017). In any case, the analysis of spatial dimensioning provides an adequate first point of reference for possible restrictions and thus for the delimitation of potential transport concept right from the beginning of planning.

Material dimensioning is mainly about the goods to be transported and their characteristics. In this context, the generic dimensions should be addressed in more detail. The assessment of these qualitative properties of the material to be transported is essential in order to narrow down the applicable transport concepts, due to the requirements of the material for the transport process (Martin 2016). Quality standards for the materials to be transported also play a decisive role. For example, the planner is confronted with questions regarding the additional effort required for unpacking, packing or creating sets (Liebetruth and Merkl 2018). Aside from this, the quantitative dimensions also play a decisive role in material dimensioning (Martin 2016).

No less essential for the planning of the transport system is *time dimensioning*. This planning paradigm is a frequent reason for exclusion of unsuitable transport concepts, especially for transport assignments supplying production. The most important aspects include operating speed, cycle time, and replenishment time (Liebetruth and Merkl 2018). Taking into account these planning requirements, conveyor technology can be evaluated and selected for speed and flexibility.

The process of recording and analyzing all of these planning fundamentals can be more or less complex, depending on the project conditions. In order to at least partially simplify and standardize it, planners draw on various supporting methods and tools.

The basis for all planning projects is initially the compilation of the numerical data. This includes the compilation of qualitative and quantitative information on the transportation process. These are typically composed of the planning paradigms already presented and rely on the availability of relevant data. Often these already exist in the company, but it is not uncommon to have to collect missing data during the planning process. Some methods and tools for transportation planning that have proven to be effective will be presented in the following.

The MTM method is often used in practice, especially when it comes to recording and analyzing time planning dimensions. Since the data situation for determining relevant time requirements does not always correspond to planning needs, the need for analog recording of working hours sometimes cannot be avoided. With the help of the MTM method, processes can be grouped into modules and evaluated independently of employees on the basis of statistically determined standard times (Liebetruth 2020).

Since planning a transportation system does not always involve a full-scale redesign, existing structures may need to be analyzed. The distance-intensity diagram supports the planner by classifying material flow relationships according to their intensity – i.e., transport demand – and the distance between source and sink (distance). They can be classified and prioritized according to their effort. Using a classic heat map, the traffic intensity can also be visualized. The planner can see the line load distribution and optimization potential at a glance.

3. LOGSOL's approach to planning and optimizing internal transport processes

Over the past 20 years, LOGSOL has gained a wealth of experience in planning and optimizing transport processes. While there is still a relatively high degree of freedom and relatively few restrictions in new plant planning or expansion, the restructuring of an existing transport system presents a much greater challenge. Typical reasons for having to adapt planning are, for example, fluctuations in demand – triggered by internal or external factors – and structural changes, such as the conversion of a production facility from workshop to assembly line production or a change in the product manufacturing portfolio.

Another reason for the need to plan a transport system, which is already relevant today and will remain so in the future, is the increasing digitalization of logistics processes. The introduction of new conveyor technologies that are able to collect multidimensional data, communicate or operate fully automatically is now one of the most important reasons for replacing or restructuring existing transport processes. In practice, there is a considerable amount of catching up to do here, as the focus is usually on control and less on planning, which generally provides the guidelines for operational management.

Depending on the motivations for planning a transportation system and the information available on the company's internal planning paradigms, the level of effort required may vary. A decisive factor here is hidden in the planning and optimization process itself. A variety of data-driven analysis tools now exist to make the planning process more efficient. However, these usually come from different providers and involve significant integration effort. To overcome this barrier in its own planning projects and for its customers, LOGSOL developed a software-based application for comprehensive planning and optimization of internal transport processes, as part of a research and development project.

As already shown, the planning of a transport system requires four basic pieces of information relevant to design, whereby the technical planning paradigm refers to the conveyor technology itself and the spatial, material and time dimensions represent the company's existing structural characteristics. In the first step in software-aided planning, data on the relevant means of transport are recorded within RoutMan® so that a complete master data library is available as a basis. The next step is the dimensioning of the planning scenario. For the design of a spatial planning basis, hall layouts and route networks as well as sources and sinks are stored in the system and attractively displayed. To define the material requirements, quantitative properties are recorded, and qualitative characteristics based on the type and design of carriers to be transported are stored. Ultimately, the time dimension can be mapped using process-based analysis methods. Transport routes can be generated both manually and automatically based on various criteria, such as conveyor sections or container types.

Once all relevant data has been recorded, various analyses can be carried out by the planner with the aim of optimizing the process. RoutMan® uses various established calculation methods, including VDI Guideline 5586 Sheet 2 "In-plant milk-run systems – Planning and dimensioning", and relies primarily on the evaluation of performance-oriented key figures to map process efficiency according to cost, quality and time-specific criteria. An added value that is particularly visual and realizable in terms of data is created by the mapping of the traffic intensity in the heat map and the distance-intensity diagram (see following figure). Furthermore, the generated results, such as tour start interval and route guidance, as well as the driver pooling created to level the employee workload, can be used as input variables for operational control.

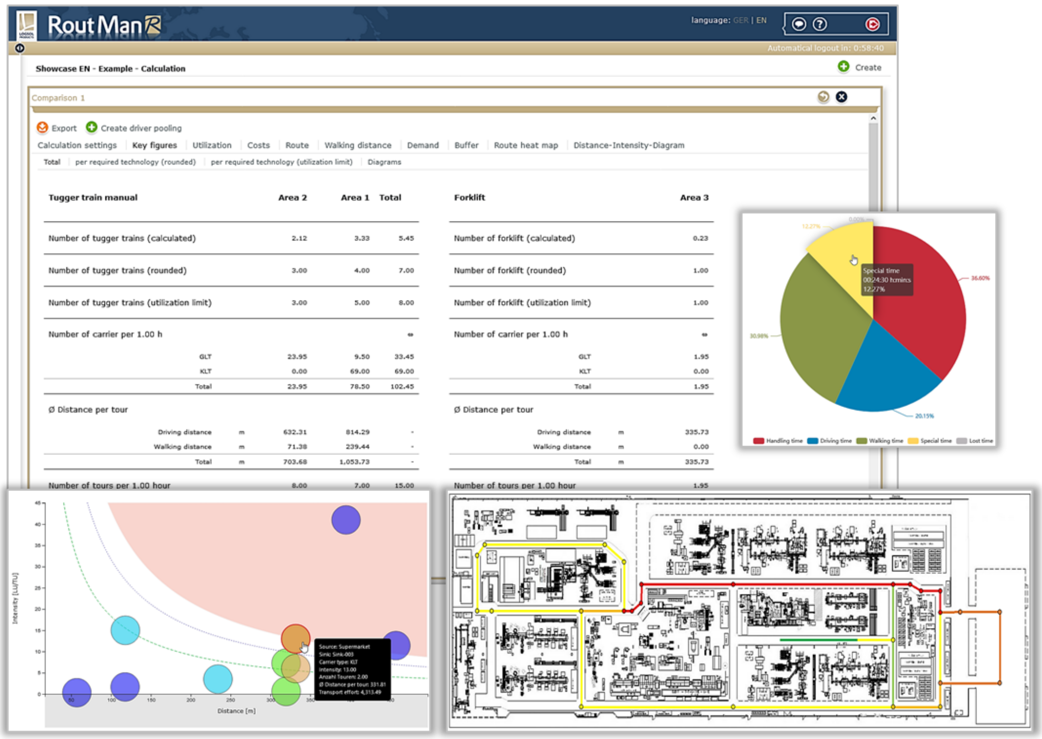

Figure 2. Exemplary evaluation of the RoutMan planning tool

Software-aided planning processes and automated data evaluations make a fundamental contribution to simplifying optimization projects for complex internal transport systems. However, parallel to the increasing need for planning, demands on the transport systems are also growing daily. In this context, their design must become faster, simpler and more automated. In order to keep pace with the developments of these turbulent times and to continue to provide an effective basis for planning, LOGSOL is continuously working on expanding the functions of RoutMan®. New ideas and expanded functionality are to be developed continuously – for example, through cooperation with academic institutes such as the TU

Dresden. By calculating envelope curves, for example, the software should be able to identify risks of tight curves right from the planning stage. Likewise, the extent to which queuing models can provide additional insights for the planner is currently being evaluated.

4. Conclusion

“Progress lies not in enhancing what is, but in advancing toward what will be.” This quote from the philosopher Khalil Gibran (von Hehn, Cornelissen and Braun 2015) essentially sums up the core of planning logistics processes today. Society and logistics, with intralogistics as a significant component, are experiencing a transformation that not only forces them to continuously adapt to internal and external changes, but also leads to efficiency-related peak performance.

From this point of view, the planning of internal transport systems represents one of the great challenges facing the logisticians of our time. Planners are faced not only with the automation of individual processes and complete systems, but also with the need to work as efficiently as possible. The availability of an orienting planning concept and evaluative software can nowadays be the decisive factor for the success of a planning project – and not only in the area of internal transport.

This article provides an insight into how best to proceed in practice when planning and optimizing internal transport processes, and which supporting methods and tools are used. The massively increased relevance of digitalization in planning, which should not stop at data collection and analysis in established office solutions, should also be emphasized. Here, other software tools can be usefully added to support the entire planning process. With the development of the RoutMan® planning tool, LOGSOL has managed to lay its own foundation for internal transport planning of all kinds. In doing so, the web-based software can be used not only to address the specific planning challenge, but the tool is also suitable for further training and the creation of standardized planning processes. Last but not least, this is the reason that RoutMan® is used not just by experienced logistics planners. The planners of tomorrow can use this tool too, to link theoretical approaches with practical case studies. This is why LOGSOL also offers the tool in the RoutMan® Academy (see following figure).

Figure 3: RoutMan Academy

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Cloud Material Handling Systems: Concept Development and Preliminary Performance Analysis

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Extended Abstract

Summary. In this extended abstract we will present a new kind of paradigm in intralogistics, called Cloud Material Handling System (CMHS), which has been introduced and developed at Logistics 4.0 Lab at NTNU (Norway). The idea is based on commonly used transportation service providers and platforms like Uber or Lyft. An Intelligent Cognitive Engine operating in cloud schedules and assigns the handling requests made by the customers (unit loads) to the available cars and drivers (material handling equipment). After an introduction explaining the industrial challenges of improving performance of material handling systems and how the emerging new technologies can be used to overcome them, CMHS concept and functioning are described. Then the results of some simulation from a case study are briefly presented and discussed, showing that CMHS has great potential in improving performance of intralogistics.

1. Introduction and Background

Nowadays, the implementation and usage of cloud technologies represents the avantgarde in production systems. Thereby, the so-called cloud manufacturing affects the management of the production system due to possibility of sharing real-time information about the status of product and all production services. Cloud technologies have been mainly analyzed and discussed on shop-floor level connecting machines, however, material handling systems have been left behind.

The typical structure of today's material handling systems is a mix of different equipment with various levels of automation (Furmans and Gue, 2018). Manual and mechanized systems, such as manual carts and industrial vehicles (i.e. pallet trucks, forklifts), in which humans still play an important decisional role, still dominate to a large extend the transportation of goods. In the last years, automated solutions, such as Automated Guided Vehicles (AGVs) or Automated Storage and Retrieval Systems (AS/RS), are implemented with their own decentralized control systems. Since these systems are not connected with each other, a multilevel hierarchical control system is necessary to coordinate the different sub-systems and allows the products to be moved from one point to the next within the production system.

The efficient utilization of the Material Handling Equipment (MHE) has a strong effect on the productivity, profitability, and flexibility of the production systems. Some examples are a machine waiting for the product to process since the forklift driver is not available, or a machine being blocked because the unit loads in the unloading station are still waiting to be transported to the next production phase.

The availability of industry 4.0 technologies, such as Indoor Positioning Technologies (IPT) as part of Internet of Things (IoT), motion tracking and control, and cloud computing is making MHE one of the most feasible solutions for increasing the flexibility of production systems.

By extending the definition of cloud manufacturing to handling activities, a new kind of paradigm, called Cloud Material Handling System (CMHS), has been introduced and developed by the authors in the Logistics 4.0 Laboratory at the Norwegian University of Science and Technology (Sgarbossa et al, 2020).

2. CMHS Concept

The concept of the CMHS can be compared to the transportation service provider and platform called Uber. In this case, the 'consumers' are the unit loads, called Smart Objects (SOs) which require a specific service from the system (typically to be transported from one point to another), while the 'cars' and 'drivers' are the MHE (forklifts, manual trolleys, conveyors, etc.) with different capabilities (capacity, cost, speed, time, service level, etc.), called Material Handling Modules (MHMs). The core of the CMHS platform is the Intelligent Cognitive Engine (ICE) that can dynamically schedule and assign the handling requests to the available MHE resources based on techniques using Artificial Intelligence (AI).

The real-time localization of the SOs and MHMs due to the IPT implementation, and the sharing of their attributes/functions along with positions, are enabling new decision-making processes for scheduling and control of all the components in the system.

Figure 1 depicts the operation model developed by the authors at the base of the CMHS. It consists of three categories of stakeholders: SOs, MHMs, and ICE, sharing a common knowledge of the system.

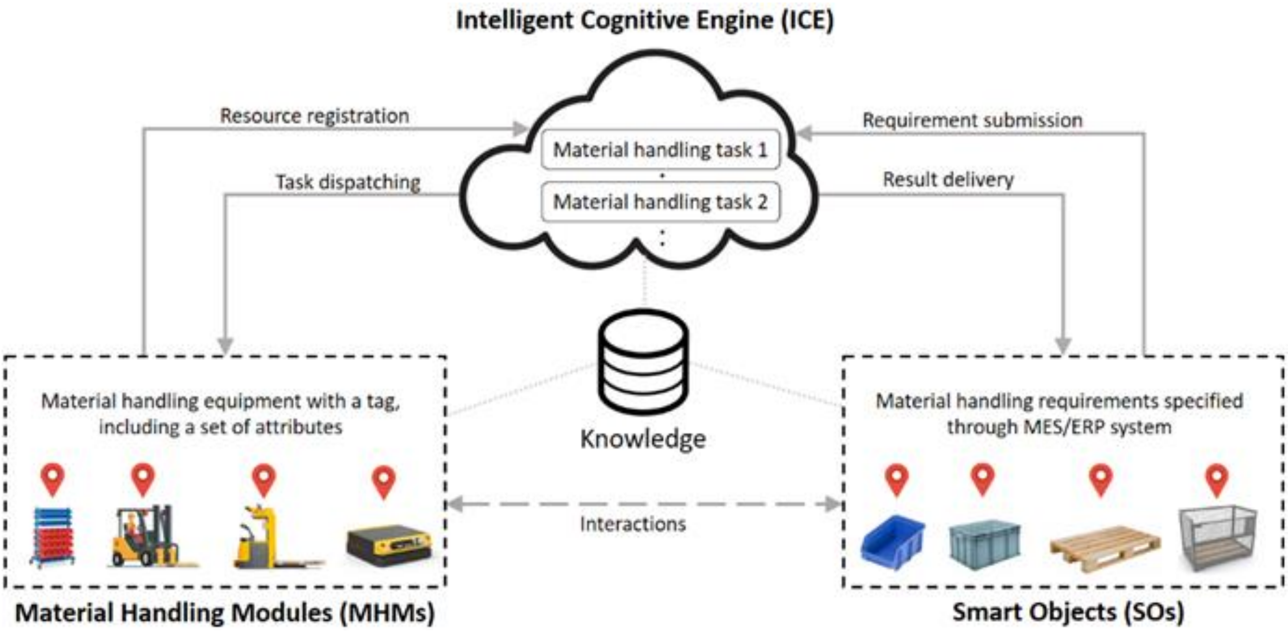

Figure 1. Operation model of Cloud Material Handling System (adapted from Liu et al, 2019)

Aligning with the concept of cloud manufacturing, the CMHS has the scope to satisfy consumers' requests (SOs) through the available resources (MHMs) in a cloud environment (ICE), reducing the complexity of a multilevel hierarchical control system and increasing the overall flexibility and productivity of the manufacturing system. The CMHS has been primarily developed for applications within a factory and production system. Nevertheless, the concept can be also extended to a multi-factory environment where the logistics activities are, for example, external transportations. With CMHS, the scheduling of the Material Handling Modules (MHMs) can be optimized, increasing the flexibility and productivity of the overall manufacturing system.

3. Preliminary Performance Analysis

From a theoretical perspective, the CMHS can bridge the gap between conventional material handling systems and fully automated ones. In pursuing a dynamic, flexible, and automated material handling system, few scientific contributions are dedicated to human-operated MHMs for material handling activities. Manual solutions often rely on conventional dispatching methods with low flexibility, restricting MHMs to predefined areas and/or material flows. In contrast, the CMHS provides automation capabilities for all MHMs, enabling increased freedom of movement. Flexibility is further enhanced as the CMHS is deployable for any facility, regardless of layout configuration and type of material flows.

In order to analyze the profitability and performance of the CMHS from a practical perspective, the CMHS has been analyzed in a fully cooperative multi-agent shop floor for the management of a forklift fleet using queuing theory. The basis of comparison measures fleet utilization and product throughput, serving as a foundation to develop general guidelines and variable thresholds for businesses to decide whether to implement the CMHS.

The fleet's performance has been evaluated by comparing two different dispatching methods: 1) fixed assignment policy where the forklifts are dedicated to specific areas and 2) on-demand policy where CMHS is used to manage the fleet. The latter approach investigates heuristic rules like Longest Waiting Time (LWT) and Shortest Travel Distance (STD), which have been used as benchmarks to assess the performance of deep reinforcement learning (DRL).

An extensive simulation model based on a case study has been developed with functionality for multiple scenario testing where the CMHS policies are compared to conventional fixed assignments. The scenarios are designed to test how the CMHS performs in situations when demand for material handling changes stochastically over time, in the event of workstation delays or when unforeseen maintenance is required.

The simulation results have shown that the CMHS returns higher total throughput (on average 25-30%) with a 40% decrease in the number of required MHMs in all scenarios compared to the fixed assignment. These results reinforce the hypothesis that the CMHS is well suited for dynamic shop-floor environments and that increased freedom of movement for MHMs can significantly increase material handling efficiency.

Furthermore, an analysis of how the MHM fleet should be dispatched optimally has been carried out. The results suggest that DRL can adapt well to stochastic material handling demand and outperforms the best heuristic by 10% in mean product throughput with a significantly lower deviation (8% compared to 16%). The performance of the DRL approach relative to the heuristics is consistently enhanced with higher variations in material flow demand and workstation delays, indicating that a machine learning implementation will be especially advantageous in such scenarios.

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Future Potentials of Circular Logistics – A SME Case Study Approach

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Extended Abstract

Summary. With the concept of a circular economy continuously gaining global momentum, industrial actors are confronted with both challenges and opportunities amidst such a fundamental transformation. Bearing disruptive potential for various industries, logistics in many respects commonly lies at the core of its realization, but yet has to unfold its full potential. While previous and ongoing research has led to an extensive conceptual framework and well-defined vision of a circular economy, the actual implementation on an operational level remains an unresolved challenge for many companies. By means of an in-depth reconstruction of a successful transformation case, this contribution aims derive tangible insights for the realization of circular economy approaches in SMEs. Laying particular emphasis on the core enabling role of logistics processes, basic constituents of a general business transformation model for circular economy are developed.

1. Background and motivation

Climate change and resource scarcity as well as the need to resiliently secure critical supply chains and industrial competitiveness in high-wage regions are key drivers of the transition to a circular economy (CE). The CE plays a central role in the European Green Deal, making such a transformation and the decoupling of economic growth from resource use (European Commission 2019, 2) a core objective of European economic and environmental policy for the next decades.

A widespread definition characterizes the CE as "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al. 2016, 224).

The systemic transformation to a CE can be disruptive in many respects and may pose both challenges and opportunities for companies. Throughout various industries, logistics play a fundamental role in the transition to and functioning of a CE, with the Association of German Engineers (VDI) stating the need to “develop and implement reverse logistics (…) as an own discipline of logistics” (Verein Deutscher Ingenieure 2019, 10). Yet, while a lively debate can be observed on the concept as a whole as well as implementation possibilities and business models in particular, the actual business model transformation which countless companies are confronted with, remains a widely unanswered question.

This calls for approaches which Schneidewind and Singer-Brodowski (2014) conceptualize as “transformative research”, in tradition of transdisciplinary (cf. Jahn et al. 2012, 1-10) differentiating between “systems knowledge”, “target knowledge” and “transformation knowledge” (cf. Waag 2012, 49; Hirsch Hadorn et al. 2008). Applied to CE, vast existing systems knowledge on the current state is combined with an increasingly clear target knowledge as most recently described by the Circular Economy Initiative Deutschland (2021). In terms of the subsequently essential transformation knowledge, among other approaches particularly case studies from the industry can provide tangible guidance on how the paradigm shift from the traditional, linear economy to a circular model can be accomplished and which logistical capabilities and technologies are needed.

2. Objectives and methodological approach

Awarded by the German Federal Environment Ministry (BMU) and the Federation of German Industries (BDI) with the German Innovation Prize for Climate and Environment 2020 (Innovationspreis für Klima und Umwelt 2020), the medium-sized manufacturing company Lorenz serves as starting point for the contribution at hand in order to develop elements of a generic circular business transformation model.

Taking into account the key significance of logistics and their interplay with product development, (re-)manufacturing processes and business models, in the contribution both concrete orientation for practitioners and a methodological input to the ongoing scientific debate is given, aiming to help concretize and leverage the opportunities of circular logistics. While numerous references (Circular Economy Initiative Deutschland 2020, 103; Lange 2017, 45-46; Schmidt 2017, 182-185) point out the pioneering role of the examined case, the transferability of empirical considerations is assessed in a structured manner for the purpose of general conclusions beyond this individual example.

Considering findings of reports and roadmaps (Ellen MacArthur Foundation, 2017; Hompel et al., 2018; Weber and Stuchtey, 2019; World Economic Forum, 2014), business model typologies (Angelis, 2018; Hansen et al., 2020) and upcoming frameworks for circular transformation (Frishammar and Parida, 2019; Lacy et al., 2020), this contribution combines such mainly high-level approaches with an in-depth analysis of a relevant individual case and adds a further distinct logistics perspective to the ongoing research. Based on a short summary and assessment of underlying concepts of CE and circular logistics, a three-step procedure is pursued.

First, the transformation process in the specific use case is reconstructed in terms of chronology, core strategic decisions’ rationale and operational execution. Due to special attention on the interdependencies of logistics, manufacturing, product and business model in a detailed case study, the complexity of circular transformations is captured to a degree which is not feasible in higher-level approaches.

Secondly, complementing this individual analysis with a more general perspective, the transferability of the given example is systematically evaluated in a delta assessment. On the one hand, the applicability of scientific frameworks to a real-world example of industrial practice is examined, and on the other hand the possibilities and boundaries of generalizing this specific case are challenged in order to better understand the nature and impact of advantageous framework conditions for the implementation of CE concepts. Thereby, basic constituents of a more general business transformation model for CE are developed with special attention to the crucial enabling role of data-driven logistical solutions and their scalability across individual products and companies.

Finally, resulting from the detailed understanding of an exemplary transformation process, the analysis of its further applicability and thereupon the foundations of a transformation model, general requirements for the broad application of CE approaches and action fields for circular logistics are derived. Closely related to this, the contribution concludes with critical reflections and by giving an outlook on further research needs reaching from the immediate logistics context to socio-technical aspects and involving political and regulatory frameworks.

3. Results and implications

While the Circular Economy is increasingly gaining global momentum, current experience shows that despite a sound conceptual foundation and extensive ongoing research the practical implementation remains an unsolved challenge for many companies, both corporates and SMEs. The approach described above can contribute on the one hand to making the concept and implementation potentials of CE more tangible to decision makers and technical staff and on the other hand to further scientifically developing the subdiscipline of circular logistics, opening the field for further cases, analyses and conceptual enhancements.

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Platform Concept for Shared E-Grocery Reception: A Simulation Study

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Extended Abstract

Summary. Online-grocery (e-grocery) shopping has become a popular alternative to stationary grocery shopping and yields a high potential to reduce traffic loads and traffic-related emissions by capitalizing on consolidation effects and economies of scale. However, the operational efficiency of e-grocery is often affected by failed delivery attempts. Hence, this extended abstract proposes a conceptional platform approach for shared e-grocery reception. The concept is developed based on a systematic literature review and assessed with an agent-based simulation model. To ensure a high degree of credibility, operational information on the system are obtained from a major omni-channel retailer and used as modelling parameters and reference values for validation. First preliminary simulation results indicate that, depending on reception share and recipient group sizes, shared e-grocery reception can yield mileage and emissions savings of up to 83.1% compared to traditional home-deliveries.

1. Introduction

Cities are running out of space. Worldwide, the growing population as well as the increasing importance of internet/mail order business and the urbanization trend in major industry nations are putting a strain on the infrastructure and present logistics in urban areas with unprecedented challenges (Coutard & Rutherford 2016). Within a city logistics context, home delivery of grocery items yields a high potential to significantly reduce traffic loads as well as environmental pollution (Auf der Landwehr et al. 2019). However, despite of increasing efforts by retailers to digitalize their product portfolio and capitalize on e-grocery business, utilization rates as well as sustainable impacts of grocery deliveries in Germany are very low yet (Seitz et al. 2017). One of the biggest obstacles remains inefficiency caused by reception procedures. Unlike in general e-commerce, where both unattended reception as well as reattempted deliveries are common practices, the individual peculiarities of grocery items require an attended reception, significantly increasing logistical planning and handling efforts (Kämäräinen et al. 2001).

To address efficiency issues regarding e-grocery delivery and reception, we propose cornerstones for a platform economy concept regarding shared grocery reception in urban neighborhoods and pre-determined geographical clusters, which is consecutively reviewed and compared to existing delivery structures by means of a simulation model. In what follows, we first outline our methodology (Section 2), before we elaborate on related studies as well as important insights from the literature review (Section 3). Subsequently, we present first elements of the sharing concept and demonstrate the potential impact of shared reception by means of a simulation study, which compares shared and individual reception in an exemplary metropolitan delivery area.

2. Methodology

In order to provide a foundation for the development of a platform concept for shared e-grocery reception and simulate the efficiency of shared reception within an urban context, we followed a multi-stage research approach. As shown in Figure 1, we first conducted a systematic literature review to exploratory identify decision, behavior and characteristics elements required for a sharing platform concept that is likely to be adopted by consumers. To ensure a high degree of data validity, we adopted a meta-characteristic coherent with our main research aim and conducted several iterations within the literature review phase to inductively gather relevant knowledge in the given research topic (Webster & Watson, 2002). We performed search queries in Google Scholar, AISeL and IEEE Xplore with the following keyword combination: ("online" OR "electronic") AND ("grocery" OR "shopping") AND "reception" AND ("sharing" OR "shared") AND ("platform" OR "concept" OR "strategy" OR "model"). Furthermore, based on the priory obtained knowledge and insights, we deduced conceptual elements serving as cornerstones for the development of an e-grocery platform sharing concept that is likely to feature high adoption rates.

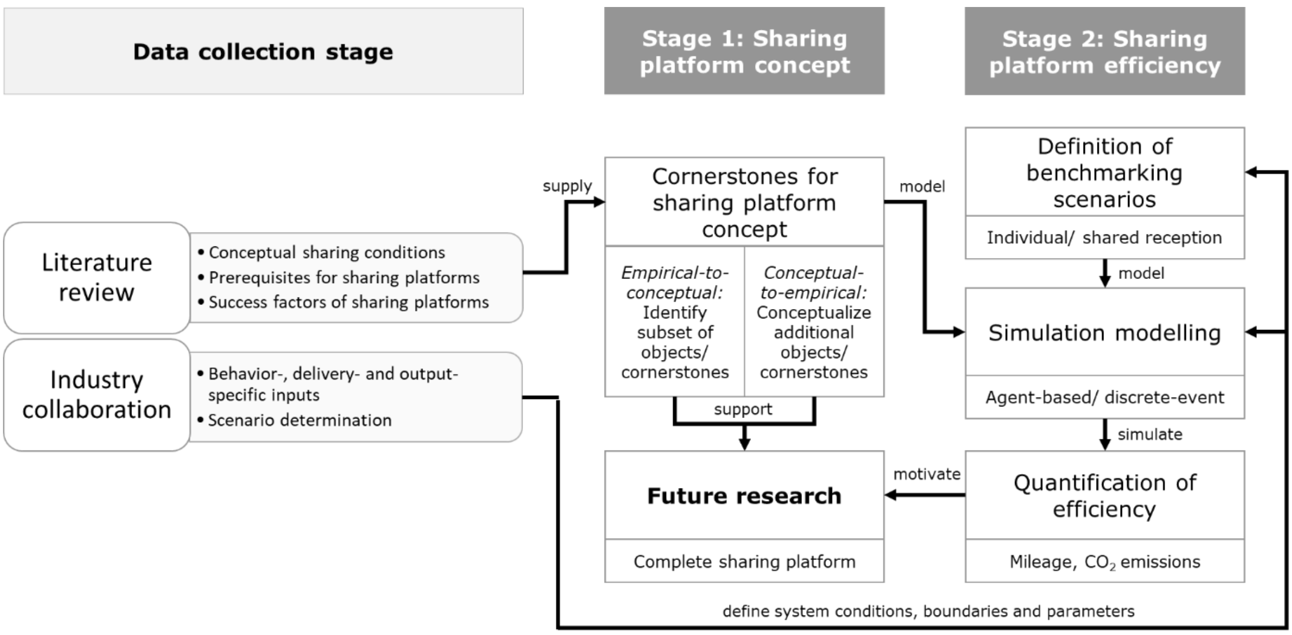

Figure 1. Multi-stage research design

Additionally, to motivate our research and highlight the need to develop a comprehensive and complete sharing concept based on our cornerstones in future research, we additionally assessed the potential impact of shared grocery reception by means of a simulation study combining agent-based and discrete event simulation techniques. The simulation model reflects all traffic influences in terms of mileage caused within a basic e-grocery scenario as well as a shared reception scenario on a mesos- as well as microscopic level (Figure 2). For conducting the simulation experiment, relevant input parameters on behavior-, delivery- and output-specific system conditions have been collected and include purchasing behavior, delivery truck capacity and utilization, basket values, vehicle emission outputs, shopping frequency and car utilization rates for grocery shopping.

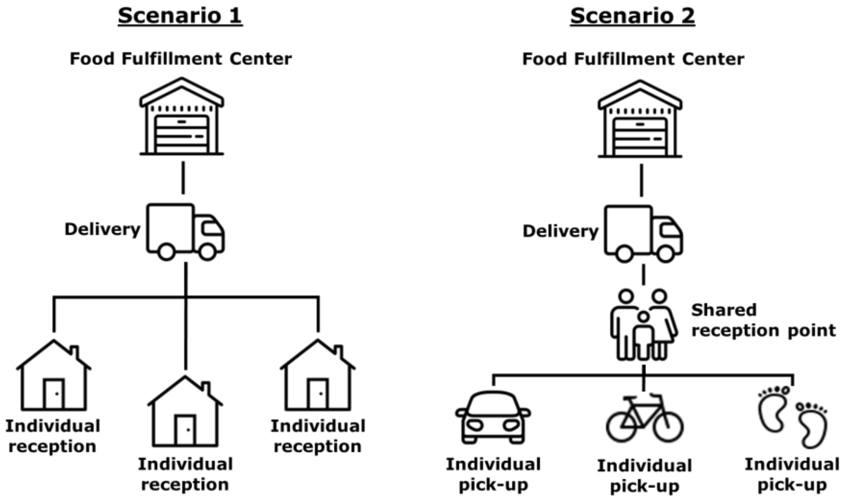

Figure 2. Simulation scenarios – Individual and shared e-grocery reception

3. Related Work and Literature Review

To overcome the obstacles related to grocery home deliveries, within the last decade, manifold fulfillment and product reception concepts have evolved. Most retail organizations focus on an attended reception with individual delivery time windows (Hübner et al. 2016). However, this concept implies major logistical challenges, costs and inefficiencies for the e-grocery, as it requires short response times, consequently leading to more inflexible timetables for both picking and delivery (Kornum 2005). Additionally, failed delivery attempts within an assigned time window result in additional expenses for transportation, handling, storing of undelivered goods as well as additional delivery tours (Hübner et al. 2016). To overcome the obstacles and disadvantages of attended reception, several providers offer different forms of unattended reception by means of reception boxes. While individual reception boxes seem to be unfavorable both in terms of economic as well as ecological benefits, shared reception boxes (SRBs) utilized to inter-store orders of several recipients are commonly used in industrial practice. According to computational insights from Kämäräinen et al. (2001), SRBs can aid in reducing logistics costs by more than 40 % and travel expenses by about 50 %. In terms of set-up, they can be placed at supermarket locations as well as points of public interest such as petrol or railway stations and have been used in manifold research and pilot projects (Punakivi et al. 2002). Besides of reduced logistical efforts, SRBs also aid in protecting customer privacy, as online shoppers can use the SRB as consignment address instead of their home address (Zhang et al. 2016). Nevertheless, unless positioned in a geographical dense network to allow consumers picking-up orders on foot or by bike, SRBs do not have a major influence on last-mile traffic as they results in a direct shift of driving activities from commercial to private individuals (Punakivi et al. 2002). Moreover, it is very difficult to determine spatial dimensions of both individual as well as shared reception boxes, as they are subject to seasonal peaks (Morganti et al. 2014) and customers generally prefer to personally check the quality of the goods received, which can only be done in attended reception (Kornum 2005). In contrast, click and collect concepts, allowing customers to order products online and consecutively pick them up within physical stores, are not impaired by seasonal demands in terms of storage facilities and control issues, however, feature a similar shift of last mile traffic compared to home deliveries as the SRB model (Hübner et al. 2016). According to González-Feliu et al. (2012), it can be expected that the shopping trip behavior for product pick-up at reception points is similar to stationary grocery shopping trips. Crowd-shipping, which has evolved as innovative concept of home delivery within recent years and deals with transferring last-mile delivery activities to third-party individuals, faces significant legal hurdles as private carriers are not as reliable as corporate service providers regarding theft or fraud (Hübner et al. 2016).

As literature indicates, several fulfillment concepts for e-grocery are available. However, current models feature various economic, ecological or social disadvantages. While attended reception is still the prevailing delivery method in Germany, shared grocery reception offers several advantages: (1) Customers and fulfillment procedures are unaffected by the delivery timing, (2) delivery times, tours, costs and distances can be decreased by dropping off manifold orders at one stop and (3) vehicle utilization can be maximized while transportation costs are minimized (Morganti et al. 2014). Still, to be economically, ecologically and socially viable, shared grocery reception concepts need to be refined further. Therefore, we subsequently propose several cornerstones required for a shared grocery reception concept based on platform economics.

Initially, the capacity of the grocery storage facility needs to be large enough to fit all order and store them in line with their individual requirements (e.g. temperature zones, cf. Punakivi et al. 2002). Furthermore, it needs to ensured that goods can be collected from these facilities for significantly long periods or in time windows that are convenient for the consumer. Hence, it is also crucial to allow consumers to influence or chose the geographical location of their preferred reception point. At the same time, e-grocers need ensure accessibility of reception points, especially in areas where no retail outlets or cooperation partners are given (Morganti et al. 2014). To increase social acceptance and the related lack of trust, community-based delivery approaches are most appropriate. In this context, the community can be a social entity with spatial implications (e.g. neighbors) or a virtual group of people sharing common values (e.g. social media group), whereby especially delivery concepts focusing on the first group seem to have a high economic, environmental and social potential. However, while market surveys suggest that leaving goods with neighbors is a popular form of unattended delivery, this approach also requires additional security procedures. A legitimacy check needs to be conducted to ensure goods are transferred to the designated (intermediate) recipient and a proof of delivery (POD) needs to be signed, whereby paper-based systems usually are more defective than electronic solutions (McKinnon and Tallam 2003). Especially the liability remains a major risk factor when recipients are not contractors. In contrast to SRBs, where liability is transferred as soon as the products are picked up by the customer, third party recipients have no contract with the supplier. Hence, even a signed POD does not effect a transfer of liability. Moreover, investments required for establishing the sharing concept need to be recovered by savings generated through decreased logistics, human resource and handling costs (Punakivi et al. 2002). Overall, last mile delivery success can be measured by six factors: (1) *Availability* (customer), *Convenience* (customer), *Security* (all stakeholder's), *Failed Deliveries* (service provider), *Delivery Costs* (service provider) and *Sustainability* (all stakeholder's) (Tiwapat et al. 2018).

In line with our insights, we propose an app-based platform economy concept for grocery (and general e-commerce) reception, utilizing the crowd (ideally within close proximity to the final consignee) as potential reception points for online shoppers, which will be elaborated on and synopsized in future research.

4. Simulation Study and Results

To show the benefits of an efficient shared reception concept (based on our cornerstones), we have conducted a simulation study, whereby individual attended reception serves as benchmarking scenario. The model employed for the simulation study was developed in AnyLogic (v. 8.5.2), contains fundamental components such as roads, intersections, driving behavior, vehicle flows as well as routing decisions and combines agent-based as well as discrete-event modelling approaches. The time advancing mechanism of the simulation is event-driven and triggered by behavioral interactions within agent networks. Several data sets regarding the e-grocery order fulfillment have been obtained from a major retail chain in Germany and utilized as input parameters for the simulation model. Moreover, the routing is conducted by means of a selective k-nearest neighbor algorithm, whereby product reception time windows act as main selection criterion. Overall, we conducted 500 simulation runs with a shopping instance population of 954 per simulation run. While shopping instances were not varied in terms of locations and amount, each run was initialized with different stochastic and discrete parameter values to identify the impact of different independent variables (share and group size of shared reception) on the vehicle mileage (sensitivity approach).

4.1. Model Assumptions

- The scope of the model is restricted to the areas "Mitte", "Oststadt", "List" and "Groß-Buchholz" in Hanover, Germany.
- E-Grocery fulfillment operations are conducted by a Food Fulfillment Center (FFC).
- The simulation scope is limited to last mile fulfillment and does not take into account logistics operations regarding the remaining supply chain.
- Delivery time windows have been determined by analyzing the mobility and shopping behavior of consumers in the given pilot districts (Wermuth et al. 2012; Nobis and Kuhnimhof 2018).
- The referenced delivery vehicle a Renault Master L2H1 with Kiesling Flat Runner box body (96 kW / 130 PS; ENERGY dCi 145 engine; Diesel; Euro 6b; 2.29 tons tare weight) and the corresponding emission factor per kilometer equals 253.52 grams of CO_2.
- Emission outputs were deduced by applying the vehicle specific emission factor to the simulated vehicle mileages.
- Acceleration and deceleration of vehicles was not specifically considered for this study and generally included in vehicle speeds.
- It is assumed that shared reception is primarily used in areas with high population density and geographically restricted, with a given radius of 200 meters.

4.2. Parameter Overview

Table 1 provides a comprehensive overview about the parameter values and variations that have been employed in the course of this simulation study.

Category	Value	Unit	Type
Fleet size	16	vehicles	fixed
Group size for shared reception	1 (min), 10 (max)	households	discrete
Loading time per trip	35	minutes	fixed
Location of FFC	52.447304, 9.697542	coordinates	fixed
Proportion of shared reception	1 (min), 10 (max)	percentage	discrete
Shared reception group size	Mean: 5, SD: 5	recipients	stochastic
Shopping frequency	51	percentage	fixed
Delivery tours per day	3	tours	fixed
Unloading time per order	Mean: 10, SD: 2	minutes	stochastic
Vehicle capacity	17	orders	fixed
Vehicle speed (inner city)	Mean: 30, SD: 5	km/h	stochastic
Vehicle speed (outer city)	Mean: 70, SD: 10	km/h	stochastic
Working days	6	days	fixed
Working hours	8	hours	fixed

Table 1. Simulation parameter values and classification

4.3. Preliminary Results

The simulation results indicate a significant reduction of mileage when employing a shared grocery reception concept compared to existing delivery routines. Table 2 provides a synopsis on the results depending on the discrete group sizes for shared reception as well as the discrete proportion of shared grocery reception. Cases with group sizes equaling one and/or reception shares equaling zero constitute the traditional scenario of individual grocery reception.

	Shared reception share										
Group Size	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
1	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473	1864/473
2	1864/473	1757/445	1678/425	1626/412	1588/403	1521/386	1464/371	1351/343	1254/318	1207/306	1072/272
3	1864/473	1757/445	1673/424	1588/403	1458/370	1369/347	1254/318	1128/286	1043/264	887/225	784/199
4	1864/473	1768/448	1650/418	1514/384	1406/356	1286/326	1205/305	1062/269	887/225	788/200	667/169
5	1864/473	1720/436	1619/410	1520/385	1445/366	1254/318	1074/272	1022/259	871/221	710/180	555/141
6	1864/473	1713/434	1622/411	1521/386	1368/347	1209/307	1072/272	907/230	784/199	667/169	478/121
7	1864/473	1714/435	1624/412	1462/371	1409/357	1177/298	1090/276	887/225	772/196	626/159	443/112
8	1864/473	1711/434	1624/412	1451/368	1351/343	1177/298	1062/269	865/219	745/189	593/150	424/107
9	1864/473	1710/434	1593/404	1458/370	1357/344	1181/299	1043/264	832/211	719/182	555/141	345/87
10	1864/473	1710/434	1600/406	1457/369	1326/336	1207/306	1033/262	813/206	717/182	528/134	315/80

Table 2. Simulated distances (in km) / CO_2 emissions (in kg)

In total, 98 % of all orders could be fulfilled within the given reception time windows. While shared reception resulted in decreased mileage and emissions compared to the benchmarking case in all scenarios investigated, the individual benefits increase with the share of consumers participating in this concept. Interestingly, the impact of the group sizes affiliating for shared reception has a minor impact on mileage and emission outputs than the share of the concept. For instance, mileage and emissions for 50 % of the entire population engaging in shared reception with a group size of ten exceed mileage and emissions for 60 % of the population utilizing shared reception with group sizes of four. Consequently, it can be assumed that the share of households engaging in shared e-grocery reception has a more significant impact on traffic reduction and environmental relief as the amount of people affiliating for shared reception. Generally, in comparison to the benchmarking scenario, shared grocery reception can yield mileage and emissions savings of up to 83.1 %.

5. Conclusion

In our contribution, we presented first conceptual cornerstones for an e-grocery sharing platform within urban neighborhoods. An in-depth analysis of multiple simulation runs has shown that the individual benefits of shared grocery reception can significantly outperform traditional grocery home delivery models in terms of mileage as well as emission outputs and therefore can efficiently contribute towards a more livable environment in cities. Consistently, our research serves as valuable foundation for both academia and practice to assess and understand consumer behavior in the field of e-grocery and to adapt given business models in order to achieve a better fit with the requirements of the consumers and the environment. In our next steps, we aim to refine and complete the sharing platform concept and to develop the simulation accordingly. Moreover, the scope of both simulation model (e.g. modal split for pick-up at shared reception sites) as well analysis (e.g. Monte Carlo approach) will be extended to provide more reliable insights.

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E-Commerce Warehousing: Order Fulfillment in Modern Retailing

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Keynote

Summary. This talk addresses suited warehousing systems and important optimization problems in modern e-commerce retailing. E-commerce mainly processes low-volume-high-mix picking orders, because private households tend to order just a few pieces per order from a large assortment. This talk gives an overview on suited warehousing systems, which are able to process a large number of these orders under great time pressure. For selected warehousing systems, we also address important optimization problems and define future research needs.

Optimization of Last Mile Parcel Consolidation From an Economic and Ecological Perspective

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Extended Abstract

Summary. Consolidation of parcels in urban areas has the potential to improve ecological sustainability. The purpose of this paper is to evaluate the economic viability and environmental impact of a micro-consolidation concept including cargo bike delivery within time windows. Methodologically, a Fleet Size and Mix Vehicle Routing Problem with Time Windows (FSMVRPTW) is designed to simulate last mile delivery routes, a sensitivity analysis is conducted and CO_2 emissions are calculated based on EN 16258. This work proves that the implementation of a micro-consolidation concept leads to benefits for the environment, but also to additional costs of more than 3 € per parcel in the presented case study. Therefore, the underlying work provides guidance of how to minimize these costs by identifying the most effective levers for operational improvement.

1. Introduction

Congested city centers and the wish of consumers for fast and flexible delivery are challenges of last mile operations. Moreover, the current parcel delivery structure with a variety of Parcel Logistics Service Providers (PLSP) is presumably not the most environmentally sustainable solution. Huge potential of consolidation on the last mile across the PLSPs to increase sustainability is not taken into account.

Pooling parcel deliveries from different PLSPs through a micro-consolidation center (MCC) in combination with cargo bikes deliveries within customer defined time windows is one consolidation concept that could lead to a more efficient, customer-friendly and sustainable parcel supply chain and at the same time relieve the urban traffic situation.

The aim of this work is to evaluate the economic and ecological sustainability impact of the mentioned concept and identify the main drivers. In order to reach this aim, a mathematical optimization model is built, enriched and validated with data of a field study and then performed on the example of a B2C parcel delivery case in a Berlin-Charlottenburg neighborhood as part of the research project „Kiezbote".

2. Prior Work

Urban consolidation can be realized using Urban Consolidation Centers (UCC) and/or Micro Consolidation Centers (MCC). UCCs are defined as logistics facilities located *relatively close* to the delivery area (Browne et al. 2005), for example aimed for a city or urban district. Whereas MCCs are located *very close* to the assigned target group and result in a very decentralized distribution structure suitable for cargo bike delivery (Assmann and Trojahn 2018). While the sustainability effects of UCCs are broadly discussed in the literature (e.g. Allen et al. 2012), MCCs have not been sufficiently explored so far. Browne et al. (2011) conducted a pilot using a MCC in London with the result that CO_2 emissions on the last mile could be reduced by 54% per parcel delivered, however, the financial results are not available due to commercial confidentiality. Sheth et al. (2019) focus only on the financial aspect of cargo bike delivery in time windows in dense urban areas. They find out that cargo bikes can be more cost effective for deliveries close to the distribution center, what emphasizes a MCC implementation. Melo and Baptista (2017) analyze the impact of consolidated cargo bike deliveries on urban logistics with the result that CO_2 emissions can be reduced by over 70%.

New consumer requirements like time window delivery are rarely considered in prior studies in the field of last mile consolidation and eco-friendly transportation as the initial overview has shown. Most of the prior work is only estimating or simulating routes in a simplistic way. With our work, we evaluate the ecological impact *and* the economic viability of receiver-centric urban last mile consolidation including delivery with cargo bikes by solving a detailed routing problem.

3. Methodology

3.1 Last Mile Vehicle Routing and Sensitivity Analysis

To simulate last mile delivery routes close to reality we design a *Fleet Size and Mix Vehicle Routing Problem with Time Windows* (FSMVRPTW), also referred to as *Heterogeneous Vehicle Routing Problem with Vehicle Dependent Routing Costs including a Time Window* (HVRPDTW) (Liu and Shen 1999; Bräysy et al. 2008). With this kind of model, a delivery with different vehicle types as well as different capacities and velocities can be simulated. Because of its more complex characteristics it belongs to the "rich" CVRPs, that are close to practical distribution problems (Baldacci, Battarra, and Vigo 2008). In contrast to the basic CVRP with cost focus, the presented model aims to find a fleet composition and a corresponding routing plan that minimizes the total time to serve all customers in the given time windows. To achieve economic sustainability, we calculate for every time window the most resource-efficient fleet composition.

The calculated vehicle routing serves as a basis for determining the required vehicle fleet, the delivery staff and the associated variable costs of the last mile delivery concept. For simulating realistic delivery conditions, we propose to use a range of stochastic parameters, such as changing parcel amounts during the week and time windows per day. In addition, the calculation of different scenarios (e.g. different parcel amount estimations) helps to validate the sensitivity of the fleet composition. This sensitivity analysis helps to predict the costs per parcel depending external conditions. Next to the described variable cost components, a share of fixed costs (e.g. the warehouse rent) needs to be included.

3.2 CO_2 Emissions Calculation

The performed vehicle routing allows determining the ecological sustainability based on transport emissions of the delivery concept. Due to obtain a holistic picture of the incurred emissions, we propose a well-to-wheel emission calculation that considers direct emissions created by the fuel consumption of the transport services (tank-to-wheel) and indirect emissions caused by the production of power and fuels, the manufacturing of vehicles and construction of streets and maintenance of the transport network (well-to-tank) (Schmied and Knörr 2012). We propose the standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" for the calculation. For measuring the sustainability impact, the traditional parcel transports of multiple parcel delivery services beginning from the final distribution center needs to be modeled in addition.

4. Case Study: Consolidated Parcel Delivery in Berlin

4.1 Description and Data Collection

The presented methodology has been applied to an urban last mile consolidation case in a Berlin-Charlottenburg neighborhood with 15,000 inhabitants as part of the research project "Kiezbote". Within this project a MCC has been operated to deliver parcels with different types of electrical cargo bikes within four time windows per day from Monday to Friday and two on Saturday. This case study has been generated as preperation for the "Kiezbote" operations with the help of secondary data and industry experts of the project consortium. Some data like the bike speeds and capacities could precisely be determined whereas a set of estimates and assumptions regarding the later real operation were necessary to solve the FSMVRPTW with an appropriate data set. The distribution of parcels across the week and the daily time windows as well as parcel volumes and handover times per parcel were stochastically simulated to cover uncertainties. The baseline scenario estimates in average 100 parcels per day, three minutes of handover time per household, ten minutes of bike loading time at the hub per trip and a parcel volume of 0.06 m^3. For the calculations, we wrote the model in Python and used Gurobi as a solver.

4.2 Results

Applying the FSMVRPTW to the collected data illustrates for every simulated time window the economically most sustainable bike fleet. This calculation proved for the baseline scenario a fundamental feasibility of the delivery with only two deliverer and two cargo bikes. It also showed that stochastic demand peaks could bring the delivery service occasionally to the limits. Apart from the costs for delivery personnel and the leased cargo bikes, the total costs also consider different types of fixed costs, including the micro hub rent and equipment, software and hardware depreciations, insurance fee, and personnel costs for hub handling, operations planning, and administration. Large daily parcel amounts significantly exceeding 200 parcels would let jump up the fixed costs due to more required warehouse space and equipment. In total, the last mile delivery concept can be operated at costs per package of around 3.40 € for a daily amount of 100 parcels. Cost drivers are particularly labor costs, followed by the micro hub rent and operational costs for the cargo bikes.

The results of a sensitivity analysis presented in Figure 1 show that even smaller variations of individual input parameters of the FSMVRPTW can have considerable effects on the resource requirements. It demonstrates that the daily amount of parcels, the length of the given delivery time windows and the average service time per customer have the largest impact on the economic performance. Further experiments have shown that best- and worst-case scenarios (by varying multiple parameters) for an amount of 100 parcels lead to even higher sensitivities.

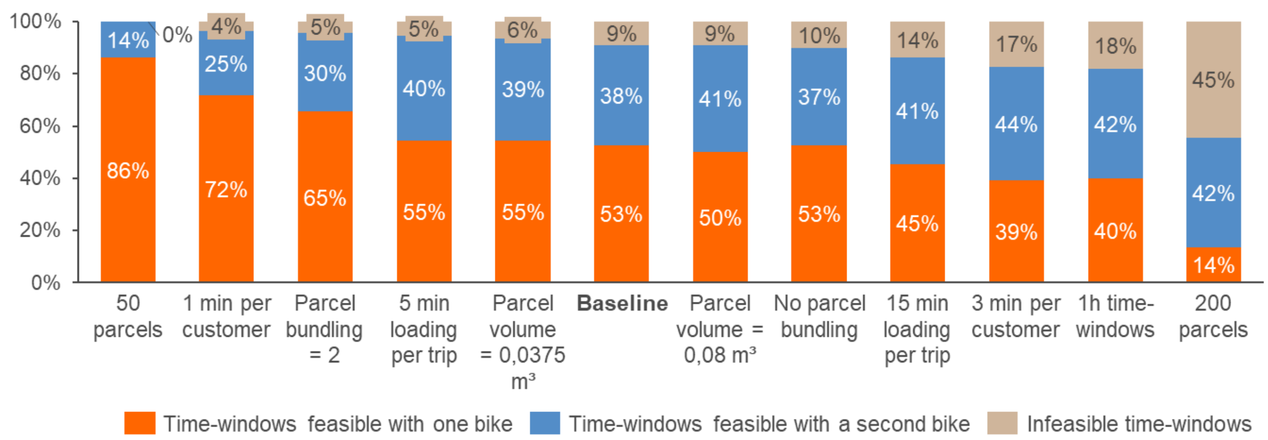

Figure 1. Share of feasible delivery time windows per scenario

To compare the sustainability of this concept with the traditional parcel delivery, the transport emissions of both variants have been calculated based on the standard EN 16258, like outlined in section 3.2. The relevant well-to-wheel CO_2 emission factors refer to the HBEFA data base (HBEFA 2020) and result in 182.3 g CO_2e/km for standard delivery vans and 15.6 g CO_2e/km for the cargo bikes. Emissions caused by energy consumptions in the micro hub are not considered. The distance between the distribution centers, mostly located near the city boarders of Berlin, and the MCC claims a high share of almost 80% of the transport emissions but cannot be prevented with this concept. The CO_2 emissions of the parcel delivery process to the end customers on the last mile can be reduced by almost 60% compared to the conventional 3.5t-diesel-vehicles.

5. Discussion and Implications

The results have shown that the customer-friendly MCC cargo bike delivery concept can be operated at costs per package of more than 3 € for a daily amount of 100 parcels. The sensitivity analysis, conducted with varying input parameters indicates that particularly the daily amount of parcels has a substantial impact on the economic performance. The results of the $C0_2$

emissions calculation confirm findings of prior work and showed that significant emission savings on the last mile delivery process could be reached, even with time window delivery. In order to obtain these ecological benefits, additional costs are caused that could be covered either by PLSP due to consolidation savings, online retailers due to customer service, city administrations due to less congested streets or parcel recipients who can flexibly choose the parcel arrival times. Public-private partnerships and subsidies for sustainable last mile consolidation can help to align the interests of public and private actors and achieve higher efficiency.

The results underlie some limitations. The size and total freight activities in the urban area served could have limiting effects on the environmental benefits. In addition to that, more real-world data could improve the model. Further efforts could also be made to improve the robustness of the optimization with the help of a very large number of calculation runs simulating the highly uncertain conditions. Further investigations could be made to enhance the concept, e.g. with other sustainable vehicle types or a broader range of services like parcel return collection. Also, the location decision of MCCs could be more researched in future. Advanced research should also be made regarding a sustainable delivery structure through all upstream supply chain stages, e.g. the transports from the regional distribution center to the MCC. Empirical studies on the acceptance of the service could provide profound insights for a widespread use.

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Key Requirements and Concept For the Future Operations Control Center Of Automated Shuttle Buses

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Summary. It will take up to 10 years before automated shuttle buses can achieve an autonomous driving level and realize their potential in terms of flexibility and cost efficiency. An approach to deploy automated shuttle buses in a mixed traffic environment in the near future is remote monitoring and intervention by an operations control center. Based on an analysis of current operations control centers combined with the market analysis of automated shuttle bus providers and the currently existing needs for human intervention in certain traffic situations, a set of use cases was developed. With the help of the use cases, the key requirements for the operations control center and the operator's remote control interface could be derived and prioritized in workshops. For example, taking control in emergency situations, stronger networking with the infrastructure and passenger communication are important tasks. This paper introduces how automation in public transport, and automated shuttle buses in particular, will influence the concept of the operations control center. For this purpose, the key tasks and requirements including the information needs are presented.

1. Introduction

Automated shuttle buses are one of the future mobility concepts that can contribute to the traffic turnaround (Agora Verkehrswende 2017, 14; Salonen and Haavisto 2019, 588). These buses combine the flexibility of individual public transport with the capacity utilization and economy of public transport (Barrillère-Scholz, Büttner, and Becker 2020, 16-17; Knie, Canzler, and Ruhrort 2019, 22-23). Furthermore, these vehicles meet many challenges for future mobility because they are automated, electric, safe, and can be shared (Agora Verkehrswende 2017; Kagermann 2017, 22-60; Sustainable Mobility for All 2019, 16-21).

However, fully autonomous driving will not be achieved before 2030, according to forecasts (Lalli 2019, 19). Currently, the automated shuttle buses drive on virtual tracks and can detect obstacles, such as other road users but cannot avoid them independently (Kolb et al. 2020, 62-63). For this purpose, an operator is present on board to control via joystick and his presence is also legally required (Kolb et al. 2020, 62-63; Michelmann, Pauthner, and Mehlert 2017, 30-32). In addition, the infrastructure along the pilot routes with automated shuttle buses must also be adapted. Measures include maximum speed limitations, information signs, no stopping signs or one-way street regulations (Beckmann, Biletska, and Zadek 2020, 308-311). Thus, the current development status of shuttle buses according to SAE J3016 is between "partially automated" and "fully automated" (Kostorz, Hilgert, and Kagerbauer 2019, 64).

In order for automated shuttle buses to be used in public transport, a high level of service reliability is required (Bout et al. 2017 63). Furthermore, public transport must also be operated economically, which is complicated by having an operator on board (Bösch et al. 2018, 81-84). These requirements cannot be met in the short term by technological development of vehicles alone (Zhang 2020, 2). Rather, the automated shuttle buses need support from outside the vehicle. V2X communication can be used to provide valuable information to the automated driving system (Wood et al. 2019, 140). As a result, safety can be increased (Lin 2015, 72). V2X communication is also a solution approach to enable communication between autonomous vehicles and human drivers (Färber 2015, 144). One form of V2X communication is the operations control center, from which the shuttle bus can be monitored remotely and intervened if necessary (Bout et al. 2017, 63; Kettwich and Dreßler 2020, 69). The use of human operators can compensate for the shortcomings of automated vehicles (Zhang 2020, 2; Kettwich and Dreßler 2020, 69). Therefore, the use of an operations control center (OCC) is a measure that enables autonomous driving in public transport earlier (Leonetti, Ackermann, and Schmitz 2020, 4).

The aim of this publication is to develop key requirements and a concept for an OCC for automated shuttle buses. In addition, the research question of whether OCCs will promote safe operation of automated shuttle buses in the future, will be answered.

For this purpose, the impact of V2X communication on autonomous driving is explained first. Afterwards, the methodical approach will be explained. Based on this, main requirements and the concept of an OCC are presented. Finally, the summary and the need for further research follows.

2. V2X Communication

As a means of improving the interaction of an automated bus or car with its environment and supplement the data from the built-in sensors, the concept of the connected car can be used (Coppola 2016, 10). As one possibility of these concepts the V2X-Communication should be discussed here. V2X stands for Vehicle-to-Everything communication and can operate on an adapted version of the 802.11 wireless standard or a cellular connection (Coppola 2016, 10). The in V2X included types of connectivity are: V2I – Vehicle-to-Infrastructure, V2V – Vehicle-to-Vehicle, V2N -Vehicle-to-Network and V2P – Vehicle-to-Pedestrian (Coppola 2016, 11). All of these types of connectivity have applications which can enhance the safety, user experience or the amount of data an automated vehicle can make decisions from. There are two types of messages which can be send out over the V2X standard. The first type of message which are sent out periodically and are called Common Awareness Messages (CAM). In contrast to these are the Decentralized Environmental Notification Messages (DENM) which are intended for alerts of hazards and other non-periodical information (Backfrieder 2018, 56). For example, a V2I application of a CAM can be the periodically transmission of a message which includes the signal phase of a traffic light and the time until it switches to the next phase. This type of message is called Signal Phase and Timing (SPAT). With this information an automated bus can for example make the decision if it can proceed on its way over an intersection, possibly even if the built-in sensors are not working properly. Furthermore, the same information could be sent to an OCC via V2N. There, all information from multiple sources can be collected and used for multiple devices, vehicles or infrastructure. From there an operator can overview a big area with all the automated busses which are currently driving. Using the information received from the infrastructure, the operator can make decisions or adjustments regarding the operation of these buses. The communication can also be used the other way around. For example, an automated bus could make a request to a traffic light at the next intersection to be given priority at that intersection. This application could reduce waiting time and energy consumption (Hobert 2015, 65). With applications in the V2P connectivity type there are possibilities to reduce the amount of traffic accidents between vehicles and pedestrians. Anaya et al. introduced a system where pedestrians and vehicles have a connection to the same network so that the used devices can locate each other and if there is an accident between them imminent (Anaya 2014, 3). Possibilities for V2V applications are plentiful. For example, could a bus which is just changing into the lane from a bus stop send out a message to all vehicle in the area that it is changing lane so that vehicles on that specific lane can already reduce their speed accordingly to avoid any accidents. In case of accidents there is a possibility to send out DENM to all nearby vehicle and to an OCC to inform of this accident. Vehicles nearby are now aware of it and can avoid to it accordingly (Coppola 2016, 11). The operator in the OCC could also reroute busses so they don’t get stuck in a traffic jam and the provided transportation service can keep up the level of service. As seen in this section the integration of V2X into automated vehicles including busses can improve the level of service and safety, especially if an OCC gets introduced into the network from where all of the date from the V2X-devices get combined.

3. Methodical Approach

In order to identify the key requirements for the future OCC for automated shuttle buses in public transport, the procedure was divided into three steps. The first step was the analysis of typical tasks of today’s OCCs. In order to structure the tasks, the publication 731 “Operational requirements for public transport operations control centers” from the Association of German Transport Companies (VDV) (Berger et al. 2015, 8-15) was referred to. In addition, OCC employees of two transport companies were interviewed and one of the OCCs was visited.

In the second step, the identified tasks of an OCC were supplemented by requirements regarding automated driving. For this purpose, the current challenges of automated driving were researched and discussed with a provider of automated shuttle buses. A market analysis was conducted on the leading providers of automated shuttle buses and teleoperation (remote operation) applications to identify current opportunities and trends in the monitoring and remote control of road vehicles. Afterwards, the following 5 use cases were elaborated: monitoring of regular operations, incoming passenger request, assistance when entering a traffic circle, assistance when crossing a traffic light intersection and assistance when driving around an obstacle. The use cases illustrate how the OCC can intervene in these situations and improve safety and service level. Based on these use cases and previous research, the main additional tasks of an OCC could be identified. For each of these use cases, the team brainstormed to determine which driving functions and other tasks would have to be taken over and what information the operator would need for this. The provision of information by the infrastructure or V2X communication was also considered.

Finally, as a third step, the identified requirements for an OCC for monitoring and remote control of automated shuttle bus fleets were discussed and prioritized in a workshop with a control center operator of a transport company. Based on the results of the literature research, the use cases and the communication with transport companies and a shuttle bus provider, the essential requirements for a control center were determined and a rough concept of a future OCC was derived.

4. Concept of the Future Operations Control Center

This chapter will clarify how automated shuttle buses affect the functional areas and tasks of an OCC and what opportunities the OCC has to increase the safety and service level of automated shuttle buses. Finally, a rough concept of the OCC is presented.

4.1 Factors Influencing the Future Operations Control Center

In addition to the typical tasks of an OCC, such as monitoring regular operations, fault and emergency management, dynamic passenger information and passenger communication, dispatching of on-demand services, performance and quality controlling (Berger et al. 2015, 4; Janecke et al. 2005, 167-174; The World Bank Group 2019), future OCCs must meet the challenges of automated traffic and ensure its safety. In this context, the main challenges or tasks in automated driving can be classified as follows: road detection, lane detection, vehicle detection, pedestrian detection, drowsiness detection, collision avoidance, and traffic sign detection for which numerous methods such as machine learning and V2X communication exists (Muhammad et al. 2020, 2). The control center is to support the automated shuttle buses with human assistance where their own sensors and AI reach their limits, thus forming an essential fallback level in the system. The German government’s latest draft law on autonomous driving also already specifies a number of requirements. The OCC, as the technical supervisor, must be able to access the vehicle at any time, e.g., to deactivate it or to carry out necessary releases (BMVI 2021, 20). For this purpose, the remote operator must be able to view the required data in the form of a video stream of the bus environment or the bus interior or information from the infrastructure in real time at any time and use it for a quick assessment of the traffic situation. The teleoperation approach offers the remote operator this possibility (Neumeier et al. 2018, 1-2). This can be a fully featured remote cockpit that replicates the design of a bus driver’s seat, including the steering wheel and accelerator and brake pedals. It can also be a simpler setup in the form of a computer, monitors, camera and microphone to perform less complex control functions (driving maneuvers), such as stopping the vehicle or giving the command to proceed. The focus here is on decision support for the AI, especially in the areas of the more complex traffic circles or traffic lights, when, for example, V2I communication should fail and, due to adverse weather conditions, automated detection of the traffic light phase using the optical sensors is subject to high uncertainties. The image display can be done e.g. on multiple monitors or by means of augmented reality. The operator can be supported by intelligent predictive assistance systems that compensate for the possible latency-related delays (Davis, Smyth, and

McDowell 2010, 4). Thanks to today's mobile phone (cellular) network, data transmissions over long distances and with low latency are well feasible (T-Sytems 2021; Inam et al. 2016, 1). Providers for teleoperation systems like Phantom Auto or Ottopia in cooperation with T-Systems offer software solutions to monitor fleets or draw a path for a vehicle to follow (Ottopia 2021; Phantom Auto 2021). If necessary, the operator can even take over the vehicle steering manually (Ottopia 2021; Phantom Auto 2021). Other prominent examples of teleoperation application providers such as Fernride (Fernride 2021), Cognicept (Cognicept Systems 2021) or Voysys (Voysys 2021) also offer remote control solutions to increase the availability of different types of vehicles within logistic processes.

The elimination of the bus driver as the safety and contact person in the bus also brings passenger communication to the foreground as one of the central tasks of the OCC (Jaap et al. 2015, 14). This requires an audio-visual interface for passenger communication in the control center.

4.2 Requirements for the Future Operations Control Center

In the following, the essential functional areas, such as operational handling, measures to maintain safety and service tasks of a conventional control center, are supplemented by the tasks and requirements caused by the automated shuttle buses and presented in Table 1. Tasks that remain largely unchanged or have little relation to operational handling are omitted from the overview. The functions and the necessary information flows between the control center and the automated shuttle bus were determined primarily from the perspective of a remote operator.

Task	Requirement	Information needs[1]
monitoring of the traffic situation (regular operation)	display of bus routes including the essential basic data of the vehicle on a dynamic interactive map deviations from the timetable or other information should be indicated, e.g. status of routes in a color-coded format	bus ID, GPS position, direction of travel; route, stop, infrastructure plan; target/actual position comparison; forecast and proactive evaluation of deviations; connection relations to other transport lines; vehicle technical status; vehicle driving mode; vehicle speed; door status; vehicle occupancy (capacity); battery status, range, expected charging time
vehicle dispatch and dynamic rescheduling (on-demand, plannable deviations such as construction sites, events)	resource overview (see above) efficient automated matching methods and algorithms precise, dynamic real-time maps	as for monitoring of regular operations; customer requests and data (GPS position, direction of travel, number of stops to be traveled); status data of the infrastructure (technical failures); reporting data from the infrastructure (congestion information, traffic density, etc.)

[1] list is not exhaustive

Task	Requirement	Information needs[1]
fault management	initiation of measures in case of deviations from the timetable or technical malfunctions in the bus is automated to the greatest possible extent automated interfaces to the areas of performance and quality controlling (maintenance) of the vehicles as well as vehicle dispatching data is provided as a digital shadow, or better as a digital twin	as for monitoring of regular operation; status data from the infrastructure (technical faults); reporting data from the infrastructure (congestion information, traffic density, etc.)
emergency management	automated communication with the traffic management center and the emergency service operator gives information, instructions, etc. to passengers through an audio-visual interface in the shuttle bus	decentralized Environmental Notification Messages (DENM); audio and video stream from vehicle inside and outside; operational status: vehicle occupancy, speed, door status, position and range; technical status: connection status, sensor status, number and location of technical faults
remote control of the vehicle	remote control maneuver-based (provide a new path for the vehicle) or fully manual and then return control (remote cockpit for teleoperation needed) remote operation by approval (e.g. continuation of the ride after evaluation of specific situation, in complex traffic situations, after intervention request from the vehicle)	bus ID, GPS position, driving direction; video stream from outside (front, side and rear camera) and from inside the bus; additional information from infrastructure such as images from cameras or sensor data; operational status: vehicle occupancy, speed, door status, position and range; technical status: connection status, sensor status, number and location of technical faults
infrastructure monitoring	big Data algorithms dynamic interactive map manual access to the individual infrastructure objects and their data implementation in the OCC interface / remote cockpit	technical status of traffic lights, road side units, other sensors and networked infrastructure objects; camera images of complex traffic junctions (traffic circles, intersections); traffic density; charging infrastructure
infrastructure control	dynamic interactive map of infrastructure objects, including bus routes coordinated prioritization of traffic flow by influencing the signaling systems	as for monitoring of the infrastructure; relevant information from other authorities (emergency service)
passenger safety	answering of the emergency calls rapid alerting of the authorities	alarm plans, bidirectional video and audio transmission

Task	Requirement	Information needs[1]
cybersecurity	secure data transmission channels and encryption AI and cloud-based solutions	(programs run automatically in the background)
passenger communication	answering requests from bus, stops, etc. voice communication preferred, but also app messages possible	fault messages and causes; actual and target timetable, deviations; forecast (e.g. estimated time of arrival, available connections, etc.)

Table 1. Key tasks of an operations control center for automated shuttle buses and requirements as well as concrete information needs

The key requirements for a future OCC are thus the technical interfaces and a user (operator) friendly interface for rapid situation assessment and remote control of automated shuttle buses when needed, communication with passengers especially in emergency situations, stronger networking with the infrastructure, and cyber security.

While currently the information transmission from the bus is mainly done as predefined text blocks or voice calls, the OCC must be able to process large data (video) streams in the future. In the interviews with an operator of a transport company, for example, there were concerns about the permanent use of VR glasses because of the possible stimulus overload. When designing the control center, attention should be paid to reducing the workload of employees (especially when dealing with faults and smaller incidents). There is also a great fear of manipulation and hacker attacks, both on the part of the providers and operators of automated shuttle buses and on the part of potential users. For this reason, as well as for economic reasons, it is desirable that the vehicle can operate as autonomously as possible or with automated support from infrastructure, as described in chapter 2. Nevertheless, the level 5 of automation should not be waited for and a balance must be found between the minimum possible need for intervention in the vehicle control and the guarantee of safe operation. An obvious solution therefore is to support the sensor detection of the shuttle bus by V2X technologies. If this is not sufficient, the operator can manually assess the situation and issue commands such as the release to continue driving. If a driving maneuver is required to avoid an obstacle, the driving route can be executed by entering certain parameters or by drawing it on an interactive map. The role of the charging infrastructure and innovative concepts such as inductive charging while driving will increase significantly, so the operator will need the related displays (e.g. battery status) and control instruments.

In the future, the control center operators can be supported by the cloud-based assistance systems, up to the complete takeover of the vehicle control by the AI, which analyzes diverse information of the infrastructure and the individual vehicles and gives maneuver instructions to the vehicle (cloud-based driving). Thus, human teleoperators could be replaced by automated teleoperation through cloud-based AI services. Figure 1 illustrates the role of the OCC for monitoring and controlling automated shuttle buses and places it in the overall ecosystem.

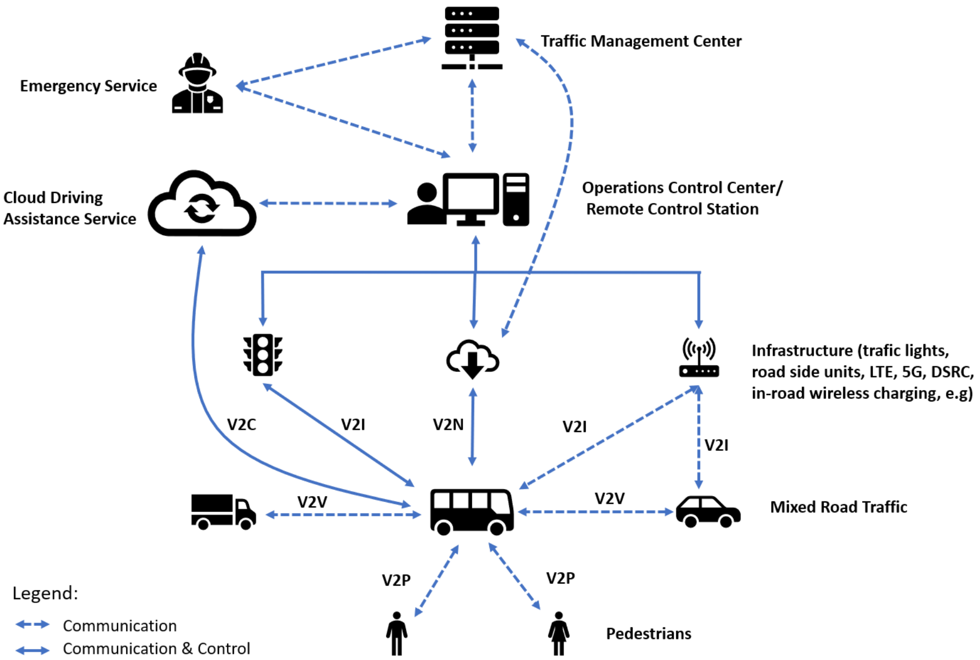

Figure 1. Digital ecosystem of the future operations control center

5. Summary and Future Research

According to current forecasts from science and industry, level 5 autonomous driving according to SAE J3016 is still at least a decade away from technological realization. Until this level is reached and the automated shuttle buses have to operate in mixed traffic, but also according to the current legal situation in Germany, remote monitoring and intervention by an OCC will be indispensable in the future. By means of literature research and interviews as well as workshops with transport companies and control center operators, we identified the most important requirements for an OCC for automated shuttle buses and some hints for implementation, which were presented in chapter 4. In conclusion, many of today's tasks, some of which are still performed manually, will continue to be automated. To achieve this, the individual task areas of the OCC must be more closely networked with each other and with the environment in the sense of a digital ecosystem. However, completely new tasks will also be added, such as human assistance in assessing the traffic situation or taking over vehicle control remotely. To consolidate the findings, the various levels of monitoring, communication and intervention options in an automated shuttle bus were graphically depicted as a rough concept of a future OCC. Whether the primary driving functions such as longitudinal and lateral guidance should be taken over manually by the remote operator needs to be investigated in greater detail because many different factors such as cyber security, studies on the attentiveness and responsiveness of teleoperators, legal regulations, etc. play an essential role here. The level of service for each specific operational situation should be determined based on risk analyses of the possible scenarios and the failure probabilities of individual network elements, so that the balance between security and the required fallback levels and the investment and operating costs can be maintained. It is also necessary to further investigate which spatial and functional organizational structure is best suited for automated driving and which parameters can be used to determine the number of shuttle buses supervised by an operator.

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Last-Mile Delivery with Truck-And-Robots

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Extended Abstract

Summary. During recent years, several companies have introduced autonomous delivery robots and evidenced their technical applicability in field studies. However, a holistic planning framework for routing and utilizing these robots is still lacking. This paper presents an approach to cost-optimal routing of a truck-and-robot system for last-mile deliveries with time windows, showing how to minimize the total costs of a delivery tour for a given number of available robots. Our algorithm is based on a combination of a neighborhood search with cost-specific priority rules and search operators for the truck routing. We show in numerical experiments that our approach is able to reduce last-mile delivery costs significantly. Within a case study, the truck-and-robot concept reduces last-mile costs by up to 68% compared to truck-only delivery. Finally, we apply sensitivity analyses to provide managerial guidance on when truck-and-robot deliveries can efficiently be used in the delivery industry.

1. Problem Description

The last mile in order fulfillment is an essential challenge for retailers and logistic service providers and is responsible for a large share of total logistics cost. The volume of online orders constantly increases (Allen et al., 2018), which leads to an increasing volume of traffic, especially in dense urban areas. This paper addresses this issue by proposing a method for cost-optimal truck-and-robot delivery in urban areas.

The concept of autonomous electric delivery robots launched from a truck ("truck-and-robot concept", see Daimler, 2019) can significantly reduce traffic congestion, emissions and cost of last mile deliveries in cities. The small robots, e.g., developed by Poeting (2019a), Marble (2019) and several competitors, transport an order (e.g., parcel or a grocery basket) to a single customer until a given deadline. Robots navigate on sidewalks at pedestrian speed and can safely move in autonomous mode most of the time or switch to remote control in case of problems. Once the robot arrives at the door, the customer is notified and can then unlock the freight compartment to retrieve his order. Delivery robots have been successfully tested in different setups (e.g. Starship, 2019). For large-scale application, the challenge is to deal with their low speed. Thus, they are combined with faster means of transportation such as trucks. The truck carries all goods to be delivered and stops at defined drop-off points to release the robots for delivery. From the customers, the robots return to charging stations, where a truck can pick them up again on its route. Consequently, the truck repeatedly picks up robots waiting at charging stations such that it never has to wait for robots to return from the customer. Figure 1 shows an illustrative example of a truck-and-robot tour.

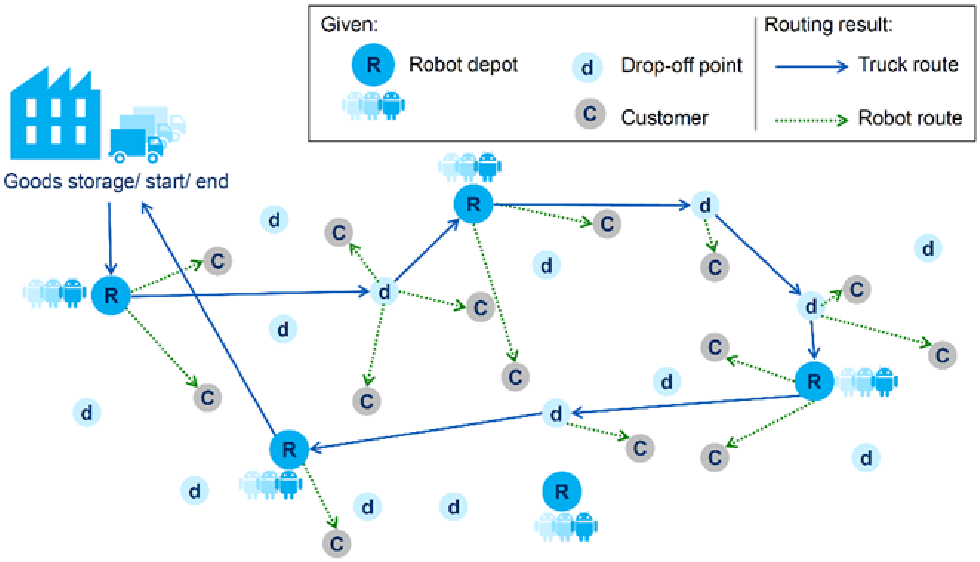

Figure 1. Illustrative truck-and-robot tour

The combination of trucks and robots for the delivery results in a complex routing problem that involves the synchronization of the truck, the movement of robots and the compliance to existing delivery deadlines. We must find a route for the truck and a starting location on that truck route for every customer delivery by robot, considering costs for the truck (mainly labor and fuel), robots (mainly amortization, maintenance and electricity) and potential delay costs if a customer is reached late. Robot availability in locations is limited.

2. Literature Review

The concept of robot charging stations (also called *robot depots*) was proposed by Boysen et al. (2018). Their routing method is focused on demonstrating logistical performance for small problem sizes and under particular assumptions. Namely, it minimizes the number of late deliveries under the assumption that unlimited robots are available at every charging station. This is achieved through a multi-start local search heuristic for truck tours and an exact mixed integer program (MIP) to find optimal robot schedules for each truck tour. Alfandari et al. (2019) have further investigated this idea by comparing three alternative lateness measures and proposing a Branch-and-Benders-cut scheme to solve problems within an hour. The two publications mentioned above are the only existing truck-and-robot routing methods to the best of our knowledge. Jennings and Figliozzi (2019) have assessed the potential performance of a truck-and-robot system but not solved a routing problem. Other publications (Bakach et al., 2019 and Poeting et al., 2019b), follow a hub-and-robot approach, in which each customer is assigned to a hub, where goods are stored and robots are loaded. This decouples the truck and robot movements but also reduces the system's flexibility and performance as we show below.

So far, there is no holistic approach to evaluate delivery costs, which would be essential for companies and the real-life application of the concept, though. We therefore propose an extended truck-and-robot routing problem that optimizes total cost, considers restrictions relevant for the use in practice and quantifies the cost and emission reductions compared to traditional truck only delivery.

3. Solution Approach

Our solution approach is based on a combination of neighborhood search and a mixed integer program (MIP). We apply priority rules to generate initial truck tours based on the customer locations and corresponding deadlines for deliveries. The resulting initial tours are then used as starting point for an improvement heuristic, namely a local search. As operators within the local search, we use both cost-specific ones and standard operators known from vehicle routing literature. To evaluate any truck tour, we propose a MIP that finds the cost-optimal robot launch plan for a given truck tour – under consideration of robot availability. Figure 2 shows the structure of the solution approach applied. Moreover, we present an alternative, heuristic approach to determine robot schedules that can replace the MIP to reduce computation times. More details on our approach will be presented in Ostermeier et al. (2020).

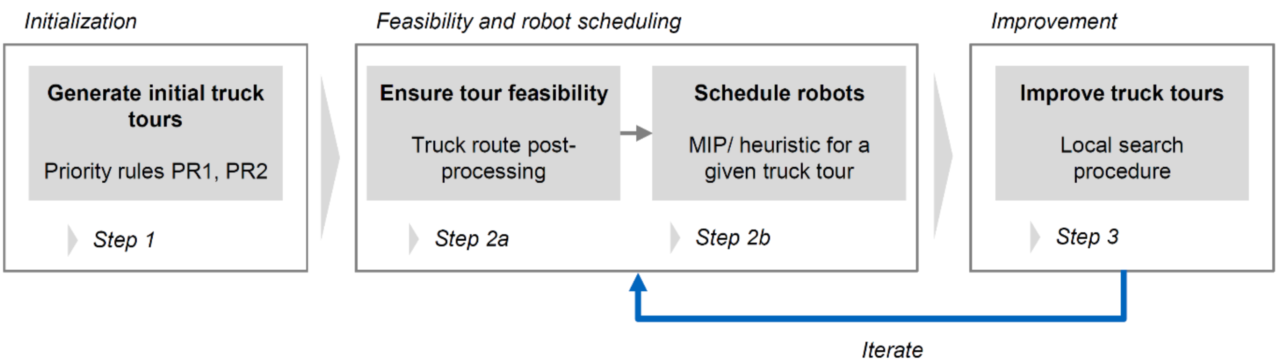

Figure 2. Structure of solution approach

4. Numerical Results

Comparison with Benchmark Approach

In Ostermeier et al. (2020), we present several numerical case studies based on generated problem instances with 25 to 125 customers. The results show that our approach leads to applicable solutions with respect to practice and a smaller required fleet of robots. Computation times are similar to the only known existing robot routing method by Boysen et al. (2018), which ignores cost and robot availability. Further, our method reduces cost by 46%, average delay time by 93% and truck distance by 49%, e.g. in the case of 75 customers. In addition, the maximum amount of robots started at a single depot (a driver of required robot fleet size) was reduced by 66%. These improvements highlight the need to consider the actual cost components and limited robot availability in the optimization process.

Comparison with Classical Truck Delivery

We compared the performance of our truck-and-robot cost heuristic to classical truck deliveries – known as the vehicle routing problem (VRP) with time windows. The VRP was solved with a MIP and the same cost rates for truck use and delays. Up to four vehicles were available at no fixed cost per vehicle. Since optimality could not be proved within our 3 h time limit, we compare the truck-and-robot cost to the lower bound of VRP costs as well.

In cases with 50 customers, our truck-and-robot routing method leads to cost savings of 59% to 68% (compared to the lower bound and the best-known solution, respectively). In comparison to the best known VRP solution, the truck distance is decreased by 82%. This is equivalent to CO_2 emissions when diesel trucks are applied. While delays occur 27% more often, their average duration is reduced by 68%. This shows that classic truck delivery cannot eliminate delays even though four delivery trucks were available of which an average of three was used. In contrast, the truck-and-robot approach is able to adapt its solution in order to minimize the total delay time by accepting smaller delays for a few more customers, and thus reducing total cost. Further details are provided in Ostermeier et al. (2020).

5. Conclusion

Our work shows that the truck-and-robot concept with robot depots is a promising approach to reduce the cost of last mile delivery and at the same time its environmental impact. If total tour cost is minimized, the approach can lead to significant savings compared to truck delivery.

Opportunities for future research include the assessment of city policies such as no-truck-zones or robot fast tracks. Furthermore, the advantage of independent robot movements between depots would be interesting to quantify, as this could ensure sufficient robot availability along a truck route with a smaller robot fleet. Another potential area of improvement is to combine robot and truck delivery on a single truck tour such that bulky goods that do not fit into the robots can be included as well.

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Supply Chain Analytics: Application Areas and Industrial Adoption

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Extended Abstract

Summary. Supply chain analytics (SCA) comprises a broad range of data analytics approaches, applied to value-adding use cases across the supply chain. We combine the results of a multivocal literature review (MLR) with survey results and find a varying relevance of SCA for different supply chain processes and analytics types. Additionally, gaps between literature and practitioners' views are identified and discussed. One of the most prominent divergences is noted to be the discrepancy of perceived relevance of predictive analytics relative to that of descriptive analytics, where the latter is deemed much more important in practice than literature treatment seems to suggest. Based on these findings we derive implications for future research to closer examine SCA in research and practice.

1. Introduction

Due to the emergence of new technologies, more data than ever is captured, stored, and processed (Mahdavinejad et al. 2018). The generated data are estimated to make up millions of terabytes (Tiwari et al. 2018), typically characterized by high volume, variety, and velocity (Papadopoulos and Spanaki 2018). While these big data were infeasible or too expensive to analyze years ago, it is now within reach to examine them through the immense increase in computing power (Usuga Cadavid et al. 2018). The analysis of big data – big data analytics (BDA) – has a disruptive and transformative character (Papadopoulos and Spanaki 2018) that enables new business models and has the potential to improve existing processes in supply chain management (SCM) and logistics (Arya et al. 2017; Klein et al. 2018). This potential led to a growing interest in the past years within research and industry (Chae et al. 2014).

BDA in supply chain management is also referred to as supply chain analytics (SCA) (Tiwari et al. 2018). There are many studies on the benefits of SCA. Brinch et al. reported that SCA can significantly improve SCM by enhancing existing processes and creating new products or services (2018). Klein et al. confirmed this notion by reviewing multiple empirical studies (2018). However, to reap the benefits of SCA, a company must understand for which application SCA can be employed, and it must make use of the right tools and methods. Unfortunately, while SCA has a vast scope, its adoption is still in its infancy (Arya et al. 2017). Schoenherr and Speier-Pero argue that there is missing guidance on which supply chain questions can be addressed by SCA (2015).

This work aims to address these gaps by synthesizing a comprehensive picture of SCA from a theoretical and practical point of view. The work aims to provide evidence on the following research objectives:

1. Provide an overview of SCA applications researched in scientific and industry-driven (grey) literature.
2. Provide an overview of analytics types researched in scientific and industry-driven (grey) literature
3. Identify the current status of SCA adoption in the industry and areas where the industry sees the biggest potential, and invests most in SCA.

Research objective one and two provide the envisaged holistic picture of SCA by depicting where and which type of SCA is mainly used in scientific literature. The inclusion of grey literature provides a first indication of whether the industry has a varying focus. Research objective three then gives – based on a survey of industry experts – insights into the industry's SCA adoption and provides the ground for a more detailed comparison and deduction of future research possibilities.

2. Background: Supply Chain Analytics

Today, companies collect large amounts of data and increasingly try to utilize this data by means of supply chain analytics (SCA). SCA is a collective term for big data analytics techniques that reveal optimizations for existing and future supply chains. The literature provides various definitions of SCA, with most of them describing SCA as using analytics in an SCM context (e.g., Arunachalam et al. 2018; Chae et al. 2014; Gunasekaran et al. 2017; Waller and Fawcett 2013). In this paper, we follow the definition proposed by Zhu et al. (2018): 'Supply chain analytics refers to use of analytical tools and approaches in supply chain environment in order to make more informed decisions and ultimately improve supply chain performance.'

In general, analytics techniques can be separated into the categories descriptive, predictive, and prescriptive analytics (Davenport 2013), which are also predominantly used to classify SCA (e.g., Arunachalam et al. 2018; Herden and Bunzel 2018; Souza 2014). Descriptive analytics is the analysis of historical data to understand what happened and why it happened (Lepenioti et al. 2020). Predictive analytics uses historical data to make predictions about trends and events in the future and estimate what is going to happen (Mishra and Silakari 2012). Prescriptive analytics examines the impact of specific decisions on the supply chain and recommends which decisions offer the greatest potential for action. It is concerned with the question of what should happen (Souza 2014; Varela Rozados and Tjahjono 2014).

While it is critical to differentiate between the different types of SCA, it is also essential to know for which application areas of the supply chain it can be helpful. These areas can be separated as proposed by the supply chain operations reference (SCOR) model, which is one of the most recognized reference frameworks for SCM (American Production and Inventory Control Society 2017). The model consists of the macroscopic supply chain processes plan, source, make, deliver, return and enable. These are in turn subdivided into several process categories. The process 'Plan' describes the planning of the entire production, material requirements, finances, and distribution. 'Source' deals with the procurement of raw materials and materials needed for production. 'Make' includes the production process, 'Deliver' defines the delivery process of the finished goods, and 'Return' describes the reverse logistics process of a supply chain. Lastly, 'Enable' is the process category within a supply chain that monitors and controls the entire process (American Production and Inventory Control Society 2017).

3. Methodology

To provide an overview of identified SCA applications and analytics types (research objectives one and two), a multivocal literature review (MLR), according to Garousi et al. (2019), is conducted, which offers a way to additionally include grey literature in a literature review. Because SCA is a topic of high interest to both research and practice, an MLR is a well-suited methodology for the first and second research objectives. After searching three scientific databases (Scopus, IEEE Xplore, and Web of Science) for scientific literature, reviewing the abstracts and remaining full papers, a set of 120 (from a total of 1381) articles was deemed relevant. Grey literature – according to Garousi et al. (2019) reliable sources are e.g. articles or reports published by companies – was searched in the Google search engine. Here, nine grey sources remained at the end of the review process. Each described several applications summing up to roughly 40 use cases. In contrast, each of the 120 scientific papers usually discusses one application case. Thus the sample size of the grey literature is smaller but big enough to warrant a good comparison and ultimately enable a comprehensive retrieval of insights. As a next step, all relevant sources were classified based on (1) which SCM process was targeted and (2) which analytics method was applied. The classification categories are based on the SCOR model and the analytics types described previously.

To achieve the third research objective and examine the current status as well as perceived future potentials of SCA in the industry, a survey is conducted among experts of the German supply chain and logistics community. Here, the perceived relevance and degree of implementation of SCA are juxtaposed and contrasted with the results from the MLR. A comparison of the results reveals aspects that need to be considered in future studies to make the application of SCA easier and more successful.

4. Results

Enhancing SCOR Processes with SCA

Corresponding to the first research objective, Figure 1 shows the distribution of which SCOR process is addressed by literature. For both, white and grey literature, there is a strong focus on planning processes (65% vs. 62%). Within this category, the majority of papers addresses cross-functional planning (sP1 – Plan supply chain). This is mainly due to the high relevance of demand or sales forecasting application cases (e.g., Sathyan et al. 2020; Wen and Yan 2019). Enable is the second-most discussed category (28% for white and 14% for grey literature). It encompasses studies dealing with risk management (Cavalcante et al. 2019), managing the SC network (Papagiannidis et al. 2018), or performance management (Dev et al. 2019). Especially scientific literature seems to prioritize issues of the operative SC functions lower. Source, make, deliver and return are in sum only addressed by 6% of all white papers. In contrast, grey literature addresses one of these functions in 24% of the cases. The biggest gap can be seen in the source process. Only one scientific paper could be put in this category (Mancini et al. (2020) who discuss a quality assessment method for incoming goods). On the other hand, grey literature presents application cases for commodity pricing, identification of delivery mismatches and material management (Gjendem and Deep Aakash 2016; IBM 2009; Rowe and Pournader 2017).

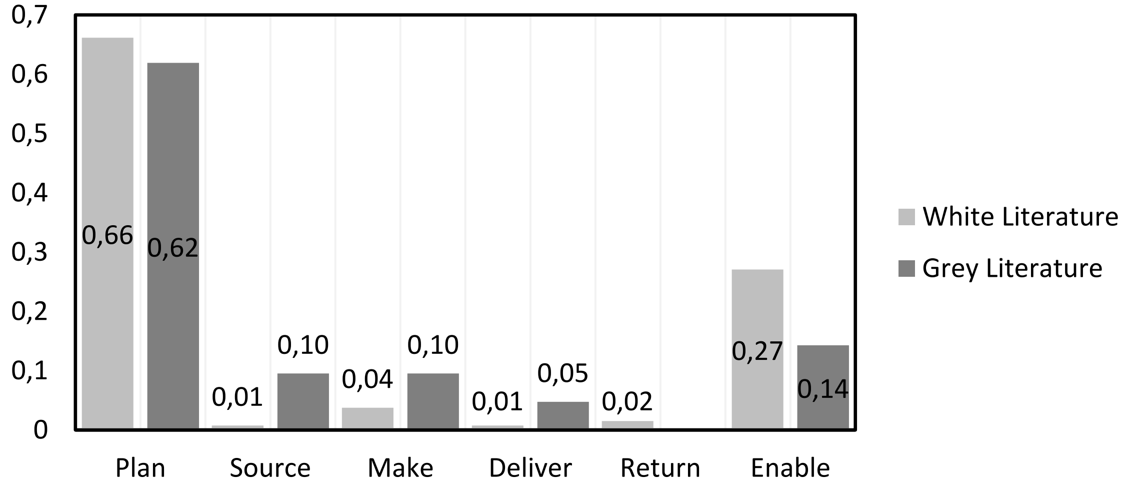

Figure 1: Prevalence of SCOR processes (literature)

'Source' and all other operative processes seem to indicate a slight miss-alignment between scientific research and industry-driven publications. The industry seems to focus more on using SCA for operational functions. Nonetheless, there is a strong alignment regarding the application potential of SCA for planning processes. Both, research and industry, seem to see the biggest opportunities within this category.

Analytics Types

To achieve research objective two, Figure 2 provides an overview of how many sources discuss descriptive, predictive, and prescriptive application cases.

Discussed applications of descriptive analytics (23% white and 39% of grey literature) mainly revolve around supply chain transparency and visibility. Examples are the identification of often-ordered products (Viet et al. 2020) or the implementation of a tool providing real-time visibility into operations of a pharmaceutical company (Gjendem and Deep Aakash 2016). Predictive analytics (47% of white and 29% of grey literature) revolves around regression and classification tasks. One of the most addressed issues is demand forecasting (Villegas et al. 2018; Grackin et al. 2016). But regression and classification are also applied in all other SC processes, e.g., machine failure prediction (Rowe and Pournader 2017) or supplier classification and selection (Hosseini and Khaled 2019). Prescriptive analytics is the least-discussed category (30% of white and 32% of grey literature). Papers of this category use optimization or simulation to assess consequences of decisions or test alternative scenarios, e.g. for determining optimal order quantities (Punia et al. 2020), or analyze the SC network's performance depending on different scenarios for market behavior (Sandiford 2013).

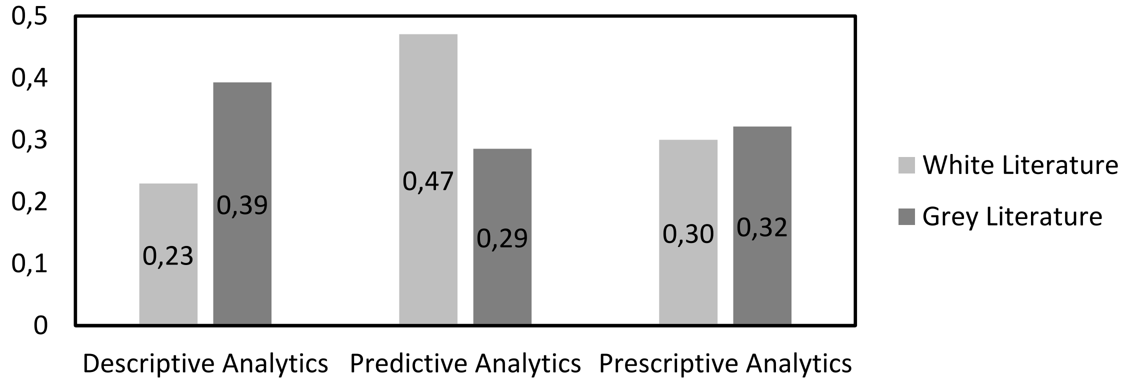

Figure 2: Prevalence of SCA types (literature)

Comparing the analytics types, a difference between scientific and grey literature becomes evident. While the most addressed analytics type in scientific literature is predictive analytics (47% for white but only 29% for grey literature), grey literature instead focuses on descriptive analytics (39% for grey but only 23% for white literature). The main issue addressed in grey literature is the visualization of data. In contrast, scientific literature already seems to assume that data is available in a suitable format to apply predictive analytics. Consequently, there seems to be a gap, which should be investigated further.

Industry Insights

After the prevalence of the SCA types and their application to SCOR processes are analyzed in the literature, they are compared to the survey research results.

Addressed SCOR Process

Survey respondents (n = 67) were asked to rate the potential of SCA for the different supply chain management areas, classified with the SCOR model. Figure 3 presents the average rating per SCOR process. Most respondents saw a high to very high potential of SCA for ‘Planning’ (average 4.38) and high relevance for ‘Deliver’ (3.96) and ‘Source’ (3.74). ‘Make’ achieved a moderate average rating (3.44), while ‘Return’ is rated as the least promising process category for SCA with a moderate average score of 3.25. ‘Enable’ was not queried in the survey, so there is no value for this process.

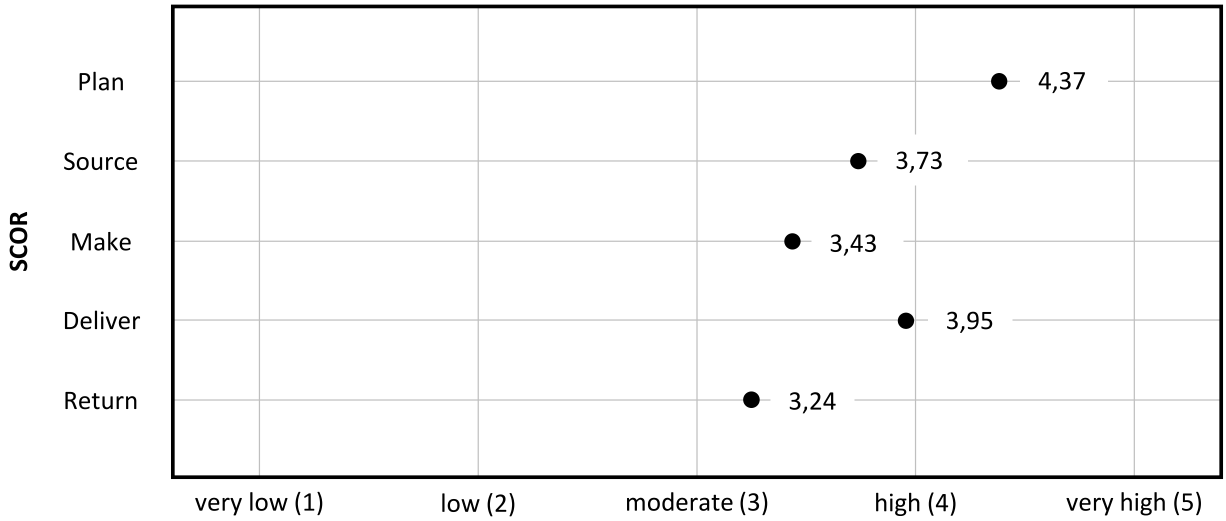

Figure 3: Relevance of SCA for SCOR processes (survey)

While the industry respondents also regard the planning process as the most promising application area of SCA, the gap to all other categories is not as high as when looking at the numbers of publications in each area. Relatively, survey respondents see much more application potential in operational processes ('Source', 'Make', 'Deliver', and 'Return') than is discussed in the literature. These obvious differences between industry and research and their reasons have to be investigated. Additionally, it needs to be clarified whether a call for more research on SCA for operational SC functions is needed.

Analytics Type

The survey respondents (n = 299) gave their opinion on both the relevance and the implementation status per analytics type (cf. Figure 4 and Figure 5).

Surprisingly, the survey respondents rated both descriptive and predictive analytics with a moderate to high relevance. Scientific literature deviates from this rating and addresses predictive analytics twice as often as descriptive analytics. In contrast, the prevalence of descriptive was slightly higher than predictive analytics in grey literature. Regarding prescriptive analytics, such a differing perception is not evident: Experts rank the relevance of prescriptive analytics slightly lower, which corresponds to the lower number of papers dealing with prescriptive analytics.

When looking at the actual implementation of SCA in practice, one can see that the more sophisticated the analytics, the lower the level of adoption (Figure 5). While 60% of respondents (n = 314) have implemented descriptive analytics at least marginally, only 47% have implemented predictive, and 30% prescriptive analytics. In the coming years, at least the gap between descriptive and predictive analytics might close because 28% of the respondents stated that they planned the implementation of the latter, while descriptive analytics implementations are only targeted by 18%. The share of respondents that plan to implement prescriptive analytics is even higher (30%), but so is the percentage of practitioners that have not planned an implementation (39%). This might be explained by the comparatively lower relevance they assigned to it.

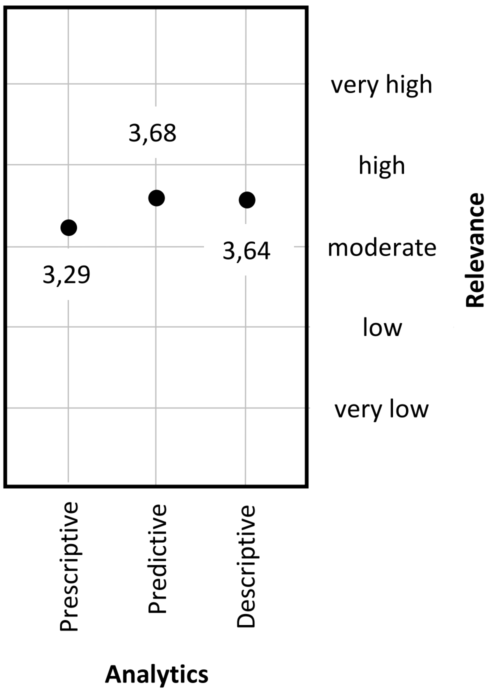

Figure 4: Relevance of SCA type (survey)

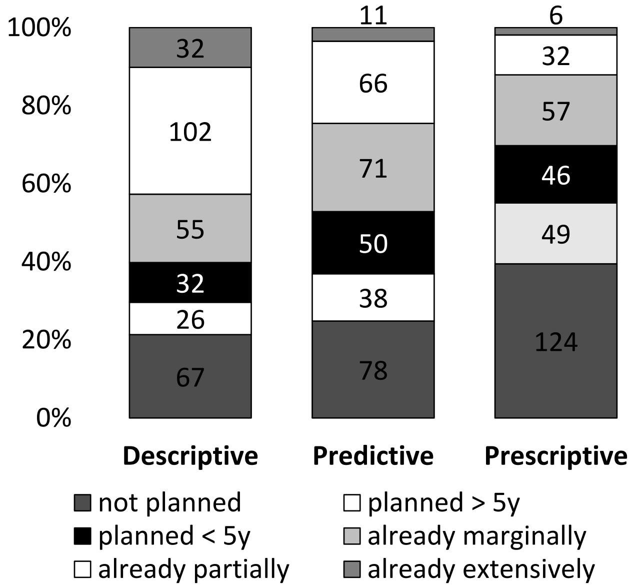

Figure 5: Implementation of SCA types (survey)

5. Conclusion

This paper gave a first overview of which analytics types are applied to address which SCM tasks both in grey and white literature. While planning is considered the most, specifically white literature seems to neglect potentials in operative processes. A first look at the survey results shows an even bigger gap between literature and experts' views. Survey respondents also rate planning as the most promising application area, but the relevance of all other SCOR processes is comparable. Reasons for this misalignment between research and industry need to be investigated.

There is also a difference between white and grey literature regarding the analytics types: White literature mainly focuses on predictive analytics, while grey literature primarily applies descriptive analytics. Looking at the survey results, all types are estimated as roughly equally relevant. However, the implementation status shows deviations: The more sophisticated the analytics type, the less it is implemented. Thus, while the industry only starts to implement predictive analytics, research already heavily focuses on application cases for this analytics type.

Of course, this paper only provides a first glimpse of the literature review and survey results. In further research, a deep dive is necessary to verify the first impressions and extract further insights. Hence, the following aspects will be addressed in future research:

- *Extended and more detailed analysis of white and grey literature:* Future research will not only look deeper into the already presented categories (SCOR and analytics type) but also analyze further aspects such as the motivation for and goals of using SCA or the data applied. This will allow for a more detailed discussion and comparison of application possibilities and potentials in white and grey literature.

- *Extended and more detailed analysis of survey results:* On the one hand, the discussed expert views need to be analyzed in more detail. There might be correlations or causalities, e.g., between the SCOR processes and analytics types. On the other hand, it could be analyzed why there is a difference between literature and practice by extending the study beyond SCOR processes and analytics types. For instance, different motivations to use SCA or data availability could substantiate why there is a gap.
- *Further literature/survey comparison and research agenda:* Based on both the MLR and the survey results, a detailed comparison of research and industry is possible. In this paper, some aspects are already touched, such as the different opinions on the relevance of SCA for the SCOR processes, but this paper does not discuss them in more detail or tries to find reasons for them. Such a comparison and corresponding identification of gaps between research and industry can provide the ground for a future research agenda that helps scientists to conduct relevant and valuable studies.

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Predictions of Disruptions in Multi-Modal Transport Chains Using Artificial Intelligence

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Summary. In this paper, a Machine Learning (ML) based approach for the prediction of cross-actor Estimated Times of Arrival (ETA) in multimodal transportation chains as well as ETA-based decision support is presented. The approach enables logistics actors and industrial companies to detect delays and consequent disruptions in transport chains at an early stage and to act proactively with appropriate measures. The implementation was carried out for the combined road-rail transport of containers in the port hinterland, provided as an open accessible online demonstrator. Furthermore, an insight into a current implementation for an ETA prediction for inland waterway transport is given. The contribution addresses crucial development steps for a ML-based ETA prediction and discusses the achievable potentials for logistics.

1. Introduction

Today's logistics networks are confronted with increasing customer demands concerning reliability, transparency and sustainability of logistics services while at the same time increasing cost pressure (cf. Handfield, Straube, Pfohl and Wieland 2013, 8-9). As a consequence, international transport chains, as important links in the supply chain, and their actors, are also subject to increasing demands in terms of reliability and efficiency. Against this background, it is important for the logistics companies to ensure an optimal utilization of their assets, to reduce the vulnerability of their processes towards disruptions and to foster the attractiveness of eco-friendly transportation modes.

Innovative data technologies such as machine learning (ML) as part of artificial intelligence (AI) offer great potential for overcoming these challenges through the ability to predict Estimated Times of Arrival (ETA) and upcoming interruptions in transport chains more precisely. ETA information is associated with high potential for both logistics and industrial companies, which benefit from an increase in the transparency and plannability of processes. From a production perspective, for example, there are opportunities to plan incoming deliveries with greater foresight, to detect impending supply bottlenecks and to adjust production programs at an early stage (cf. Servos et al. 2020, 1-2). From a logistics perspective, ETA information enables better planning and coordination of transport and handling processes as well as the required resources like vehicles, personnel and infrastructure (cf. Poschmann et al. 2018, 168) and thus contributing to higher utilization rates and shorter process times (cf. Walter and Elbert 2014, 1803). From a mobility perspective, potentials comprise and early verification and adjustment of schedules as well as improvements in dispatching and traffic control in case of delays (cf. Marcovic et al. 2015, 252).

Despite the high demand for ETA information in practice, the maturity of existing information in the maritime transport chain is currently low (cf. Weinke et al. 2018, 71-72). Until now, expert- and model-based approaches like simulations are predominating the process prediction. These approaches have the disadvantages of low scalability and adaptability to changing conditions as well as costly development. Despite enormous potential, the use of data-based approaches, especially machine learning, has only been explored selectively for particular processes so far. Especially for rail freight transport or marshalling yard there are not any solutions, yet. Moreover, an integrated approach for transport chains is still missing.

In the research project SMECS (Smart Event Forecast for Seaports, the Chair of Logistics at the Technische Universität Berlin, together with DB Cargo and Kühne Logistics University, developed a ML-based decision support for maritime hinterland transport. The project was funded from 2017 to 2020 as part of the Innovative Port Technologies (IHATEC) funding program of the German Federal Ministry of Transport and Digital Infrastructure (BMVI) and was supported by numerous practical partners. In the project, an intelligent prototype was developed that enables a "door-to-port" prediction of arrival times for intermodal transport chains. Using a rule-based system, the developed prototype is also able to identify conflicts in the chain and determine suitable measures for disruption management. This paper shows the procedure and fundamental results of using ML approaches to predict ETAs and disruptions in multi-modal transport chains.

2. Research Methodology

The development of the prediction follows an iterative approach, similar to the well-known CRISP-DM cycle (cf. Wirth and Hipp 2000). In the first step, an expert-based analysis of the physical processes, the information flow as well as occurring disruptions and factors influencing process times were investigated. Furthermore, the potentials of a data-based ETA prediction, corresponding implementation requirements and use cases, including three transport relations for pilot implementation, were identified. Based on the identified disruptions and influencing factors historical data for 4 years out of 15 different IT systems of several logistics services providers was collected which represents the multimodal transport processes on different transport relations. The data included about 50,000 train runs and 110,000 container movements like truck trips and handling events. Subsequently, the process chain was split into sub-problems covering individual transport segments according to Figure 1.

For each segment, an individual prediction model was developed and trained, using the corresponding historical data as well as various regression and classification methods from the field of supervised learning such as random forest and gradient boosting. For each submodel, a large number of input variables were identified during a feature engineering process representing the various influencing factors for the process in question as well as possible. In the area of rail transport, these include timetable data, planned processes, train and locomotive characteristics, construction sites and weather data amongst others. Finally, all submodels were integrated into an overall system providing a "door-to-port" ETA for a specific transport order as well as the detection of probable conflicts.

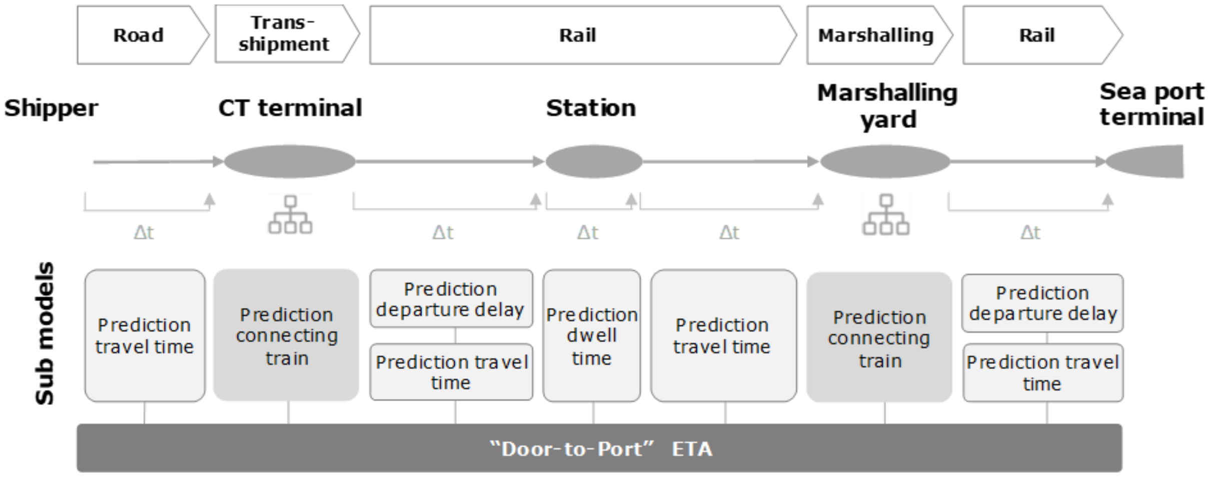

Figure 1. Overview of sub-models

The developed ETA prediction system was subsequently supplemented by a rule-based decision support system which automatically detects connection conflicts in logistics nodes (e.g. marshalling yards) and provides the actors involved with recommendations for actor-specific measures. This enables the actors in the transport chain to detect disruptions and process delays at an early stage and to initiate appropriate measures. For this purpose, suitable measures in the case of connection conflicts in logistics nodes were determined and evaluated with all partners involved.

3. Results

Compared to previously available arrival times based on the timetable, the developed approach already shows high potentials, which can probably be further increased by integrating additional data. For a route with an average travel time of approximately 5 to 7 hours, the predictions of the train arrival times at the time of departure allow a mean deviation (MAE) of 38 minutes. Thus, around 80 % of arrival times can be correctly predicted within a +/− 60 minute interval. A correct prediction of the expected connecting train in the marshalling yard is possible before the departure of the hinterland train on the pilot relations considered in 70 % of all cases (no-information rate: 37 %).

The results of the SMECS project have been released in the form of a web-based demonstrator (www.smecs-eta.de), which allows to test the system for historical cases and compare predictions to actual arrival times (Figure 2). In this way, potentials and limitations of AI for this use case are demonstrated and can be tested. In addition, various information on IT development is provided, including used ML methods and achieved prediction quality. The demonstrator also shows how, in the sense of proactive disruption management, connection conflicts can be detected along the transport chain on the basis of the predictions and how actor-related action measures could be visualized to avoid them.

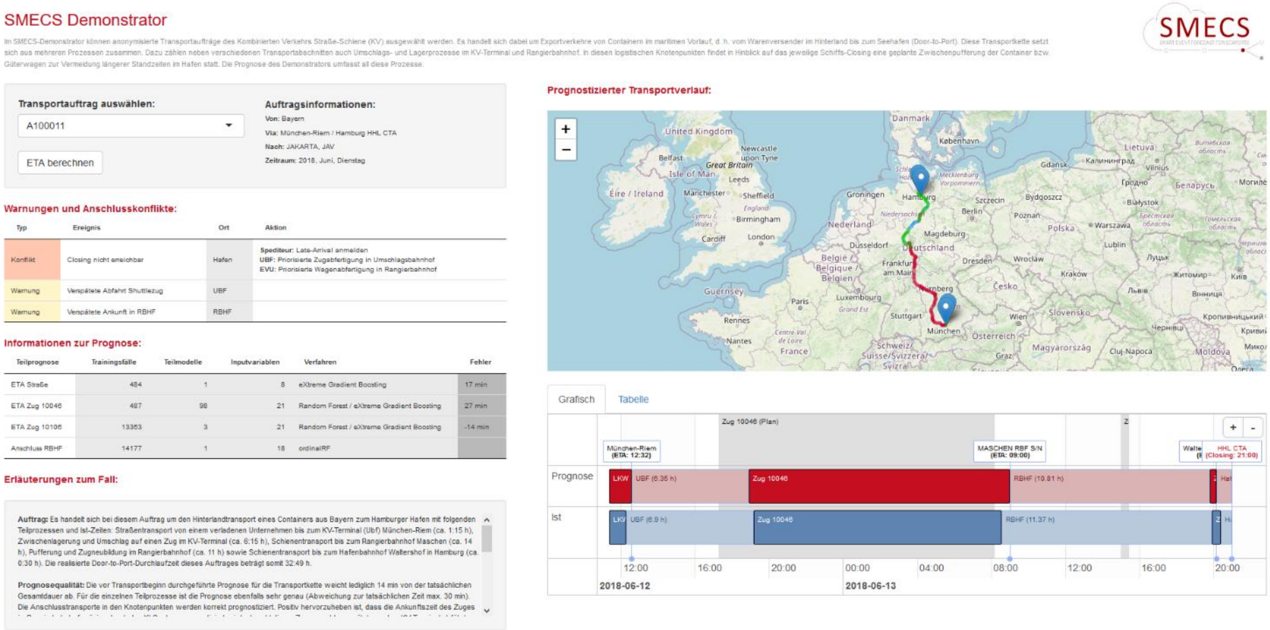

Figure 2. Web-based SMECS demonstrator (www.smecs-eta.de)

4. Development of a Solution for Inland Waterway Transport

After demonstrating high potentials and feasibility of ML-based ETA predictions for intermodal road-rail transport, a transfer to other transport modes is currently underway. A high demand for ETA solutions could be identified especially for inland waterway transports, which so far shows a very low level of maturity in terms of arrival time information. In the current research project SELECT, funded by IHATEC from 2020 to 2023 (cf. IHATEC 2020), a similar solution for the application case is being developed on the basis of the knowledge gained in the land transport. Under the leadership of the Chair of Logistics at the TU Berlin, various companies from the German inland shipping and port industry are cooperating to this, including BEHALA, Deutsche Binnenreederei, duisport, HGK and modal 3 Logistik.

The objective of SELECT is the development of an ETA prediction for inland vessels between seaports and inland ports as well as a decision support in the form of situation-specific optimization measures. The ETA prediction should not only cover the traveling process but also locking processes and resting times along the chain as well as turnaround times in the port, which finally allows to calculate process times for complex ship journeys. The development and validation are conducted for different relations in the area of the Rhine between Frankfurt and Rotterdam as well as the Elbe, Mittellandkanal and Elbeseitenkanal between Berlin and Hamburg.

Compared to the transport modes considered in the land transport, inland shipping shows several differences and special requirements. For example, compared with rail transport, the processes in inland navigation have a higher degree of flexibility and are less determind by planned values. Resting hours, for example, can be taken at different points along a route and are thus more difficult to predict. In addition, the process design is significantly dependent on the type of goods (e.g. container, bulk, liquid cargo), the type of vessel (e.g. ship, barge) and also the individual behavior of the crew. For these reasons, the ETA prediction for inland navigation requires different approaches than for combined road-rail transport.

Another important difference is the data between both use cases. Most inland vessels are already equipped with transmitters for Automatic Identification System (Inland AIS) and send position and movement data at regular intervals. The data is recorded by various providers, which serves as the basis for the project. However, the data initially contain position reports of all ships equipped with AIS without reference to a voyage or a transport order. In the first step, a comprehensive filtering and processing of the data is needed. In the SELECT project, AIS data was obtained for three years in specific geo-areas. The data comprises approximately 300 million position reports. Algorithms, which first had to be developed, were used to extract journeys on specific routes from these. In addition to Inland AIS data, various other problem-specific data sources were gathered and used for prediction, like weather data, water level data, and fairway and traffic messages from ELWIS platform, provided by the "Wasserstraßen- und Schifffahrtsverwaltung des Bundes".

5. Findings and Outlook

The presented research activities provides for the first time appropriate approaches for the ML-based prediction of intermodal transport chains with subsequent actors-specific measures. By using and testing various ML methods and different model configurations, new insights were gained into the implementation of data-based process and disruption predictions in complex logistics processes. Potentials and restrictions of the current data availability in intermodal transport chains could be identified. By integrating IT systems from different companies with comprehensive historical data, it allowed the identification of cross-actor optimization potentials for the planning and control of transport chains to achieve a better synchronization. This includes a detailed insight into the complex operational processes and interactions of the transport chain, including disruptions.

The conducted projects provide an important contribution to increasing transparency demand in logistics by offering, for the first time reliable information on the prediction of arrival times of intermodal transport chains. The great advantage is that this information is already available at the beginning of the transport and at the same time, the effects on the entire chain are taken into account. This improved basis for decision-making allows proactive measures in the case of a predicted disruption or delay, which could be taken by the stakeholders at an early stage.

The obtained results will be continued within various research and practical activities. The provision of the intelligent system in the form of a demonstrator serves as an important instrument for the accelerated development of an operational solution by the practical partners, both in terms of model development and data requirements, as well as for the visualization of information for the user. This deployment of the intelligent system could increase the flexibility and cost-effectiveness of transport chains with a simultaneous improvement in reliability and sustainability. This will have a positive effect on logistics service quality and thus on customer satisfaction. All in all, this leads to a reduction in obstacles for shippers and freight forwarders to use alternative transports like rail and inland waterway transport, thus in the long term a contribution is made to increasing their competitiveness and attractiveness.

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How Usage Control Fosters Willingness To Share Sensitive Data In Inter-Organizational Processes of Supply Chains

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Extended Abstract

Summary. Information sharing in supply chains always requires companies to provide internal information for process optimization or risk mitigation. As such information can often be considered as sensitive for competitiveness of a company, it needs to be protected even on receiver's side. An increasingly used approach to obtain data sovereignty is to apply usage control, which allows data providers to define technically constraints (usage policies) which are applied and enforced on the data receivers' side. This paper provides a blueprint for usage policy realization in an inter-organizational c-parts management process within the logistics supply chain. It shows in particular how usage control can be applied to protect sensitive information and, thus, raise willingness to share sensitive information in business relationships.

1. Introduction

Collaboration in supply chains requires multiple entities to share information (Lee and Whang 2000; Li and Lin 2006). An often-faced hurdle is information considered as non-sharable (Pucihar et al. 2019), leading to missing opacity in processes (Opriel et al. 2021). Nevertheless, information sharing is a key factor of success, especially for data-sharing processes with the opportunity to gain more transparency resulting in supply chain resilience, better risk assessment, and other benefits (Fan et al. 2016; Kersten et al. 2017). Data analyses in general require a very deep insight into the participants' data and, thus, their conditions such as information about tracking and tracing, estimated time of arrivals or even capacities. These data are highly sensitive since they potentially allow powerful conclusions about internal processes and the overarching business network. This results in fears of data misuse and ultimately unwillingness to share further information than already exchanged today (Lotfi et al. 2013).

In order to enable practitioners to share business-sensitive information, we conduct a Design Science Research (DSR) study (Hevner et al. 2004) conceptualizing data-sovereignty enabling mechanisms (Otto 2016) with the concept of usage control (Park and Sandhu 2002). The goal of the DSR study is to overcome mistrust and simultaneously effectively prevent its root cause data misuse, ultimately resulting in a higher willingness of companies to share sensitive data. Therefore, we define following research question: *How can usage control be integrated into a concept to foster data-sharing willingness in inter-organizational collaborative logistic processes with multiple participants?*

2. Research Background and Methodology

Data sovereignty, which is "the self-determination of individuals and organizations with regard to the use of their data" (Jarke, Otto and Ram 2019), gained attention in the recent years and represents a promising approach to protect own data overcoming data-exchange hurdles. Especially in the ongoing times of digital transformation with a shift from traditional business models to digital ones, data sovereignty becomes a necessity.

Aside from several research projects and communities (Munoz-Arcentales et al. 2020; Opriel et al. 2021; Zrenner et al. 2019), scientific literature lacks concepts and blueprints for researchers and practitioners how to handle trust-related issues between supply-chain participants by applying technologies. One approach is data usage control (Park and Sandhu 2004), which can be used in software architectures to enforce usage constraints (defined by the data provider) in systems of data receivers. In contrast to today's mechanisms, it is not just controlled and monitored who accesses information like with user logins, but additionally control what a recipient of the data is allowed to do (e.g., processing or forwarding), which constraints apply (e.g., time or usage limits), and which obligations (e.g., delete data after 24 hours) are technically enforced by the receiving information system.

International Data Spaces (IDS) (Otto et al. 2019) provide a standardized data-sovereignty architecture, which make use of usage control and policy enforcement at its core (Eitel et al. 2021). To define usage policies, ODRL (W3C.2018) is used and for its enforcement an adjusted XACML (OASIS.2013) architecture is used in software components called IDS Connectors. These components exchange information end-to-end encrypted and enforce policies (Otto et al. 2019).

The research approach summarized in Figure 1 is embedded in a design science context of information systems research (Hevner et al. 2004) and applies the six-step Design Science Research Methodology (DSRM) (Peffers et al. 2007). Following the DSRM, a concept for usage-control application in a broad use case of an industry supported c-part management process within a research project is developed and evaluated with practitioners (Hevner 2007).

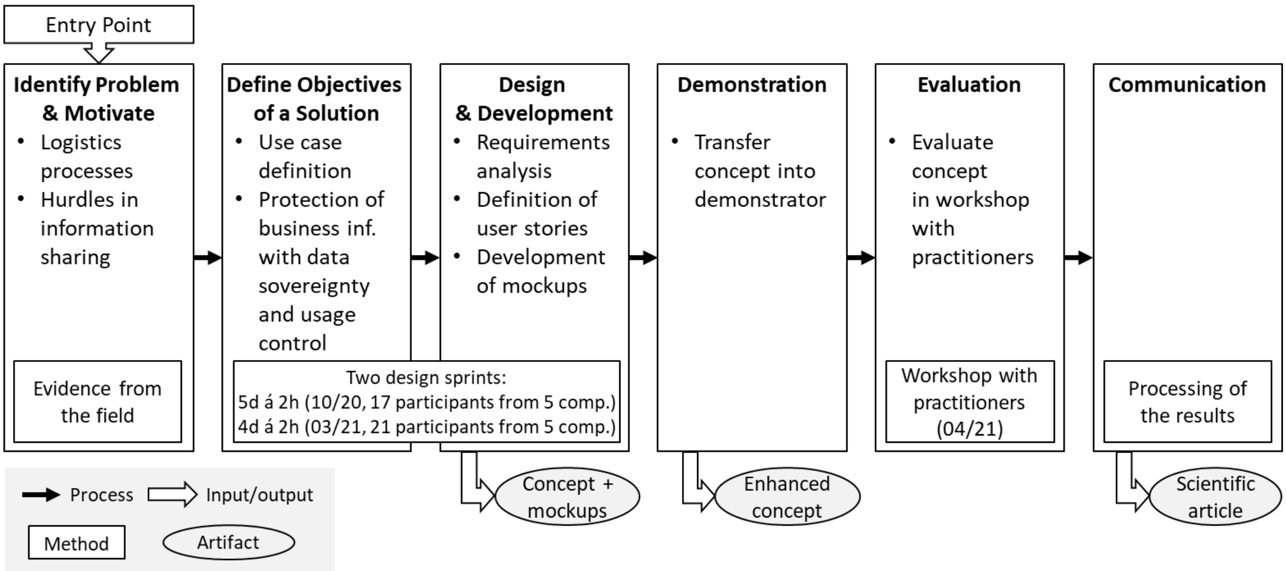

Figure 1. Instantiated DSRM of Peffers et al. 2007, 54 for C-Part Management

The research project deals with a logistics ecosystem in Germany and applies the architecture of IDS. Furthermore, the chosen supply chain represents a dynamic logistics network where services and products are substitutable. Therefore, there is a need for flexible management tools allowing an easy connection of partners and finally an exchange of sensitive information.

Within the project, six companies represent the following roles: c-parts manager (M), supplier (S), logistics service provider (L), warehouse provider (W), customer (C) and payment service provider (P). The development is based on the agile SCRUM framework but includes in addition, technical spikes and separate design sprints to meet the different requirements of all industry partners. In particular, the design sprint and the evaluation workshop series are core to make the needs for data exchange transparent and to address aspects of data sovereignty.

3. Applying Usage Control in Event Publishing

The use case focused on c-parts management is characterized by high trading volumes, low gross margins, and several substitutable suppliers. Thus, a Kanban system is used for replenishment control. As c-parts are standardized, both suppliers and manufacturers are replaceable, which leads to highly dynamic supply chains. Therefore, flexible management tools to allow an easy connection of partners are required. Yet such connections can be disrupted by the fear of data misuse after sharing sensitive event information.

To ensure always having sufficient c-parts, a customer collaborates with a c-parts manager which incorporates further logistics service providers and manufacturers. Figure 2 shows the simplified c-parts management process that starts with the notification of an empty container by the customer. If parts are available at the warehouse, the c-parts manager arranges their picking and shipping. Otherwise, parts are picked and shipped by the supplier, sent to the warehouse, and are repacked according to the needed amounts and in customer specific handling units, which are finally provided as aforementioned. The logistics service provider is responsible for the pick-up and transport of parts. Lastly the c-parts manager provides a receipt of the parts.

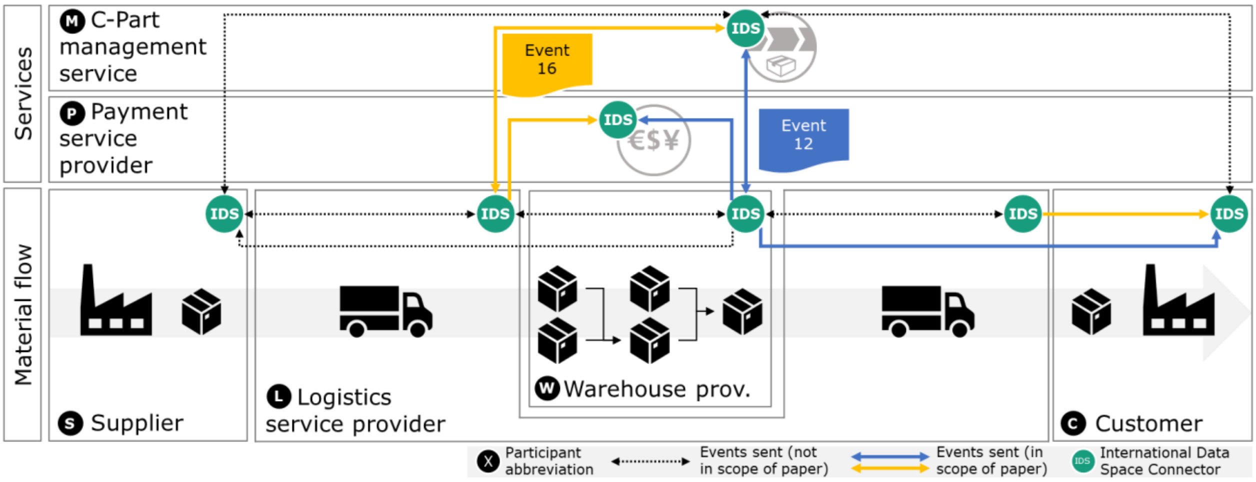

Figure 2. Simplified C-Parts Management Process

In its full scope, the material flow is supported by 19 events that are being processed. For example, the status of the order and the matching between parts and their information must be processed. Yet some of the data might be too sensitive to be shared with everyone. Those risks must be identified to define which data can be shared under which circumstances with whom. For example, the logistics service provider must share the ETA with the c-parts manager, yet there is no willingness to share exact positions, because there might be up-and-running contracts with other companies, which the provider does not want to disclose. To ensure responsible data handling, risk management and usage control are needed. Table 1 provides information about two selected events published within the process highlighted in Figure 2.

ID	Event Name	From → To	Data fields
12	Item packed into handling unit	W → M, P, C	eventType, eventDescription, eventTime, eventDestinationUuid, eventSourceUuid, containerLogUuid,
16	Arrival (electronic proof of delivery)	L → M, P, C	eventType, eventDescription, eventTime, eventDestinationUuid, eventSourceUuid, containerLogUuid, palletLogUuid, shipmentId

Table 1. Selected Events from the C-Parts Management Process

Misuse Case and Usage Policies of Event 12 (W → C)

To constantly assess and mitigate possible risks (e.g., bottlenecks in supply) the customer is informed about all process steps. Therefore, exemplarily event 12 is published by the warehouse provider to inform the customer that the needed parts are packed into handling units. Due to the gained transparency (in accordance with the other events), the customer is able to identify the exact status of the replenishment.

As a downside for the warehouse provider, the customer could draw conclusions from the received events and provided information. For example, information of `eventTime` could be misused with regards to performance tracking issues. The customer could calculate lead or buffer times, ultimately resulting in an unintended revelation of business processes or identification of other customers by analyses of less truck loads' lead time.

As the receiving system of the customer is an IDS Connector, the warehouse provider attaches three usage policies which (1a) revoke access and (1b) delete the information after receiving the next event of the physical material flow. Additionally, the provided information is (1c) restricted to be used by the desired (receiving) IDS Connector and thus not extractable via APIs or sharable with other IDS Connectors (Eitel et al. 2021). In a formal specification, policy (1a) is considered as an ongoing-usage authorization (Zhang et al. 2005) that is regularly checked on usage (must be valid) and whilst stored at database (data in rest). In case the constraint is no longer valid (i.e. a subsequent event of given `eventType` is available that refers to the same `containerLogUuid`) access to this information is denied. Additionally, a post-usage obligation is triggered to delete the information by decoupling the information from the information model (delete pointers to concerned object) and deleting the event details from database.

By restricting to share the information and by revoking access and deleting it, analyzing lead or buffer times becomes almost impossible. Nevertheless, the receiver has full access to the desired information purpose: observe the status of the order.

Misuse Case and Usage Policies of Event 16 (L → P)

As the process shall be as automated as possible, event 16 is published by the logistics service provider as an electronic proof of delivery. One of the event recipients is a payment service provider, which arranges the payment of logistics service provider and additionally offer transport insurances.

As the "receiving" event is also the end of transport, start and end event can be used to verify contractual insurance-related constraints. Interest could arise to misuse provided information in order to calculate a custom risk-scheme for a specific customer's (i.e. logistics service provider) insurance policy. Therefore, origin's company and destination's company (referred by `shipmentId`) as well as the transported goods (referred by `palletLogUuid`) could be analyzed. As such analyzes may have negative impact on the logistics service provider's insurance policy, it is not intended to allow a further processing of this information beyond a payment process.

To avoid such potential misuse, the data provider specifies a usage policy that allows access to information just for specific purposes (payment process). Due to a regulatory framework of IDS, applications and algorithms within IDS Connectors are bundled as application containers that are certified and authenticable by technical signatures. As APIs of these containers are specified with parameters and return values, data providers can verify calculated and returned results.

As the usage policy is finally enforced by the receiving IDS Connector, access to these data from other application containers is denied and thus ensured that processing takes place just for the intended purpose of the data provider – which is ultimately data sovereignty.

4. Discussion and Conclusion

Design Science Research Methodology of Peffers et al. is used to enhance a c-parts management use case by usage control mechanisms. These mechanisms enable participants of the collaborative ecosystem to protect sensitive information which is used for process alignment and risk mitigation. The use case shows that applying usage control policies is not trivial due to weighting up sensitiveness of the shared information and needed effort to protect it. As a best practice, we applied the approach of misuse cases of Sindre and Opdahl to identify potential information misuse and lowering their exploitability by usage control policies. Indeed, bypassing of described usage control enforcement is possible in some cases, like by taking photos or screenshots when displayed. Nevertheless, the assumed effort to misuse this information is much higher than having access to raw data and processing them in appropriate algorithms. Evaluation with industry experts prove the securing of information with usage control as a valid approach. Thus, the research serves as a blueprint for other researchers and practitioners who want to make use of usage control or have similar use cases securing usage of sensitive information. Ultimately, usage control can foster trust, enables data ecosystems, and allows new data-driven business models. Further research will be conducted to enlarge usage-policy application and piloting of developed concepts in test environments.

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Silicon Economy – Logistics as the Natural Data Ecosystem[1]

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Summary. The "Silicon Economy" is synonymous with a coming digital infrastructure (digital ecosystem) based on the automated negotiation, disposition and control of flows of goods, enabling new, digital business models (not only) for logistics. This infrastructure requires and enables the trading of data without losing sovereignty over the data. It is the digital infrastructure and environment for the highly distributed AI algorithms along value networks. As a contrast to oligopolistic developments in the B2C sector (amazon.com, AirBnB, Alibaba, Uber, etc.), the Silicon Economy is a federated and decentralized platform ecosystem the basic components of which are made available to the general public as open source for free use. The Silicon Economy ecosystem is becoming an enabler of supply chain ecosystems in which goods, autonomously controlled by Artificial Intelligence (AI), undergo orchestrated processes according to the situation. This article focuses on the origins and potentials but also on the technological foundations and challenges of the transformation toward a Silicon Economy.

1. The Digitization of Everything and Artificial Intelligence in Everything Will Change Everything for Everyone

By the end of the twenties, AI algorithms will determine, regulate and control nearly everything in the logistics sector – and not only there. Platforms will hoard data and generate knowledge. Swarms of autonomous robots will explore their surroundings, negotiate with each other and organize themselves.

A new "Silicon Economy" is emerging. It will outclass the business models of Silicon Valley and turn the world upside down. And there is no alternative to the introduction of AI – human intuition

 in: ten Hompel, Michael; Schmidt, Michael (2021): Silicon Economy – Logistics as the natural data ecosystem. In: Otto, Boris; ten Hompel, Michael; Wrobel, Stefan (eds.): Designing Data Spaces – The Ecosystem Approach to Competitive Advantage. Springer, Cham.

and hierarchical order have failed in the attempt to master the complexity of existing networks and processes. AI algorithms and their machine learning will define the game. Logistics and supply chain management are the crucial domains where the initial stage of this new B2B competition will be decided.

1.1. The coincidence in time is crucial

The introduction and universal application of AI characterizes the era we live in. Autonomously interacting entities increasingly determine the course of development. Driven by the hardware development of digital semiconductors such as memory, low-power sensors and processors, the automation of entire processes and supply chains on the basis of autonomous entities in software and hardware is now becoming focus of attention. The decisive factor here is the coincidence in time of a wide range of technical developments:

- From Industry 4.0 and the Internet of Things including AI in devices (Edge AI),
- to real-time networking (5G, Wi-Fi 6),
- AI-based platforms (AI Platform as a Service),
- Blockchain (distributed ledger), and automated negotiation (smart contracting),
- Swarms of autonomous robots (LoadRunner®),
- Virtualization and simulation (simulation-based AI),
- immersive technology such as augmented reality (AR) and virtual reality (VR), which connect humans with AI,
- cognitive computing
- to quantum computing.

The common element in each case is the universal application of AI – albeit in a wide variety of forms. From the simplest, rule-based systems in the trackers of our containers, the support vector machines in "intelligent" sensors and simulation-based reinforcement learning of swarms of autonomous vehicles to deep learning algorithms in supply chain management. Obviously, it seems to be logistics where all these technologies are now breaking through simultaneously. Due to its comparatively simple processes performed millions of times and yet its enormous systemic complexity as a whole, logistics is the sector that is virtually a prime example of AI application. For example, the automatic identification and measurement of individual packages via camera and AI is already a market worth billions. However, the real market potential will be leveraged when the process chains on the AI platforms of future supply chain management close and AI algorithms fully permeate logistics networks both vertically (from the sensor to the cloud) and horizontally (along logistics processes).

There is no single development that is currently leading to a disruptive change or by which the entire era is named. It is the temporal coincidence that concentrates a multitude of exponential developments on just one point. However, the outcome is indeed singular. And then, in turn, a "connected and autonomous supply chain ecosystem" (PwC 2020) emerges: the Silicon Economy.

1.2. Social change

It's not just about engineering and technology, but also about an essential change in our society. Humans will no longer be the "decisive authority", but will hand over the reins of action to machines and their algorithms. The change is universal and will not take the form of a machine man, as Fritz Lang once depicted in his film Metropolis. On the contrary, imitating humans in robot form would essentially be a waste of resources and the corruption of a technology that can do many things, but is by no means human. It will be essential to relocate humans and their position in relation to AI.

In the first three industrial revolutions, mechanical work was transferred to machines and robots. For such an industrial application, it was pointless to think about whether computers could develop creativity or intuition. Today, their abilities are far beyond human capabilities in certain areas. For example, even painting pictures and composing pieces of music can be learned comparatively easily by a computer via AI[2]. Even experts are no longer able to distinguish whether some works were based on human or machine creativity.

In the Silicon Economy, intellectual work is increasingly being transferred to machines. In logistics, for example, this will manifest itself in the planning, control and scheduling of processes and in new business models. In this context, Indset et al (2018) speak of an emerging "knowledge society" in which we as humans only react primarily to predefined knowledge from our search engines and databases that has been algorithmically processed by AI, and which must therefore be overcome. This would make humans increasingly obsolete – at least in terms of repetitive skills or the representation of knowledge.

After the automation of assembly processes in the third industrial revolution and the associated loss of jobs, cashiers at the supermarket checkout could lose their jobs or the banker who might only reproduce what the automated check via AI revealed. Today, operations are supported by AI. A, surgeon who operates on a cataract might be replaced at some point in future, or the teaching profession might be enriched by artificial avatars – at least as far as pure knowledge transfer is concerned. The consequence of this development is the demand for a change from a purely reflective knowledge society to an "understanding society" in which a return to humanistic values and the abilities for philosophical, artistic and scientific discourse are considered essential for human beings.

It is a technical question how we leverage the potentials of neural networks in our computers, it is another question how AI changes the neural networks in our brains. Elon Musk, founder of Tesla and SpaceX, faced this question and came to the conclusion that we have to combine the human brain with AI in order to avoid ending up as its own pet. In his characteristic consistency, he founded the company Neuralink in 2016 and now intends to connect the human brain with a computer to enable paralyzed people to use computers. However, this should only be the first step in ensuring the intellectual participation of humans in future and in connection with the machine world.

However, AI will develop in relation to humans and one thing seems indispensable: A profound debate is needed about what it means to be human today and tomorrow.

1.3. Sharing Economy

The universal challenge of the ubiquitous introduction of AI raises the question of how to ensure the participation and sharing of many people and companies.

On the one hand, the aim is to prevent AI from becoming independent, as feared by Elon Musk et al (see above).

On the other hand, however, the dimension of this development exceeds what can be achieved by a single organization – no matter how large it may be. At the same time, "sharing" is the new generation's leitmotif of developers who have grown up with the principle of swapping and

[2] cf. e.g. Barreau, Pierre: AIVA – Artificial Intelligence Virtual Artist

sharing on the Internet and have internalized a different logic of giving and taking: "Using instead of owning" is their motto. The principle has spread to large areas of the economy and has become the basis for new value creation models.

This leitmotif is followed by the open source software movement, i.e. the freely accessible provision of source code, which offers people and businesses the opportunity to use, adapt and distribute this source code. The publication of construction plans as open hardware or the provision and use of data as open data are also expressions of the sharing mindset, as are open innovation processes with internal and external forces (open innovation). Common to all these trends is the underlying confidence that business potentials generated by intact and open ecosystems can be better leveraged together – for example, through greater innovative strength, better stability and IT security, or through the avoidance of licensing costs, etc.

Open source software is now an integral part of the digital economy in Germany and a constituent part of almost all innovation processes – across countries and with the participation of numerous organizations. This does not only apply to the Internet economy, but also to industrial production where 50% of the code base is now built on open source software (Bitkom e.V. 2020). It is impossible to imagine today's world without it. The digital transformation and therefore also the Silicon Economy will not succeed without using open source.

2. Potential of the Silicon Economy for Logistics and Supply Chain Management

The importance of logistics has increased strongly in recent decades in parallel with the growth in world trade. Logistics forms the basis of global trade. It connects places and companies in global networks – from the physical flow of materials and goods to the exchange of data in the flow of information and the flow of finance in logistics management. In this respect, logistics is one of the most important factors influencing free world trade.

Before presenting the potential of the Silicon Economy in this domain, the terms Logistics and Supply Chain Management should be defined.

2.1. Logistics, Supply Chain, and Logistics Management

Logistics describes the reasonable movement of things, in places, through time and in relations. It is a fundamental principle that permeates everything physical and its movement. At the same time, it is an expression of man's striving to set things in motion. Based on Delfmann et al., we will define logistics as an applied science, as an industry as well as an operational function. Logistics analyses and designs economic systems as flows of objects (above all, but not exclusively: goods and people) in networks, supplying recommendations for action on the design, implementation and operation of these networks.

Across Europe, the logistics market amounts to around 1,050 billion euros. Important economic functions are the control of goods and information flows, the transport and storage of goods.

More than any other industry, it is highly standardized and thus ideal for the widespread use of digital platforms, blockchains and AI processes. AI-equipped technology such as intelligent containers and pallets that negotiate autonomously and route and pay themselves to the recipient, or swarms of autonomous vehicles in factories, exemplify that and how value chains will function in the future.

As with the above-mentioned definition of logistics, no single definition or use of the term Supply Chain Management (SCM) has been established. Overlapping with the statements made at the beginning, SCM (or: Logistics Management) should be understood as follows: SCM encompasses "both the targeted development and design of company-related and cross-company value creation systems according to logistical principles (strategic management) and the targeted control and monitoring of the flow of goods and information in the value chains under consideration (operational management)".

On the one hand, SCM understood in this way addresses the basic, goal-oriented design, which describes the initial planning as well as the structural organization of a logistic process, system or network – in order to create it as an object and as a unit capable of action for the reasonable movement of goods and people. On the other hand, it includes the ongoing, permanent planning and design of logistical processes, systems or networks in terms of continuous, goal-oriented further development. The execution and realization of logistical activities and their monitoring and control are also largely assigned to SCM. As a central and increasingly important component of management, SCM should be understood as an integrative, cross-functional perspective on and along the entire life cycle of logistics processes, systems and networks. The primary elements of SCM therefore include: design and organization, planning, execution/implementation and monitoring.

2.2. The open and federated approach of Silicon Economy

The potential for optimizing processes or designing new digital services and new business areas appears almost endless. Digital platforms and their AI are crucial for this. Companies like Amazon have demonstrated how a new business model can completely change and even dominate a market within a few years through the intelligent combination of logistics and IT. The consequences of this development are already evident for companies in the logistics industry (Schlautmann 2019).

The market shares of a coming platform economy have not yet been allocated in the B2B sector, but the race is on. The winners will be digital platforms with AI algorithms that permeate the entire logistics sector and thus the economy. Globally, the logistics industry is coming under the scrutiny of technology developers and investors (Konrad 2019; CB Information Services 2018). Given the high degree of standardization in logistics, it can be assumed that within a few years, logistical AI will negotiate, control and schedule the flow of goods in this world. At the same time, the consistent expansion of the Silk Road reflects China's extraordinary commitment to the field of physical logistics in an increasingly globalized world economy.

The Silicon Economy is being developed in Germany: with over three million employees and more than a quarter of a trillion euros in annual turnover, logistics is the third largest industry in Germany, ahead of mechanical engineering and telecommunications. Deutsche Post DHL is considered the largest logistics company in the world. DB Schenker and Kühne + Nagel are two other companies from German-speaking countries among the global top ten. The same applies to the technology sector with SSI Schäfer (2nd place) or Beumer (largest manufacturer of sorting machines in the world at 8th place) (World Bank 2021).

The development is slower in logistics than in the times of the e-commerce hype and is therefore not perceived as decisive by the public. This is partly due to the much higher complexity of B2B logistics applications. However, this effect is increasingly being compensated for by high investments in technology and start-ups. The classic methods of Silicon Valley, which is focused on the B2C sector, are increasingly giving way to long-term commitments in terms of a Silicon Economy.

The challenges lie at both the operational and strategic levels. And the venture of implementing a Silicon Economy must develop both technical and management solutions to overcome existing limitations.

- *Heterogeneous & fragmented system landscapes:* Historically grown and highly fragmented system landscapes result in data silos and a lack of information transparency
- *Specialized & multimodal value chains:* Different logistics areas and segments have very specific requirements for their digital infrastructure
- *New business models & (digital) competitors:* Companies like Amazon.com or financially strong Chinese companies occupy logistics based on their B2C platforms and business models
- *Limited financial and human resources:* Particularly in the areas of digitization and AI, there is a lack of human resources and, due to low margins in logistics, in-house developments in this area are limited to the bare essentials.

No single company by itself has sufficient motivation, market power or resources to succeed on its own in the logistics of a Silicon Economy. Open, federated and strong consortia from business and science, in which technologies, de facto standards and new business models are quickly brought together and developed, would be able to create the basis for economic use of AI solutions with new services, technologies and applications in logistics and supply chain management and enable decisive participation for (German) SMEs. It is necessary to create open and federated platforms that all can benefit from.

2.3. The emergence of Supply Chain Ecosystems

The leitmotif of the change toward a Silicon Economy is a new type of cooperation in global, digital ecosystems. Today's rigid and well-defined value chains are being replaced by flexible, highly dynamic and globally connected value networks. The availability and transparency of relevant data is a key prerequisite for this (Plattform Industrie 4.0 2019) and a decisive driver of innovation and growth. In this context, data sovereignty – understood as the ability of a natural or legal person to decide in an exclusive and sovereign way on the use of data as an economic asset – plays a key role. On the one hand, data sovereignty acts as an enabler for the use of AI applications and thus automation and autonomization in supply networks. On the other hand, it represents a basic prerequisite for the cooperation or connection of previously separate value chains and networks. The silo-like, discontinuous vertical linking of companies along the value creation process, which is currently mostly dominated by producers of an end product (OEM), can be expanded to include horizontal and spontaneous or situational cooperation between chains or networks that were previously separate or in competition.

Supply chains will be connected at all levels - autonomously and in real time. Logistics services will be traded, scheduled and supervised via platforms. Devices will negotiate and pay autonomously. The control loops of logistics planning and scheduling will be closed. Supply chains will plan, organize and optimize themselves autonomously. Consequently and finally, an autonomous logistics ecosystem will emerge.

Synergy potentials that clearly exceed the potential of an isolated and optimized chain are the result. These include: the reduction of emissions through optimization and consolidation of transports with a simultaneous acceleration of throughput times through transport networks; the reduction of logistics costs and the vulnerability of transport chains to errors (increase in resilience); the setting of impulses for an ecologically and economically sustainable, cycle-based economy and much more.

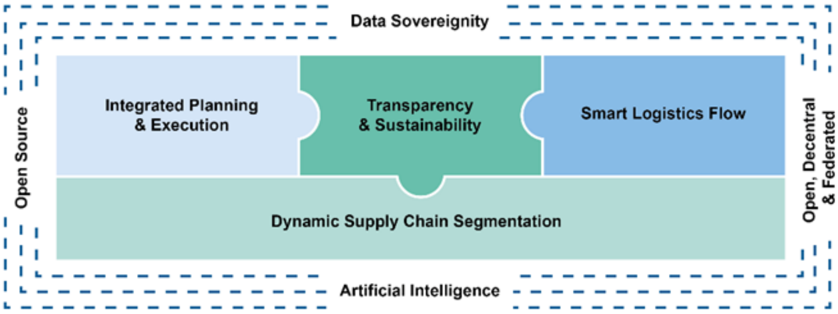

Figure 1. Characteristics of Supply Chain Ecosystems in the Silicon Economy (adapted from PwC (2020))

3. Silicon Economy Inside

3.1 Big Picture and Vision

The "big picture" of the Silicon Economy shows the complete data chain: from data generation in the Internet of Things (IoT Broker) to the trading and booking of data (Blockchain Broker) to the organization of (logistical) processes (Logistics Broker) with the all-connecting secure data space (International Data Spaces IDS) and the platforms above it for the realization of new digital business models (see Figure 2).

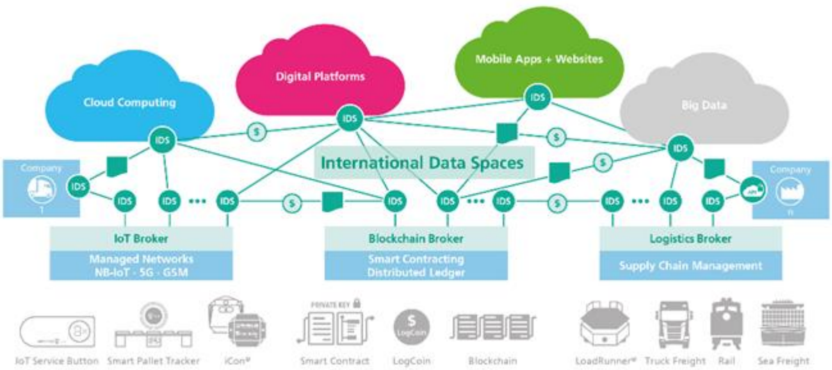

Figure 2. An open and digital ecosystem as a digital infrastructure for autonomously acting and highly dynamic supply chains

This digital infrastructure enables end-to-end transparency in value networks and creates trust along complete supply chains – from raw material suppliers to end customers – perhaps the most important prerequisite for the participation of all companies. Many of the technologies required for the "big picture" are already available. Starting with logistics, this comprehensive vision could be successively translated into products and business models. The key to realizing this vision is to combine the following key areas and lines of action into a holistic solution in the Silicon Economy sense.

Integration and connectivity of infrastructures. The basic constitution of the technical infrastructure must be based on European values. Data protection, IT security and data sovereignty must take a central role. This can be achieved in a Silicon Economy by using the components of International Data Spaces (Fraunhofer Gesellschaft 2020) to create secure data spaces that ensure data exchange between a network of companies while maintaining data sovereignty (trust anchor, trusted platform, data usage control and no transfer of ownership rights) as a central criterion of sovereign management of data.

Realization of open and federated digital infrastructures and platforms. Participation in the digital ecosystem of the Silicon Economy should take place by means of open and barrier-free access to all basic technologies (open source, see opensource.org). The goal must be to minimize the entry thresholds into the Silicon Economy for companies and developers. These, in turn, are free to build new data-driven business models or adequate services, etc. The open basic technologies also include methods of AI.

Capabilities for real-time connection of things. The basis of all digital business models or services is made possible by current developments, particularly in the field of information and communications technology. By developing components for networking devices of an industrial Internet of Things with open and federated platforms, a technological basis for new services and process models will be created.

Smart services. Companies that understand how to use data as a basis for creating unique customer offerings are among the most successful companies in the world: on the list of most valuable companies, Alphabet (Google), Amazon.com, and Facebook are at the top positions with their data-driven business models, and 80% of the approximately 260 Unicorns existing in 2018 had data-driven business models (CB Information Services 2017). This includes, for example, new solutions for digitally negotiated contracts (smart contracts); receipts and payment models by using distributed ledgers - for example, for booking and billing logistical services (transport, handling, storage) or also platforms and digital environments for autonomous planning and scheduling processes.

3.2 Silicon Economy Architecture

The architecture of the Silicon Economy can be characterized firstly by the central architectural patterns used. Secondly, it is characterized by its essential architectural components. Both architectural patterns and components will be briefly presented below.

3.2.1 Architectural Patterns

An architectural pattern is a general, reusable solution to a commonly occurring problem in software architecture. Central architectural patterns of the Silicon Economy include micro-services, self-contained systems, application containers, application container orchestration, and event-driven communication.

Microservices. A microservice architecture[3] is a version of a service-oriented architecture (SOA). The target system combines a set of small-scale services ("micros") that allow for easy, independent distribution, as well as independent changes and extensions. Each microservice has a high degree of autonomy and isolation, and can be developed autonomously and deployed in

[3] VMware (2020): What is vSphere Hypervisor? https://www.vmware.com/de/products/vsphere-hypervisor.html

its own Docker container (see also descriptions of the Application Container architectural pattern). Each microservice can be implemented using a different technology; they communicate with each other using lightweight protocols (fast, data-efficient protocols such as REST).

The goals of this pattern are reuse, high cohesion, low coupling, separation of concerns, single responsibility, and information hiding. Its advantages are modularity and maintainability, as well as faster adaptation to changing requirements (scaling). Furthermore, these goals are supported by the use of the additional architecture pattern called Self-Contained systems.

Self-contained systems. Self-contained systems (SCS)[4] divide a system into independent web applications, in this case built with microservices. They communicate preferably via asynchronous application programming interfaces (API). Here, the preferred architecture is based on the Independent Systems Architecture (ISA) best practice guidelines[5].

Application Container. In the Silicon Economy, a microservice is always delivered and executed in exactly one application container. Containers do not only include the application or the microservice itself, but also all the required dependencies. These include, for example, runtime environments and system libraries. In contrast to virtual environments or virtual machines (VM), containers use core functionalities of the underlying operating system and are therefore more lightweight in comparison.

Application container orchestration. The use of the architecture patterns described above leads to a large number of containers. This results in a high effort for the management of the containers. This is exactly where application container orchestration comes into play[6]. Orchestration solutions, such as Kubernetes, perform the following tasks, for example:

1. managing resources, such as storage
2. management of nodes on which individual containers are run
3. allocation of resources, such as memory and network
4. scaling containers based on redundancy requirements
5. monitoring containers for functionality and resource usage

Event-driven communication. Software components are loosely coupled via known interfaces. In a purely event-oriented system, this knowledge is no longer necessary, since events can simply be triggered and assigned to receivers via certain criteria (e.g., topics). This enables asynchronous or event-based communication, in which the sending and receiving of data takes place asynchronously and, for example, waiting for a response from the recipient does not block the process. Events can be triggered both from outside the system, e.g. by user input or by sensor values, and internally by the system itself.

There are several implementations of this architectural pattern. In Naik (2017) and Dizdarević et al. (2019), different asynchronous messaging protocols with wide distribution are compared

[4] NNOQ (2020): SCS: Self-Contained Systems. Assembling Software From Independent Systems. https://scs-architecture.org/.

[5] INNOQ (2020) ISA: Independent Systems Architecture. Principles For Microservices. https://isa-principles.org/.

[6] Kubernetes (2020): What is Kubernetes? https://kubernetes.io/docs/concepts/overview/what-is-kubernetes/ und Mirantis | Pure Play Open Cloud (2020): What is container orchestration? https://www.mirantis.com/blog/container-orchestration/

and referred to the respective standards and technical description documents of the protocols. In the Silicon Economy architecture MQTT[7] and AMQP[8] are used.

3.2.2 Architectural Components

International Data Spaces. The International Data Spaces (IDS) address the design of a reference architecture model and associated reference implementations for industrial data spaces. The basis is built by the so-called IDS connectors. The functionality and security of these connectors is based on the three topics of trust anchor, trustworthy platform and data usage control. One of the fundamental principles of IDS is to maintain sovereignty over one's own data. This principle excludes the transfer of ownership rights to any central entities or providers. IDS provide a generally applicable technical infrastructure for the exchange of any kind of data and has no direct technical reference to the logistics application field.

IDS connectors establish connectivity between the individual platforms while maintaining data sovereignty. They are used to communicate securely with the outside world.

IoT Broker, Blockchain Broker, Logistics Broker. Central to the concept a Silicon Economy are so-called brokers.

IoT Brokers are important data sources of a Silicon Economy. They connect cyber-physical systems (CPS), such as smart containers and pallets, the same way they securely connect smart machines via 5G technology, NarrowBand IoT or conventional networks and offer data over the Internet. An IoT broker encapsulates IoT devices and their low-level protocols (data is typically sent in binary representation) and also real-time capable protocols, and transforms the messages into open standards (e.g., HTTP(S), AMQP, or MQTT(s)) and open data format JSON, except for visual data (e.g., images, point clouds & 3D sensor data).

Blockchain Brokers offer integrated and standardized blockchain solutions for horizontal and vertical networking in value networks. The IT architecture required for this is provided by the Blockchain Broker setup and is integral to the Silicon Economy ecosystem. Contracts (i.e., smart contracts) can be signed via Blockchain Brokers. One of the central building blocks of the Blockchain Broker is a component for smart-contract-based billing of services. Payments via crypto tokens and micropayments are also among the services offered by the brokers. Performed transactions are announced, immutably chained and validated. Current developments in e-money and cash-on-ledger are taken into account. A framework will be created that considers the requirements of international trading operations. An integrated payment system acts as an enabler for new and disruptive business models in Industry 4.0, supporting instant payments at the value-added and enterprise level on the one hand and micro-transactions at the system level between individual CPSs on the other.

Logistics Brokers provide connectivity between services in the Silicon Economy that run on different platforms. Logistics services and their execution are organized via Logistics Brokers. They connect providers of logistics services with customers and users. This applies equally to both internal logistics/facility logistics and external logistics, e.g., the internal transport or picking of a customer order as well as the (road or rail) transport and handling of goods. In

[7] MQTT Version 3.1.1. http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/os/mqtt-v3.1.1-os.html und MQTT Version 5.0. https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.pdf.

[8] ISO/IEC 19464:2014. Information technology – Advanced Message Queuing Protocol (AMQP) v1.0 specification, https://www.iso.org/standard/64955.html und AMQP – AMQP Working Group, 0-9-1. https://www.amqp.org/specification/0-9-1/amqp-org-download.

addition, the Logistics Broker is responsible for orchestration, i.e. combining several Silicon Economy services to form a meaningful business process. This means that even complex IT service business processes can be automated.

Silicon Economy Services. Silicon Economy services (SE services) are developed and operated on the basis of the above-mentioned infrastructure and architectural patterns. From a technical perspective, SE services consist of several microservices. Cross-company use of services and brokers takes place via IDS. Generally, independent and exchangeable web applications (SE services with web user interface as self-contained systems) are developed for specific use cases. These consist of individual software as well as standard products. For each SE service, it can be decided individually which system platform is to be used, although there are basic specifications that must be met (IDS, Web User Interface technology, programming language portfolio, database system portfolio, tool portfolio). Developer guides and style guides provide the necessary standardization. Viewed from the outside, an SE service forms a decentralized unit that communicates with other SE services (as asynchronously as possible) only via IDS. The business logic is usually implemented as microservice. Due to the clear, isolated functional scope, an SE service can be developed, operated and maintained by one team.

3.3 The Role of Open Source

The abovementioned developments present a challenge for traditional logistics service providers. An already competitive market, in which profits are made through standardization efforts, is put under pressure by the requirement of increasing integration into complex, digital supply chains. Consequently, logistics service providers are facing a conflict between offering their traditional services and providing and developing new, digital products and services to meet the (digital) requirements of their customers. At the same time, already established platforms such as Amazon or Uber are increasingly entering the B2B market, followed by startups that act as fourth party logistics providers, for example, by decoupling technologically driven, smart services and solutions from the actual logistics service (Seiter et al. 2019; Sucky et al. 2019).

Platforms, through their inherent characteristics of strong network effects and the ability to incorporate complementary goods, offer traditional companies the opportunity to expand their product portfolio and value proposition. By including other companies in a platform-based ecosystem, platform service providers can achieve integration into their customers' supply chains in addition to their core logistics tasks. Until now, B2B platforms are mostly still very specialized and hardly benefit from strong, indirect network effects (Bundesministerium für Wirtschaft und Energie 2019). Moreover, the integration of complementary providers rarely succeeds and is associated with high costs. In particular, the challenge of trust relationships and the question of orchestration are crucial for platform building (Tian et al. 2020). Since logistics, which is in any case a link between the individual supply chain partners, must establish trust and orchestrate processes and tasks, it can be attributed a central role here in building a B2B platform economy.

Open source developments in particular play a decisive role here. On the one hand, open source is a driver of a federated platform economy, as the open provision of processes and implementations enables integration into further platform and offerings from other partners and thus contributes to the growth of the ecosystem. On the other hand, open source in combination with collaborative software development is by definition a good way to work collaboratively, openly and transparently, thus increasing the trust relationship between the partners involved.

That is why the crucial aspects of a coming federated platform economy are linked to strategies such as open source, open innovation and collaboration. No company (in logistics) has sufficient motivation, market power or resources to implement the "big picture" of a Silicon Economy on its own (see above). Only together open and federated platforms can be developed and thus technologies, de facto standards and new business models can be established quickly. Consequently, it is about a "Linux for logistics" and thus about the joint foundation of a European Open Logistics Community as a driver of open developments of a Silicon Economy. Through the joint development and use of open source software and hardware, efficiency and participation are to be achieved in equal measure. Common standards, tools and services are created, which in turn enable successful commercial use in companies, act as growth drivers for the industry and become the starting point for new products and services that can be generated from them.

Design of an open source concept for the Silicon Economy. The core component of the Silicon Economy ecosystem is a repository in which components for infrastructure (platforms and brokers) and applications (Silicon Economy services) are provided. These Silicon Economy components are mostly not a finished program or a finished software platform. They provide a reusable, common structure and (AI) algorithms for applications and devices and are generally developed with the goal of multiple use in a wide variety of logistics areas. Brokers provide a framework through which companies can connect Silicon Economy applications (e.g., web services or service platforms such as freight exchanges), services, or devices (e.g., IoT and blockchain devices). Components are developed by the open source community. They are made available as open source. Companies build their own applications on top of them and extend them in such a way that they meet their specific requirements. In sum, a logistics operating system is created, a "Linux for logistics".

Initially, this "operating system" will primarily cover existing logistics services and components that are either shared by a large number of companies or form the basis for individual implementations. This will create, use, further develop and continuously improve a common source code basis. Previously very different IT implementations can converge both technically and functionally by using the common basis and thus realize greater interaction with less integration effort. Typical logistics use cases, such as Track&Trace or the integration of freight forwarders into corporate IT, can be easily used and reused via existing components from a repository (see Figure 3).

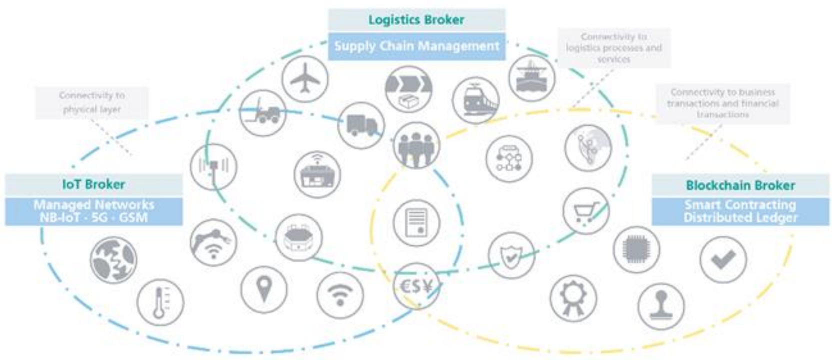

Figure 3. Silicon Economy Repository

4. Conclusion

The world is no longer divided into East and West, but into digital and non-digital. The motto is: Whatever can be digitized will be digitized. Supply chains will be networked independently and in real time at all levels (link + virtualize). Logistics services will be traded, planned and controlled via platforms (trade – plan – control). Devices will negotiate and pay independently (smart contracting + blockchain). The control loops of logistical planning and scheduling will close (closed loop) and supply chains will independently schedule, organize and optimize themselves (plan – organize – optimize). Due to secure communication and data spaces, this will happen without losing sovereignty over data. All in all, an autonomous logistics ecosystem will emerge – in short: the Silicon Economy. This is too complex an undertaking for one company alone, so that open source developments and open innovation (must) take on a central role.

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How Much Value Do Consumers Put On Environmental Sustainability When Choosing Last-Mile Delivery?

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Summary. E-commerce has been rapidly growing, creating challenges for urban logistics. To archive sustainable last-mile delivery, consumer involvement is key. This paper aims to study to what extent e-commerce customers value environmental sustainability when choosing a last-mile delivery. Conducting a stated-preference survey and a conditional logistic regression, we show that higher delivery costs, longer delivery times and higher CO_2 emissions make a last-mile delivery option less preferred by customers. Longer delivery times are irrelevant when consumers do not face time pressure. We also derive the trade-offs between the factors: to save 100 grams of CO_2 emissions, consumers would be willing to pay around 1€ more or wait additional 0.86 days (or even 1.63 days in less time-critical situations). When there is no urgency, they would be willing to wait as long as needed. The derived trade-offs offer insights for designing sustainable delivery methods and for setting up environmental policies.

1. Introduction

In recent years, e-commerce has been growing at a fast pace, resulting in an increase in the direct-to-consumer deliveries within urban areas, and thus creating huge challenges for sustainable logistics (Savelsbergh and Van Woensel 2016). The last-mile delivery, already regarded as one of the most expensive, inefficient and polluting part of the supply chain, is becoming even more problematic. The increase of shipments, high delivery failures, empty trip rates, as well as gas emissions, make it the most polluting section of the entire logistics chain (Gevaers, Vanelslander, and Van de Voorde 2011).

Accordingly, diverse new approaches towards more sustainable last-mile delivery have been suggested (e.g. drone delivery (Yoo and Chankov 2018; Khalid and Chankov 2020) and crowdsourced delivery (Chen and Chankov 2017; Ciobotaru and Chankov 2021)). To achieve sustainable logistics in urban areas, the commitment of all stakeholders is essential (Ranieri et al. 2018). However, one aspect that seems to be ignored so far both in research and practice is the customer perspective on sustainable delivery (Buldeo Rai et al. 2021).

As a way to tackle this challenge, Ignat and Chankov (2020) suggest that delivery companies should provide customers with transparent information about the delivery options not only on economic factors (e.g. time, cost, and location) but also on environmental and social factors. The authors demonstrate that displaying the environmental and social impacts of last-mile deliveries influences E-commerce customers, and generally makes them more likely to choose a more sustainable last-mile delivery. In particular, participants are willing to wait longer, pay more, or choose a less convenient location in exchange of a more environmentally- and/or society-beneficial delivery. However, Ignat and Chankov (2020) do not analyze the exact trade-offs that e-commerce customers would be willing to accept (e.g. how much longer they would wait, or how much more they would pay). Investigating those trade-offs offers both theoretical and practical implications for sustainable last-mile delivery.

Thus, the main purpose of this paper is to study to what extent e-commerce customers value environmental sustainability when choosing a last-mile delivery. Accordingly, we conduct a stated-preference survey with different scenarios in which participants have to select a preferred delivery among four available options based on information on the deliveries' cost, time, and CO_2 emissions. Finally, we a conduct conditional logistic regression to determine the trade-offs that consumers make between environmental (CO_2 emissions) and economic (cost and time) factors when choosing a last-mile delivery.

2. Hypotheses Development

E-commerce customers are, so far, only provided with information in terms of the delivery cost and time when placing orders online (Amazon 2018). Those factors could be attributed to the economic pillar of sustainability (Ignat and Chankov 2020). This study investigates consumers' preferences when a factor from the environmental pillar is added (the delivery's CO_2 emissions).

Nguyen et al. (2019) show that the most important attribute in shaping consumer preferences for a last-mile delivery is its fee. Moreover, customers often rank the delivery cost as the most important consideration for their delivery method choice (Garver et al. 2012). Additionally, the Consumer Research Report by MetaPack (2018) revealed that 75% of ecommerce consumers take advantage of a minimum spend "free delivery" option and 62% of them expect free delivery for everyday purchases. Thus, the first hypothesis is formulated as follows:

H1: The higher the cost of a last-mile delivery option, the less preferred it is by customers.

The second most important last-mile delivery attribute for consumers after cost is the delivery speed (Garver et al. 2012). Customers' expectations for shorter delivery time are constantly increasing (AlixPartners 2016) and thus setting new standards for e-commerce deliveries (Mangalindan 2015). Hence, fast delivery options, such as same-day delivery, are most preferred by customers (Nguyen et al. 2019). Thus, the second hypothesis is formulated as follows:

H2: The longer the time of a last-mile delivery option, the less preferred it is by customers.

Customers are increasingly concerned about the impact their online shopping behavior has on the environment (MetaPack 2018). Moreover, Ignat and Chankov (2020) demonstrate that displaying the environmental impacts of last-mile deliveries influences E-commerce customers, and generally makes them more likely to choose a more sustainable last-mile delivery. Buldeo Rai et al. (2021) confirm that providing information on the ecological footprint of delivery options is the most decisive incentive to encourage consumers' sustainable decision-making for ecommerce delivery. Finally, the Consumer Research Report by MetaPack (2018) showed that

51% of consumers are conscious of the last-mile delivery’s eco-impact. Hence, to test the role that CO_2 emissions have on consumers’ decisions, the following hypothesis has been formulated:

H3: The higher the level of CO_2 emissions of a last-mile delivery option, the less preferred it is by customers.

3. Survey Design

A stated-preference survey was chosen for this study as it is considered to be one of the most efficient methods for investigating consumers’ preferences over products and services with more attributes (Lang Yang 2009) and has also recently been adapted to the field of last-mile delivery (Nguyen et al. 2019; Ignat and Chankov 2020; Buldeo Rai et al. 2021). Complementarily, an online survey was chosen due to its four main advantages: speed, economy, convenience, and simplicity (Sue and Ritter 2012). The survey was developed using the “Unipark” platform.

The survey focuses on participants’ decision-making process when it comes to various delivery methods. The participants were presented with four different scenarios (see Table 1). The scenarios were designed to cover different time frames. The first scenario was made in such a way that it would put the participants under the pressure of an event coming up in a very short time frame. The second scenario was formulated as to put the participants under the pressure of a longer time frame than the first one. The third scenario was structured so it would not put the participants under any time pressure. The fourth scenario was devised in such a way that the time pressure is very much dependent on the individual. This means that participants’ willingness to wait, or patience, determines when the participants want to acquire the product.

In order to test consumers’ preferences towards the different factors (cost, time and CO_2), we selected different levels for each of the three factors (see Table 2) and used them to develop different delivery options. Following the approach of Ignat and Chankov (2020), the levels for the economic pillar factors were chosen by using the delivery cost model of Amazon (2018), whereas the levels for the environmental pillar of CO_2 emissions were chosen based on the findings of Edwards, McKinnon, and Cullinane (2010) and Moroz and Polkowski (2016).

Using the different levels, seven questions were designed for each scenario, resulting in 28 questions in total. Table 3 shows the questions for scenario 1. The questions were developed combining constant, ascending, and descending values for cost and time. The values for CO_2 were kept the same throughout all questions, with them descending from left to right. The two different options for ascending time were designed to cover the different time frames in the different scenarios (with higher values for scenarios 2 and 3).

No.	Scenario
1	It’s your friend’s birthday in two days and you don’t have a gift for them yet. Which option would you go for when ordering the gift?
2	It’s Monday and you are about to start the preparations for your Halloween party which is taking place on Saturday. Which option would you go for when ordering the things you need?
3	Your next trip is in two weeks and you need a suitcase for it. Which option would you go for when ordering one?

No.	Scenario
4	The newest version of your favorite phone brand was just released. You have been saving up but the budget you have at the moment will only cover the costs for the phone; however, your friend has offered to pay for shipping as long as you pay them back in the near future. Which option would you go for?

Table 1. The four scenarios

Factor	Direction	Values			
Cost	Constant	5 €	5 €	5 €	5 €
	Ascending	5 €	7 €	8 €	10 €
	Descending	5 €	4 €	3 €	2 €
Time	Constant	2 days	2 days	2 days	2 days
	Ascending	2 days	3 days	5 days	8 days
		2 days	3 days	4 days	5 days
	Descending	2 days	1,5 days	1 day	0,5 days
CO_2	Descending	400g	300g	100g	15g

Table 2. All possible values for the chosen factors of sustainability

4. Results

Data Collection and Sample Description. The survey was addressed to e-commerce customers and advertised on social media and the mailing list of Jacobs University. 114 people participated in the survey. 59 participants (52%) shop online once every few months, followed by 37 (32%) who shop online a few times a month, 12 (11%) shopping once a year and 6 (5%) shopping multiple times a week. 101 participants (88%) belong to the 18 – 24 years age group, whereas 1 (1%) belongs to the 17 or younger group, 11 (10%) belong to the 35 – 44 age group, and 1 (1%) belongs to the 55 years or older group. When it comes to the education level, 68 (60%) are still attending some college, followed by 31 (27%) have a bachelor's degree, and 9 (8%) have a master's degree. Consequently, it seems rational that 71 (62%) of them have a monthly income lower than 500€, while 27 (24%) have a monthly income of 500€ - 1500€, followed by 14 (12%) whose incomes are above 2000€. Regarding the location where they currently reside, the majority of participants (65%) said Germany, followed by Kosovo (11%), UK (4%) and other (20%). This implies that most of the participants were students at Jacobs University, where the survey was heavily distributed.

Conditional Logistic Regression. Conditional logistic regression allows for individual respondents to be subjected to a set of alternatives before making a choice (binary dependent variable Y, where 1 is chosen and 0 is not chosen) (Long and Freese 2006). For example, a participant can be given four choices for transportation (car, train, bus, or bike), each with its own characteristics, and asked to choose only one. The conditional logit model then takes into account that these four options were given together to a respondent and a choice was made amongst them.

		A	B	C	D
	Cost	5 €	5 €	5 €	5 €
1	Time	2 days	3 days	5 days	8 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	7 €	8 €	10 €
2	Time	2 days	2 days	2 days	2 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	5 €	5 €	5 €
3	Time	2 days	2 days	2 days	2 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	4 €	3 €	2 €
4	Time	2 days	3 days	5 days	8 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	7 €	8 €	10 €
5	Time	2 days	3 days	5 days	8 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	7 €	8 €	10 €
6	Time	2 days	1,5 days	1 day	0,5 days
	CO_2	400g	300g	100g	15g
	Cost	5 €	4 €	3 €	2 €
7	Time	2 days	1,5 days	1 day	0,5 days
	CO_2	400g	300g	100g	15g

Table 3. Survey questions for Scenario 1

Due to the intentions of this study, the choice of using conditional logistic regression is appropriate. With the customer delivery preference being the single dependent variable, and cost, time, and CO_2 being the independent variables, it will be possible to test and analyze the choices made among the participants, in terms of the different delivery methods. It will also be possible to see how the individual variables affected the decision-making, or in other words, which specific variables influenced the participants to choose a method over the other. In addition, the responses provided by the participants were of the binary type. This would mean that their choice would either be regarded as the *chosen* (selected) one (i.e. participants' actual choice; indicated by a value of 1) or the *else* one (i.e. participants' choice of any of the other options; indicated by a 0 value). This way, the responses would be characterized into two groups.

Considering the attributes tested in this study, the resulting model is:

$$\text{customer delivery preference} = \beta_{cost}\, X_1 + \beta_{time}\, X_2 + \beta_{CO2}\, X_3 + \alpha_{id} \quad (1)$$

In this case, the β values represent the coefficient for each predictor X. The α value represents the stratum or the homogeneous sample group.

The odds ratio can be particularly helpful when interpreting the results of a logistic regression. It can be described as the exponential of β, or, exp(β) and is an indicator of the change in odds resulting from a unit change in the predictor (Field 2013). In other words, it calculates the odds of an event occurring divided by the odds of an event not occurring.

Main Findings. A separate model was created for each of the four different scenarios. To check the model fits, R^2, Likelihood ratio test, and Wald test were applied. The measures indicated good model fits (see Table 4). The results of the four models are shown on Table 5.

Scenario	R-square	Likelihood ratio test (on 3 df)	Wald test (on 3 df)
1	0.094	313.9***	207.0***
2	0.103	348.1***	236.8***
3	0.180	631.6***	315.9***
4	0.107	359.8***	247.2***

Table 4: Model fit

For scenario 1, when looking at the coefficients for each factor: cost, time and CO_2 emissions, it can be concluded that there is a significant negative relationship between the independent variables (cost, time and CO_2 emissions), and the dependent variable (i.e. customer delivery preference) due to the negative sign. In terms of this study, an increase in cost by 1€ would decrease one's odds of choosing a delivery option by a factor of 0.6633, or 33.67%. Likewise, there is a negative relationship between time and choice. This would mean that increasing the time by 1 day would decrease one's odds of choosing a delivery option by a factor of 0.5888, or 41.12%. As per the third factor, there is also a negative relationship between choice and CO_2. This way, increasing the CO_2 emissions by 1g would decrease one's odds of choosing a delivery option by a factor of 0.9955, or 0.45%. Thus, H_1, H2 and H3 are confirmed for scenario 1.

For scenario 2, the coefficients for cost, time, and CO_2 emissions again show a significant negative relationship with the dependent variable (i.e. customer delivery preference). This would mean that increasing the cost by 1€ would decrease one's odds of choosing a delivery option by a factor of 0.5997, or 40.03%, increasing the time by 1 day would decrease one's odds of choosing a delivery option by a factor of 0.722, or 27.8%, and increasing the CO_2 emissions by 1g would decrease one's odds of choosing a delivery option by a factor of 0.9947, or 0.53%. Thus, H1, H2 and H3 are confirmed for scenario 2.

Different from *Scenario 1* and *2*, in *Scenario 3* only two values are significant: cost and CO_2 emissions. With the coefficients for cost and CO_2 emissions being negative, this would imply that increasing the cost by 1€ would decrease one's odds of choosing a delivery option by a factor of 0.469, or 53.1%, and increasing the CO_2 emissions by 1g would decrease one's odds of choosing a delivery option by a factor of 0.9922, or 0.78%. Considering time is not significant, it can be concluded that in Scenario 3, the delivery time did not influence customers' choice of a delivery option. Thus, H1 and H3 are confirmed for scenario 3, while H2 is rejected.

Similar to *Scenario 3*, in *Scenario 4* the only two significant values are cost and CO_2 emissions. The negative coefficients for cost and CO_2 emissions show that increasing the cost by 1€ would decrease one's odds of choosing a delivery option by a factor of 0.582, or 41.8%, and that increasing the CO_2 emissions by 1g would decrease one's odds of choosing a delivery option by a factor of 0.9951, or 0.49%. Similar to Scenario 3, the delivery time did not influence customers' choice of a delivery option. Thus, H1 and H3 are confirmed for scenario 4, while H2 is rejected.

	coefficient	z-statistics		odds ratio	odds ratio [%]
Scenario 1					
cost	-0.4106	-10.81	***	0.6633	33.67%
time	-0.5296	-13.03	***	0.5888	41.12%
CO_2 emissions	-0.0045	-11.67	***	0.9955	0.45%
Scenario 2					
cost	-0.5114	-13.72	***	0.5997	40.03%
time	-0.3257	-5.39	***	0.7220	27.80%
CO_2 emissions	-0.0053	-13.80	***	0.9947	0.53%
Scenario 3					
cost	-0.7571	-15.79	***	0.4690	53.10%
time	0.0532	1.56		1.0546	N/A
CO_2 emissions	-0.0078	-14.74	***	0.9922	0.78%
Scenario 4					
cost	-0.5412	-14.22	***	0.5820	41.8%
time	-0.0360	-1.08		0.9646	N/A
CO_2 emissions	-0.0049	-11.55	***	0.9951	0.49%

Table 5: Results for all scenarios

Hypotheses	Scenarios			
	1	2	3	4
H1: The higher the cost of a last-mile delivery option, the less preferred it is by customers.	Yes	Yes	Yes	Yes
H2: The longer the time of a last-mile delivery option, the less preferred it is by customers.	Yes	Yes	No	No
H3: The higher the level of CO_2 emissions of a last-mile delivery option, the less preferred it is by customers.	Yes	Yes	Yes	Yes

Table 6. Hypotheses support summary

Table 6 shows an overview for all three hypotheses and the four scenarios. Overall, H1 and H3 were supported in all scenarios, while H2 was supported for scenarios 1 and 2 and rejected for scenarios 3 and 4. Those results are discussed in the following section.

5. Discussion

The *delivery cost* does indeed prove to be significant in people's decision-making throughout all four scenarios. Moreover, this study proves that as the price increases, customers' odds of opting for a certain delivery method decrease (see Table 5). The same stands for the variable *CO_2 emissions*. As concluded by MetaPack (2018) and Ignat and Chankov (2020), customers are aware of the fact that their shopping behaviors have the potential to impact the environment. This is confirmed by the significance of the variable *CO_2 emissions* in all four scenarios, increasing the level of *CO_2 emissions* would decrease someone's odds of choosing a delivery method.

The case for the variable *time* stands rather different. As mentioned earlier, the findings of previous studies (Garver et al. 2012; AlixPartners 2016; Nguyen et al. 2019) show that customers' expectations have increased over time, and consequently, they expect faster deliveries, this way implying that time plays a role. This is also confirmed by our findings for scenarios 1 and 2, where increasing the delivery time would only decrease their odds of choosing a delivery method (see Table 5). However, our findings for scenarios 3 and 4 are different, the delivery time does not alter customers' decision-making in those two cases. Looking at the different scenarios helps to understand this (see Table 1). On the one hand, scenarios 1 and 2 presented situations where customers are under time pressure; on the other hand, scenarios 3 and 4 offered a bigger time frame and no strict time pressure. The significance of the time factor in scenarios 1 and 2 and its insignificance in scenarios 3 and 4 shows that customers are not as concerned about the delivery time, when there is no urgency. This is a fascinating finding as it shows that customers do not always need to acquire their products within a very short time. In fact, when a time constraint does not exist, customers focus more on the cost and CO_2 emissions.

Moreover, in order to determine the trade-offs that consumers make between environmental (CO_2 emissions) and economic (cost and time) factors when choosing a last-mile delivery the Marginal Rate of Substitution (MRS) was applied. The MRS can be used to estimate the trade-off between two attributes that an individual is willing to make without a change in utility (Rao 2014). As we would like to derive customers' trade-off between environmental and economic factors, we suggest a new term "value of environmental sustainability", inspired by the the commonly used term "value of time" (Beesley 1965). As we compare customers' preferences on cost versus CO_2 emissions, as well as on time versus CO_2 emissions, we suggest two dimensions for the "value of environmental sustainability": the monetary one and temporal one. Hence, the ratio changes in the cost:CO_2 relationship and time:CO_2 relationship were taken into account. The changes were calculated using the respective coefficients from the regression models.

For the monetary value of environmental sustainability (MVES), the equation follows:

$$MVES = \frac{\beta_{CO2}}{\beta_{cost}} \tag{2}$$

Likewise, for the temporal value of environmental sustainability (TVES), the equation follows:

$$TVES = \frac{\beta_{CO2}}{\beta_{time}} \tag{3}$$

Table 7 shows the MVES and TVES for the four different scenarios (the values are converted for 100g of CO_2 emissions for better interpretation of the trade-offs). The MVES values vary between

0.90 € in scenario 4 to 1.11 € in scenario 1. The TVES value in scenario 1 is 0.86 days and 1.63 days in scenario 2. The TVES values for scenarios 3 and 4 cannot be calculated as the coefficient for time variable was not significant in those cases, showing that consumers give much higher priority to CO_2 emissions than to time in those two scenarios. The different TVES values for scenarios 1 and 2 can be explained with the different levels of time pressure (see Table 1). While scenario 1 had an urgency of only days, scenario 2 had urgency of 5 days.

In conclusion, when choosing last-mile delivery, customers seem to give equal value to a reduction of approximately 1 € and a reduction of 100g of CO_2 emissions, as well as equal value to a reduction in delivery time of 0.86 days (1.63 days in a less time-critical situations) and a reduction of 100 grams of CO_2 emissions. In situations of no time pressure, the customers completely disregard the time dimension when choosing a last-mile delivery. The importance of these findings can be emphasized as they indicate that customers put a very high focus on the environmental sustainability of the delivery method and not only on the economic factors. In days when the effects of high concentrations of CO_2 emissions in the environment are becoming more pressing by the day, consumers are ready to exhibit a more environmentally friendly behavior when shopping online. They are willing to pay an additional Euro or wait 0.86 days (or 1.63 days) for every hundred grams of CO_2 emissions being saved. When there is no urgency, they would be willing to wait as long as needed.

Scenario	MVES [€/100g]	TVES [days/100g]
Scenario 1	1.11 €	0.86 days
Scenario 2	1.04 €	1.63 days
Scenario 3	1.04 €	N/A
Scenario 4	0.90 €	N/A

Table 7: Monetary and Temporal Value of Sustainability

6. Conclusion

The main objective of the paper was to investigate to what extent e-commerce customers value environmental sustainability when choosing a last-mile delivery. Conducting a stated-preference survey and a conditional logistic regression, we show that higher delivery costs and higher CO_2 emissions make a last-mile delivery option less preferred by customers. Longer delivery times also make the delivery options less preferred in situations when consumers need a product urgently. However, longer delivery times are not a problem in cases when consumers do not face time pressure.

Moreover, we were also able to determine the trade-offs that consumers make between environmental (CO_2 emissions) and economic (cost and time) factors when choosing a last-mile delivery. We showed that saving 100 grams of CO_2 emissions, saving approximately 1 Euro or shortening the delivery by 0.86 days (or 1.63 days in less time-critical situations) are equally important to customers. Hence, to save 100 grams of CO_2 emissions, consumers would be willing to pay approximately 1 Euro more or wait additional 0.86 days (or even 1.63 days in some cases). In situations of no time constraints, they would be willing to wait as long as needed.

The main limitation of the study resides in the relatively small and homogeneous sample. Further research can focus on verifying the results in large-scale choice-based conjoint studies. Moreover, the fact that the participants' answers in the survey might differ from their actual ecommerce shopping behavior is also a limitation. Hence, conducting a revealed preference survey would be important to better estimate the existence of a value-action gap. Finally, the "value of environmental sustainability" could also be studied in other consumer purchasing decisions, to better understand consumers' preferences towards more environmentally friendly products and services.

This study allows customers to evaluate their decisions in a more knowledgeable manner when it comes to online shopping since the information provided makes it possible for them to weigh in the different economic and environmental factors and provides a different and more transparent perspective to online shopping. The derived trade-offs offer a first basis for companies and governments who can use them when designing sustainable delivery methods or when setting up environmental policies respectively.

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City Crowd Logistics

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Extended Abstract

Summary. Growing demand for last mile home delivery services encourages new home delivery concepts. One of these concepts is city-crowd-logistics (CCL), which can be interpreted as a local urban instance of the physical internet (PI). We explain the concept of CCL, report on a physical proof of concept test for CCL, summarize related process aspects and network design aspects, report on a small scale survey which provides a first insight into the willingness of urban citizens to participate in CCL-services in exchange for a monetary compensation, and indicate the needs for further research.

1. Introduction

While home delivery services as part of e-business fulfillment have steadily grown in recent years, the Covid-19 pandemic has significantly added to this growth. Thus innovative sustainable concepts for home delivery are sought for and experimented with. One of these concepts is city crowd logistic, a concept which can be interpreted as a specific implementation of the physical internet (PI).

The physical internet (PI) is a concept that was introduced by Montreuil (2011). Similar to the classical internet, where data packages are successively forwarded from router to router until they reach their destination, the PI mimics this principle in the physical world. Shipments are routed from PI-router to PI-router until they reach their destination. This principle requires standardized packages and standardized processes, which enable different transport operators to seamlessly perform partial transports (similar to the transport of a baton through a relay network with different couriers).

City Crowd Logistics (CCL) can be interpreted as one possible instance of PI in an urban environment. Whereas most crowd logistics services require a 1:1 assignment of an order to a crowd-courier and thus depend on couriers which are willing and able to transport the order from its origin (e.g. a local operator’s hub) to the destination (e.g. the home of an e-commerce customer who ordered this home delivery), CCL allows assignments of partial order legs (shipments) to several crowd-couriers which carry out these subsequent partial delivery legs. The hand-over of the items is carried out at physical PI-router-locations or so-called "mini-hubs" (e.g. automated parcel locker stations or small shops, where items can be temporarily stored until they are picked up from the next courier). This principle is depicted in Figure 1.

Note that there are different options to carry out the CCL-transport (here: option X and option Y), and the decision on which option is to be used for this specific shipment is made dynamically based on the availability of couriers, and their respective willingness to execute the partial job which depends on the incentives for the different transport legs.

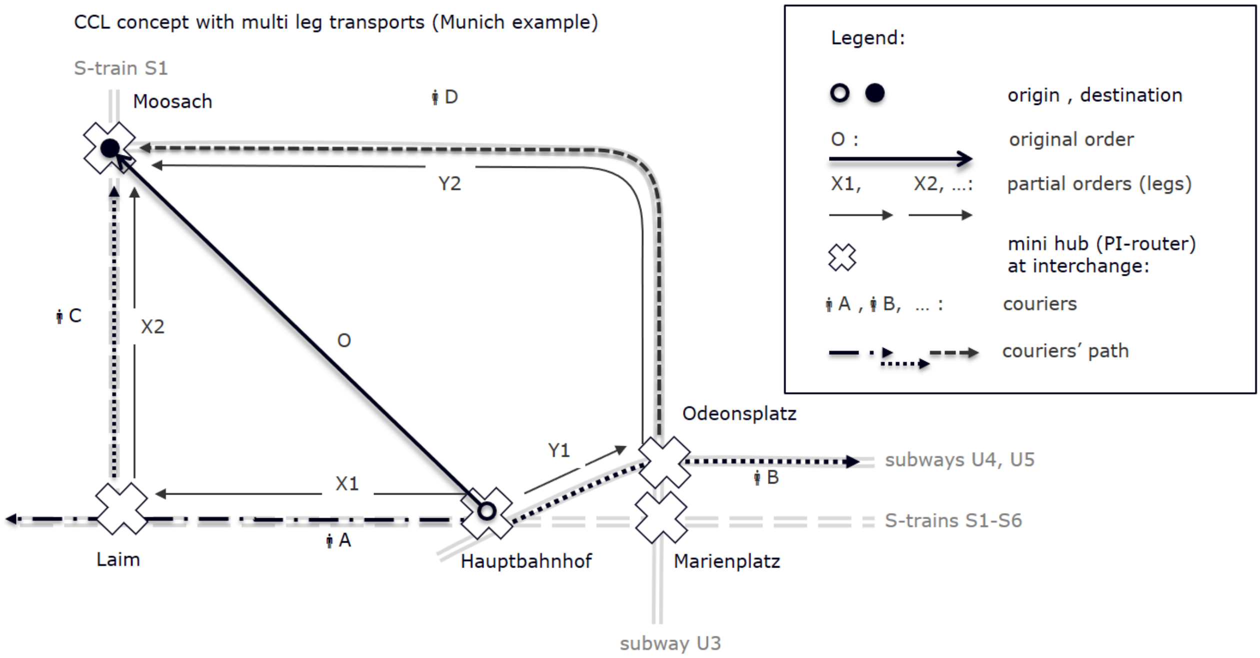


Figure 1. CCL Concept

CCL is a sustainable concept, as it harvests the transportation potential of all people moving around in a city anyhow (e.g. commuters or shoppers) to deliver the CCL-shipments without generating additional traffic.

In the scientific community, crowd logistics has been analyzed e.g. by Bludeo Rai et al. (2017) and Sampaio et al. (2019) with regard to concepts, by Frehe et al. (2017) with regard to best practices, and by Arslan et al. (2019) with regard to matching and routing. Multi leg transports in crowd logistics have been analyzed e.g. by Chen et al. (2017) and Ravid and Tenzer (2018).

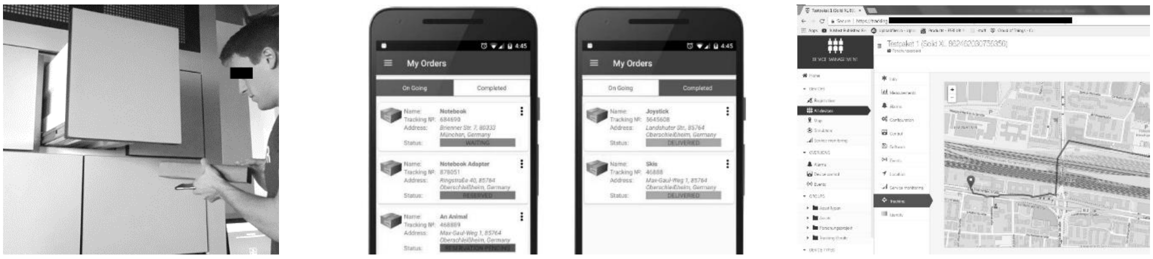
Research Questions. Before the CCL concept can mature into a commercial service, several research questions need to be addressed.

1. Can such a service physically be carried out today based on available technologies (proof of concept)?
2. How do the relevant processes need to be designed to enable such a CCL-service?
3. What network design is needed under which circumstances?
4. Which incentives are needed to attract freelance crowd-couriers and how could a commercial business model (incl. price-setting mechanisms) look like?

Other related research questions associated with scalability, legal and social aspects remain to be answered but are not addressed here.

2. CCL – Physical Proof of Concept and Process Design

We conducted a physical proof of concept test in Munich in 2019 where several parcels were transported from origin to destination. The proof of concept included three different couriers, three shipments, and two different PI routers (see Figure 2a). It also included demonstrator software components to schedule the couriers and communicate with the couriers (see Figure 2b) and a track and trace solution for the different shipments (see Figure 2c).



a) Pickup at PI-router *b) Communication App* *c) Track & Trace System*

Figure 2. CCL Physical Proof of Concept

The processes to physically conduct CCL-services not only need to cover all planned process steps, but also need to include exception handling e.g. for delays, no-shows of couriers, or deliveries to unplanned PI-routers.

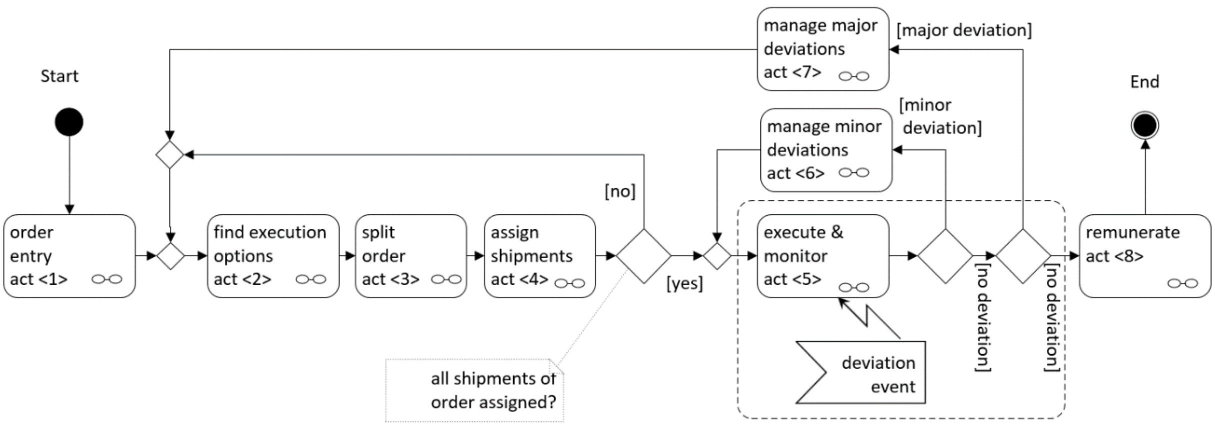


Figure 3. CCL Top-Level Process Overview

Figure 3 depicts the master process and the eight process elements (incl. sub-processes). After order entry ‹1› different possible transport execution options (routes) are determined ‹2›. Depending on these options, the original order is split into subsequent shipments ‹3›. Then an assignment process tries to assign the relevant shipments to crowd couriers until the chain of assigned shipments fulfills the original order ‹4›. Once all shipments of an order are assigned, the delivery process is monitored ‹5›. In case of minor deviations (i.e. deviations which don't require any re-routing or re-assignments) are detected, the deviation data are recorded ‹6›. In case of major deviations, re-routings or re-assignments (incl. rollback processes) are required ‹7›. Finally, the executed shipments are credited to the crowd couriers ‹8›. For a full process description see Kunze and Herrmann (2019).

3. CCL – Strategic Network Design

We investigated the value of stochastic crowd capacity and the strategic location of mini-hubs to support the operation of shipping parcels in a last-mile delivery system with express deliveries, see Nieto et al. (2021). The concept of having a supporting infrastructure of mini-hubs allows more flexibility to allocate demand to the crowd, thus avoiding the hard constraint of needing perfect demand-crowd matchings (1:1 assignment).

We model the problem as a two-stage stochastic program where the first-stage decision is the location of mini-hubs and the second stage of the problem is the demand allocation to the transportation capacity. The crowd provides stochastic transport capacity with time-dependent profiles (non-stationarity), moreover, as a strategy towards guaranteeing service for the customer, we consider professional couriers that are available on-demand. For the second stage, we use a multi-commodity flow formulation and a space-time network representation to model the time dependency of the transport capacity and the demand allocation decisions.

Sampled demand-capacity scenarios are used in a sample average approximation problem that is solved with an enhanced Benders decomposition. The proposed Benders decomposition is based on the multi-cut L-shaped algorithm (Van Slyke and Wets, 1969). The enhancement techniques include a warm-start strategy for the first stage, the computation of non-dominated cuts (Magnanti and Wong, 1981; Papadakos, 2008), and partial Benders decomposition (Crainic et al., 2021) within a Branch-and-Benders-Cut framework.

We developed an agent-based simulation that serves as a demonstrator of the CCL concept. The model incorporates exogenous parameters such as geographical information, locations of mini-hubs, (stochastic) availability of private (crowd) couriers demand information (customers) specific information on transportation modes, and available connections given the transportation infrastructure for the city of Munich. The agent-based simulation models the interactions between different agents in the CCL system, based on allocation and routing rules (matching algorithm), that return information to analyze the system behavior, i.e. Key Performance Indicators.

Numerical experiments were conducted on space-time networks of different sizes with up to 24 nodes, expanded in time across 16 periods of 30 minutes, representing one operation day. The space-time network topology is inspired by the public transportation network of Munich. The experimental design takes into account the dependency between crowd compensation, crowd capacity, and demand. We show the importance of the mini-hubs to support flexible demand-crowd allocations by allowing cross-docking between crowd flows, as 11%–20% of the crowd shipments (demand allocated to the crowd) are routed this way. Furthermore, we show that the value of the stochastic is significant: between 1% and 10% of the total expected cost, on instances with different demand, crowd capacity, and cost structure. Our experiments support the use of professional couriers as a recourse to fulfill the demand with a guarantee of service since the crowd can transport 8.3% to 32.5% of the total demand by using 4% to 24% of the crowd capacity. The experiments show average daily savings of 2.1% to 7.6% of the total expected cost.

The experiments conducted on the agent-based simulation confirm that the utilization of the crowd is sensitive not only to the compensation of the crowd agents and the cost structure determined by the business model, but also to the concentration of crowd flows in certain paths in the city. Moreover, the experiments confirm that utilization of the crowd increases when cross-docking is enabled by the mini-hubs.

4. CCL – Labor Supply & Dynamic Pricing

One of the key challenges for the viability of CCL-services is a profitable business model which ensures reliable service quality (via adequate incentives for couriers) and offers competitive prices to the users of CCL-services.

We conducted a first preliminary and non-representative survey on the willingness of potential crowd couriers to carry an item along their usual path of travel in exchange for compensation for the extra amount of time spent to pick up and drop the item in a nearby PI-router. Of the 348 people we asked 2019 in Munich, 262 were willing to pick up an item if the extra time spent is between 2 and 5 minutes. Of these, 140 were male, 113 were female, and 9 didn't specify their gender. Their occupations were pupils (101), students (72), employees or self-employed (52), and others (37). Selected results are shown in Figure 4.

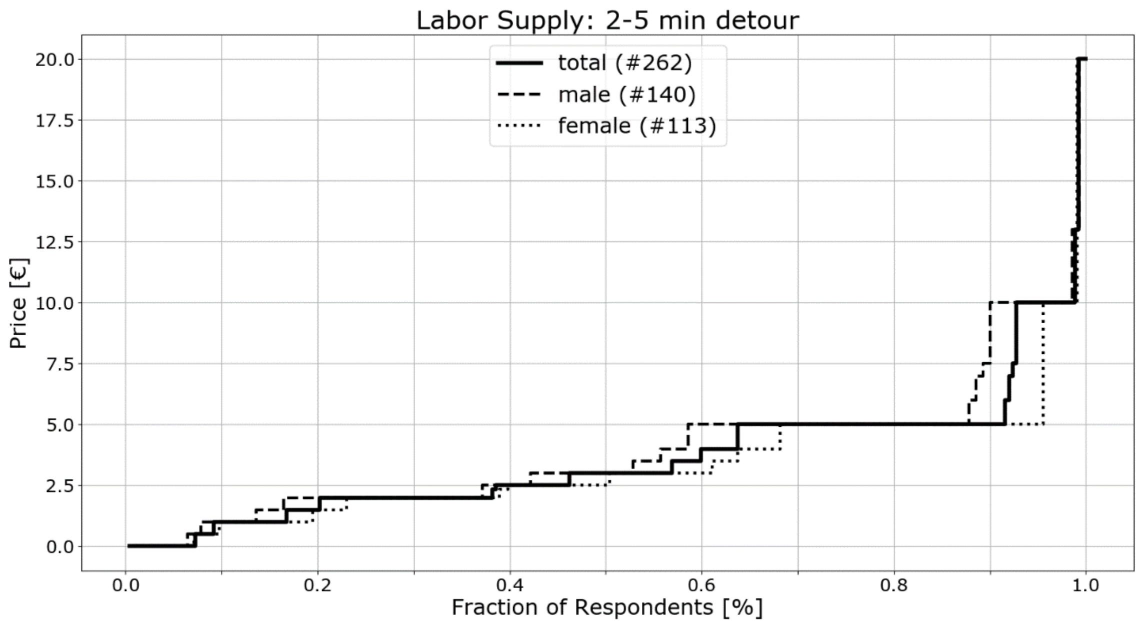


Figure 4. CCL Incentives & willingness to act as CCL-courier (survey conducted in Munich in 2019)

Results show that very few potential couriers would perform such a service for free, and approximately 20% of the respondents would be willing to carry out such a service for a compensation of 1.50 € or less, while a compensation of 2.00 € would already attract a third of the respondents.

5. Conclusions

If further empirical research confirms a sufficient number of potential crowd couriers willing to carry items for small compensations, CCL might become a commercially viable and ecologically sustainable option for last-mile home delivery services. Further research is needed on process details, network design details, adaptive dynamic pricing mechanisms, potential bundling effects, and legal details (minimum wages, spare time job restrictions, etc.).

Acknowledgments

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Dynamic Vehicle Allocation and Charging Policies For Shared Autonomous Electric Vehicles

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Extended Abstract

Summary. Electric passenger vehicle sharing platforms must decide which vehicle should pick up which customer based on the vehicle's battery level and the customer's travel distance. We design dynamic vehicle allocation policies for matching vehicles to customers using a Markov decision process (MDP). We first model the system as a semi-open queuing network (SOQN) with multiple synchronization stations to match customers with vehicles that hold ample remaining battery capacity. If a vehicle's battery level drops below a threshold, it is routed to a nearby charging station. We solve the SOQN for the costs of waiting and lost demand, and use it in the MDP to obtain a near optimal heuristic vehicle allocation policy. The heuristic policy outperforms benchmark policies in large-scale realistic scenarios. We find that reserving idle vehicles to wait for future short-distance customer arrivals can be beneficial, even when long-distance customers are waiting.

1. Introduction

Vehicle sharing systems, which are considered to be a sustainable solution for urban transportation, can nowadays be found in many cities (He, et al. 2017). In New York City, for example, there are three types of vehicle sharing services. The first, also the most popular, is ride-sharing, where a platform coordinates the rides shared by drivers with customers who need a ride. As shown in Figure 1(a), the drivers pick up the customers at their origins and drop off them at their destinations. Since the drivers instead of the platform (e.g., Uber) own the vehicles, the drivers may reject the match proposed by the platform, which may increase the overall driving distances (Wang, Agatz, and Erera 2017). Free-floating vehicle sharing is another vehicle sharing service (e.g., car2go). Customers choosing this service have to first search a vehicle in their proximity, go to it, and then drive to their destinations. This is shown in Figure 1(b). The vehicle can be left at any parking space at the destination. However, the company offering this service needs to hire a crew to reposition and to refuel the vehicles for maintaining daily operations.[1] Station-based vehicle sharing is a service where vehicles must be picked up and left at designated refueling or recharging stations (shown in Figure 1(c)). Since the platform owns all vehicles, customers must drive vehicles themselves in both free-floating and station-based vehicle sharing systems. To attract more customers to use these two types of services, more vehicles need to be deployed and more stations to be built in the service region, which lowers the utilization of the vehicles.

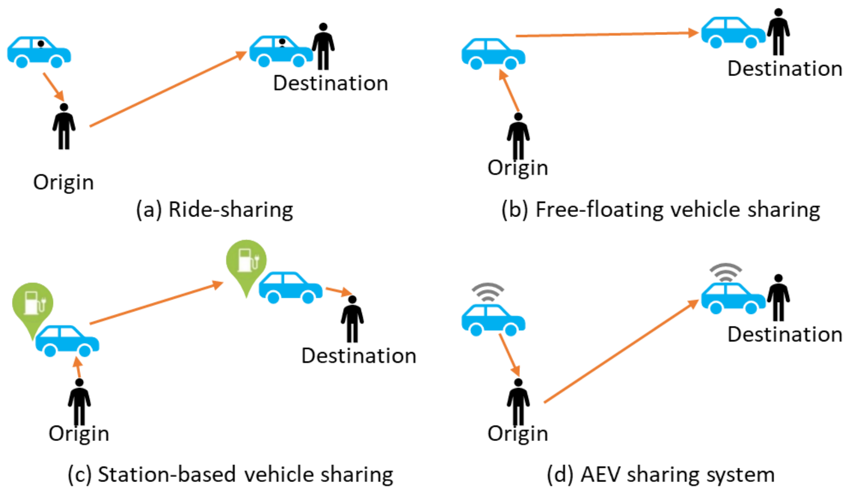

Figure 1. Four types of vehicle sharing services

Autonomous electric vehicle (AEV) sharing systems can reduce the disadvantages of the three vehicle sharing services.[2] From the customer's perspective, it is similar to ride-sharing. The only difference between ride-sharing and AEV sharing is that the latter does not need drivers (illustrated in Figure 1(d)). From the platform's perspective, the platform (or another company) owns the vehicles, which are autonomous and electric. In an AEV sharing system all processes, especially matching vehicles with customers and charging vehicles, need to be controlled by the platform. Moreover, customer patience times may vary with travel distances. In practice, long-distance customers can endure a longer waiting time than the customer who wishes to travel a short distance. If the waiting times of customers exceed their maximal patience time, they will leave the system and choose other transport options. Losing a long-distance customer implies revenue loss. Therefore, operating an AEV sharing system introduces a new challenge: How should the platform allocate vehicles to customers and when to charge them?

2. Methodology and Results

There are some differences with manned vehicle sharing systems. In ride-sharing, there is no need to consider refueling or recharging because the platform does not own the vehicles (Bai,

[1] Details can be found on https://www.brooklynpaper.com/musical-cars-heres-how-car2gos-fleet-gets-moved-around-all-day-every-day/.

[2] Details can be found on https://media.daimler.com/marsMediaSite/en/instance/ko/car2go-publishes-white-paper-on-autonomous-fully-electric-carsharing.xhtml?oid=30188368.

et al. 2019). For free-floating and station-based vehicle sharing services, refueling or recharging is executed manually, and also outside the control of the platform. Therefore, in the literature on these systems, activities related to charging are usually simplified as exogenous parameters rather than endogenous decisions (Bai, et al. 2019; He, et al. 2017). In the studies on vehicle routing and recharging, charging times and paths to charging stations are captured as decision variables in deterministic models (Schiffer and Walther 2018; Sweda, Dolinskaya, and Klabjan 2017). However, these models are not applicable in the vehicle sharing case where travel demands are stochastic. These stochastic systems can be modeled using a semi-open queueing network (SOQN). Such models can capture dynamic stochastic demand served by a fixed number of circulating resources and have been widely used to model internal transport in container terminals or warehouses (e.g., Zou, et al. 2018). In this study, we first adopt a SOQN model for the AEV sharing system to obtain key performance measures (e.g., customer waiting times and loss rates) under given customer-to-vehicle allocation and charging decisions. Then, we introduce a Markov decision process (MDP), where optimal vehicle allocation and charging decisions can be taken dynamically, using the SOQN as a building block.

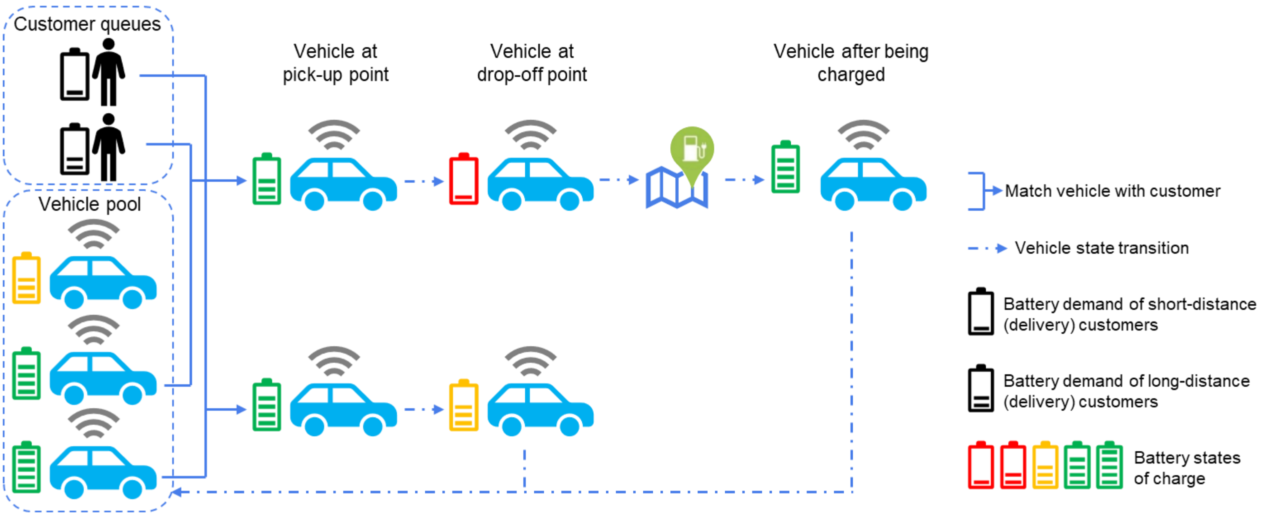

Figure 2. An example of the dynamics of the AEV sharing service

Figure 2 gives an example of how vehicles are allocated to customers and when they are charged. Customers require different battery capacities, depending on the distance they plan to travel. To capture this difference, customers are aggregated into two classes, with different arrival rates, according to travel distance (i.e., short- and long-distance customers). The idle vehicles in the pool have different discrete remaining charge levels. Vehicles allocated to customers consume battery capacity for 1) the pickup process – from the vehicle's dwell point to the customer's origin, 2) the delivery process – from the customer's origin to his or her destination, and 3) visiting a charging station – from the customer's destination to a nearby charging station. In Figure 2, one battery charge unit is required to pick up a customer from any class, and one battery charge unit is required to visit a charging station. Due to the battery constraint, a vehicle with 3 remaining charge units can only serve short-distance customers and the vehicles with 4 or 5 charge units can serve customers from both classes. With technologies such as autonomous driving, GPS, and battery sensors, vehicles with a sufficient battery level can be allocated to serve any fitting customer, and the charging time can be controlled. We model the dynamics of the AEV sharing system in an SOQN model, which is shown in Figure 3(a).

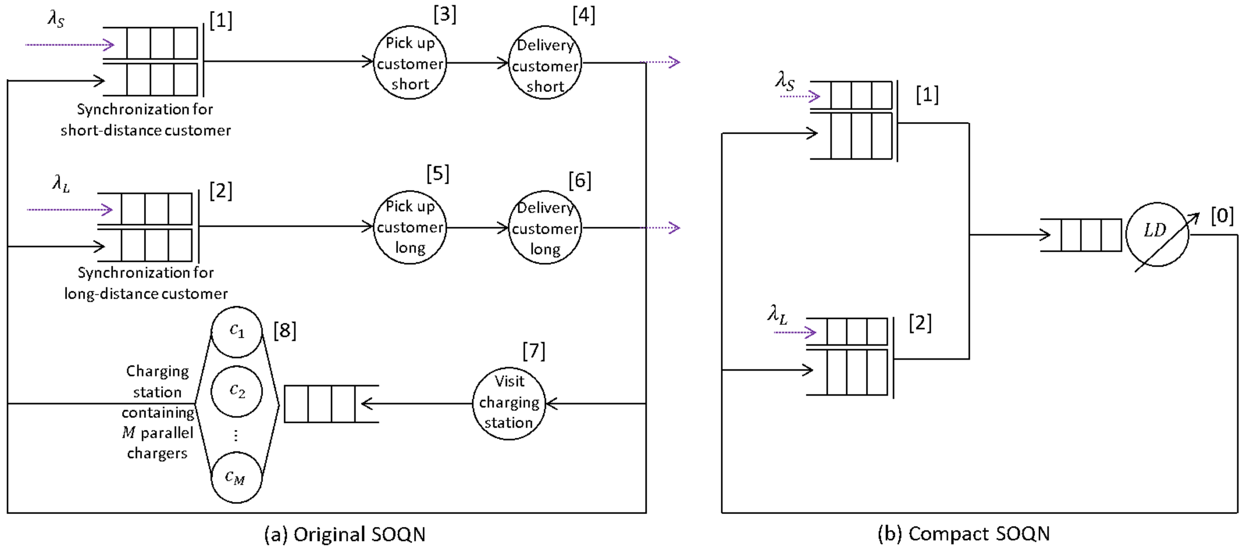

Figure 3. The SOQNs

Customers of each customer class need to be synchronized with a fitting vehicle, allocated to the customer. This is modeled as a synchronization station with a queue for customers and a queue for vehicles. To estimate the performance measures of the system, we aggregate the original SOQN into a compact one by replacing the nodes [3-8] (shown in Figure 3(a)) into a load-dependent (LD) node [0] (shown in Figure 3(b)). According to Norton's theorem, this node is equivalent to the closed network [3-8] assuming this network has a product form (Bolch, et al. 2005). The service rate of node [0] depends on the number of vehicles in this node. Therefore, once the number of idle vehicles waiting in the two synchronization stations is known, we can obtain the load-dependent service rate of node [0]. This allows us to use a two-dimensional tuple to represent the system state. By assuming that all service nodes are exponential, the system can be described by a Markov chain when vehicle allocation and charging probabilities are known. Then, system performance measures, such as customer waiting times, customer loss rates, and charging station utilization can be obtained. The allocation probabilities are later used as decisions to be taken in the MDP model.

Simulation results show that the analytically estimated performance measures obtained by solving the Markov chain are accurate. Since the analytical model can be solved relatively fast (for small instances), this allows us to use it as a building block in the MDP to determine vehicle allocation and charging decisions dynamically. The vehicle allocation decision is modeled by the probability to dynamically allocate vehicles that can serve both customer classes (i.e., with a high remaining battery capacity), to only short-distance customers. For tractability, the action space is discrete. The states are the same as those defined in the Markov Chain. The MDP minimizes the system cost, which includes customer waiting time, customer loss due to overly long waiting, and empty driving to visit charging stations.

By analyzing the properties of the MDP and solving it optimally for small instances, we find that optimal vehicle allocation decisions depend on the system state. An interesting finding is that it is beneficial to reserve some idle vehicles with high remaining battery levels for future short-distance customers even if long-distance customers are waiting. Based on these findings, we propose a state-dependent policy where the decisions are made according to the information on the number of waiting customers and the maximal customer patience times.

Finally, we test the performance of the state-dependent policy for small instances, as well as a large case study based on the operating data of the taxi service in New York City. Numerical results show that the state-dependent policy is near-optimal in small instances and it outperforms other candidate policies in both small and large instances.

We can draw the following conclusions. First, dynamic customer allocation can effectively work to reduce system costs. Second, information about the number of waiting customers and maximal customer patience times can be used to dynamically allocate vehicles to customers. Third, reserving some idle high battery level vehicles to wait for future short-distance customers can be beneficial even if long-distance customers are waiting for pick-up.

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On Broken Promises: A Study on How Supply Chain Governance Mechanisms Help Rebuild Consumers' Broken Psychological Contracts

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Extended Abstract

Summary. This study focuses on ways focal firms can mitigate the resulting negative consumer reactions. We analyze how sustainable supply chain management (SSCM) aimed at the supplier and communicated to the consumer can help restore the psychological contract between the focal firm and the consumer when this contract and the consumer's purchase intention have been damaged by the supplier's unsustainable practices. The setup of our study involves two vignette-based experiments. We find that focal firm inactivity can further damage the psychological contract with the consumer as well as the consumer's purchase intention; verbal clarification neither damages nor restores the contract or purchase intention; and sustainability-focused termination, monitoring, and development can restore both the contract and purchase intention, but only partially—not to the initial, pre-incident levels.

1. Introduction

McDonalds China suffered a slump in guest traffic and sales when it became publicly known that Simplot, one of its suppliers of French fries, had allowed polluted water to flow into the city pipes of Beijing. Although McDonalds China emphasized that it had strict environmental policies in place governing supplier relationships, Chinese consumers nevertheless steered clear of McDonalds China restaurants. In this example, McDonalds represents a focal firm, which produces and markets offerings and interacts with both suppliers and consumers, and because of this hinge role becomes subject to chain liability (Hartmann and Moeller, 2014). Chain liability is the phenomenon in which focal firms suffer adverse impacts caused by their suppliers' unsustainable practices (i.e., social or environmental misconduct). For instance, consumers may punish a focal firm by boycotting its offerings, holding the focal firm responsible for unsustainable incidents caused by its suppliers across global, multi-tier, and complex supply chains (Hartmann & Moeller, 2014; Phillips & Caldwell, 2005; Snir, 2001; van Tulder, van Wijk & Kolk, 2009).

McDonalds is only one example of a focal firm suffering substantial reputational and economic consequences from what we will refer to as unsustainable supply chain incidents. The objective of our study is to examine the capacity of SSCM to buffer negative consumer reactions associated with unsustainable supply chain incidents. Drawing on psychological contract theory (Rousseau, 1995), we outline that consumers form implicit expectations about the environmental and social conditions under which the offerings they buy were produced. These expectations are violated when the consumer is informed about unsustainable supplier practices, and this then negatively affects consumer purchase intention. A recent extension of psychological contract theory suggests that actors have different options to address such perceived violations and consequently restore the psychological contract. Actors can either verbally clarify the situation and the role of the focal firm vis-à-vis their supplier, or undertake more substantive actions to rectify the situation that led to the damage (Rousseau, Hansen & Tomprou, 2018).

2. Methodology and Results

Prior SSCM research (Hajmohammad & Vachon, 2016; Zimmer, Fröhling & Schultmann, 2016) identifies three substantive instruments that may help focal firms to reduce or eliminate sustainability problems in the supply chain: the focal firm may terminate the relationship with the supplier that caused the incident; the focal firm may engage in establishing sustainability standards and monitoring supplier compliance with these standards; or lastly, the focal firm may collaborate with suppliers with the aim of improving their environmental and social performance via supplier development. According to psychological contract theory (Rousseau et al., 2018, and compared to the baseline focal firm reaction of inactivity, in which the firm remains silent), each of these responses should restore the damaged psychological contract and consumer purchase intention.

To test this supposition, we collect primary data in vignette-based experimental studies to investigate variations in consumers' perceived psychological contract and purchase intention. We measure these two variables over time: prior to an unsustainable supply chain incident; after the incident but before the focal firm response; and after the firm's response. We find that inactivity further damages the psychological contract and purchase intention, that clarification neither damages nor restores the contract and purchase intention, and that three substantive sustainability-focused responses—termination, monitoring, and development—restore the psychological contract and purchase intention. However, this restoration is only partial, and none of the three substantive responses by itself restores the psychological contract or purchase intention to the pre-incident level. Hence, in a follow-up study we test the efficacy of different combinations of sustainability-focused responses. We find that combined responses more effectively restore both the psychological contract and purchase intention of consumers, but with diminishing returns as more responses are added.

Our study makes three contributions. First, we extend the SSCM literature that has hitherto focused on improving sustainability in supply chains by preventing unsustainable supplier practices (e.g., Hajmohammad & Vachon, 2016; Klassen & Vachon, 2003; Vanpoucke, Vereecke & Wetzels, 2014; Wu & Pagell, 2011). This extension introduces the consumer perspective and investigates the capacity of SSCM to help focal firms buffer negative consumer reactions to unsustainable supply chain incidents, thereby offering guidance for managerial decision makers in situations where preventive measures were either nonexistent or ineffective.

Second, we contribute to the literature that has focused on psychological contract formation and damage by using recent extensions of psychological contract theory (Rousseau et al., 2018) as a foundation for the investigation of effective psychological contract restoration. We examine in detail particular considerations related to psychological contract restoration, testing them empirically in a relevant and specific supply chain context.

Third, we contribute to psychological contract theory as well as to the supply chain literature by investigating psychological contract damage and restoration in a realistic triadic supply chain setting involving the consumer. Such a perspective is unique, as the extant supply chain research that has applied psychological contract theory has focused on dyadic psychological contracts between a focal firm and its suppliers (e.g., Eckerd, Boyer, Qi, Eckerd & Hill, 2016; Kaufmann, Esslinger & Carter, 2018). In contrast, our research investigates a triadic situation in which a psychological contract between two parties (a focal firm and its consumer) is damaged by a third party (the focal firm’s supplier). This psychological contract damage happens even though no direct harm to the consumer may necessarily have emanated from the unsustainable supply chain incident. The party held responsible for the psychological contract damage (the focal firm, held responsible by the consumer due to chain liability) directs its response to the third party that caused the damage (the supplier) and communicates this to its consumers in order to restore the focal firm’s damaged psychological contract with the consumers.

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A Pickup and Delivery Process With an Auction-Based Exchange Mechanism For Time Windows

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Extended Abstract

Summary. This extended abstract examines how a pickup and delivery process should be designed to implement an auction-based mechanism for time window exchange. To find a solution for this problem, the first step is to investigate the actor's requirements for the process. Based on the requirements found, it is shown that the implementation of the auction-based mechanism at the level of vehicle route planning leads to a Pareto improvement for all actors involved in the process. Finally, the modeled vehicle route planning process with an auction-based mechanism for time window exchange is described in more detail.

1. Introduction

In recent years, so-called web-based time window management systems (TWMS) have become established for planning and controlling the time window process at the loading ramp (Elbert, Thiel and Reinhardt 2016a, 255; BAG 2018, 24). Large industrial and commercial enterprises, in particular, use these systems to optimize incoming and outgoing goods processes in their warehouses (Elbert and Dominik 2016b, 1; BMVBS 2013, 78). For road freight carriers and forwarders, the introduction of TWMS is often associated with efficiency losses due to the rigid allocation of time windows according to the First Come - First Serve (FCFS)-principle (Phan and Kim 2016, 38). Good time windows are quickly no longer available, and a late arrival often leads to long waiting times at the loading ramp (Elbert, Friedrich und Thiel 2018, 49). This problem can be countered by implementing an auction-based exchange mechanism into the pickup and delivery process with time windows. A subsequent exchange of time windows becomes possible, and an increase in flexibility in the vehicle route planning of road freight carriers and forwarders can be achieved. Therefore, the objective of this extended abstract is to present how a pickup and delivery process with an auction-based exchange of time windows should be designed to increase the overall benefit for all actors involved in the system. Derived from the objective and the basics, the following research question arises:

> *RQ: How should a pickup and delivery process be designed to implement an auction-based exchange mechanism for time windows?*

To answer the research question, the first step was to analyze the current process and identify requirements that are important when implementing an auction-based mechanism for time window exchange in the pickup and delivery process. Then, based on the requirements found, the modeled process with an auction-based mechanism for time window exchange is described.

2. Current Research

Pickup-and-Delivery Problems (PDP), a subclass of vehicle routing problems (VHP), are optimization problems that focus on vehicle route planning, where goods or people are transported from one or more origins to one or more destinations (Berbeglia et al. 2007, 2). In analogy to the PDP, a pickup and delivery process is investigated in this extended abstract. Goods are picked up from an origin and delivered to multiple destinations by a truck. The shipper, where the goods are picked up, is considered the origin, and warehouses operated by industrial or commercial companies as the destination. The vehicle route planning of a forwarder then looks like Figure 1.

The process begins when the warehouse operator places an order with the shipper. The shipper starts manufacturing the product and commissions the forwarder to transport the ordered goods. The warehouse operator and the shipper optimize the incoming and outgoing good processes by dividing individual days into a set of time windows. The contracted forwarders can then book these time windows via a booking platform of the TWMS-provider according to the FCFS-principle. After booking the time windows, the forwarder can finish the vehicle route planning. The goods can then pick by truck from the shipper and delivered to one or more warehouse operators (Thiel 2018, 57; Elbert, Thiel and Friedrich 2018, 13).

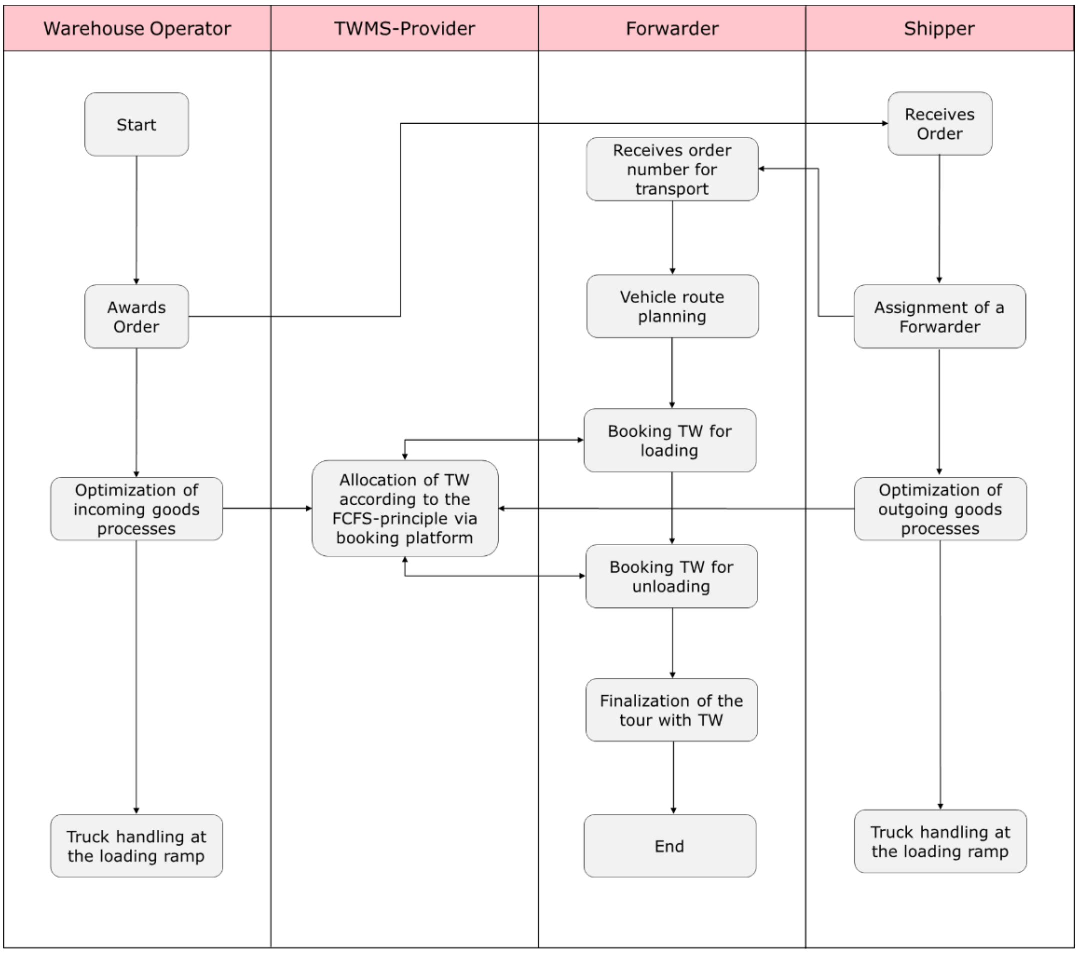

Figure 1. Vehicle route planning for a time window-controlled pickup and delivery process (according to Thiel 2018, 57; Elbert, Thiel and Friedrich 2018, 13)

3. Methodical Approach

This chapter considers the methodological approach chosen to capture requirements for a pickup and delivery process with an auction-based mechanism for time window exchange and to validate and verify the modeled vehicle route planning process with time window exchange.

A literature review was first conducted to capture the requirements that actors place on a mechanism for time window exchange in a pickup and delivery process. For this purpose, the required characteristics of the primary studies were first determined, relevant keywords, some of which were linked to the logical "and" for the search, were established, and based on this, a sample of relevant studies was identified in a database search. The studies within this sample were then filtered using further inclusion and exclusion criteria so that in the end, 39 sources could be identified from which relevant requirements could be derived.

To identify further requirements, a focus group interview was conducted parallel to the literature review. In focus group interviews, free and unstructured interviews are conducted under the guidance of a qualified moderator with a small group of usually six to nine members (Zikmund 2000, 101; Homburg and Krohmer 2003, 197). Thus, to identify additional requirements that are relevant for companies to participate in a pickup and delivery process with an auction-based mechanism for time window exchange, a focus group interview was conducted with members from nine companies. One member was from a shipper, seven members were from TWMS-providers, and one member was from a freight forwarder.

Another method used to answer the research question is the expert interview. It was used to verify and validate the modeled pickup and delivery process with an auction-based mechanism for time window exchange. Four semi-structured interviews with experts from the practice were conducted for this purpose. Four experts from two different TWMS-providers were interviewed in two interviews, one expert from a forwarder and two experts from one shipper.

4. Research Results

Based on the literature review results and the focus group interview, this chapter first explains the most essential requirements that were found. Afterward, considering the requirements, the modeled process is described in more detail.

Due to the fierce competition in road freight transport, the constantly rising fuel prices and labor costs, and the increased growth of transport legislation, there is a high-cost pressure for road freight carriers and forwarders in the market (Li, Chen, and Prins 2016, 27). Derived from the factors described, two requirements can be formulated. Participation in the mechanism should not lead to additional administrative costs for road freight carriers and forwarders. Instead, cost and competitive advantages should result from participation. For warehouse operators and shippers, the use of web-based TWMS, as already described, offers the opportunity to optimize internal processes at the loading ramp. The use of the mechanism should, therefore, not lead to a deviation from the optimized processes. In addition, a provider of a TWMS can only benefit from the use of such a mechanism if the provider acts as the operator of the mechanism.

Concerning the previously described requirements and chapter one defined objective, the best way to design a pickup and delivery process with an auction-based mechanism for time window exchange is to implement the mechanism at the level of vehicle route planning. This allows forwarders to exchange time windows with other forwarders that do not fit optimally into their route. By implementing the mechanism at the level of vehicle route planning, it becomes possible to exchange the time windows so that the optimized incoming and outgoing goods processes of the shippers and warehouse operators are not affected by the exchange.

The exchange of time windows within the framework of vehicle route planning reduces the distance to be driven. This has the effect that costs for personnel and fuel can be saved, and competitive advantages result for the participating forwarding companies. Another effect that the reduction of the total distance should observe is the increase of the delivery service due to a decrease in the delivery time. As a result, the shipper can reduce its inventory as a customer of the forwarder (Pfohl 2018, 35). If the auction-based mechanism possesses the property of weak budget balance, i.e., if the sum of all participant's payments is negative, it becomes possible for the TWMS-provider to make a profit by operating the mechanism (Krishna 2009, 77; Xu, Huang, and Cheng 2016, 1366). Therefore, with the use of an auction-based mechanism to exchange time windows at the level of vehicle route planning, it is expected that a Pareto-improvement can be achieved for all actors involved in the process.

With the vehicle route planning process from chapter one as a basis, the auction-based mechanism for the exchange of time windows can be implemented in the process. In the new modeled process with an auction-based mechanism for time window exchange, the shipper first books the time windows according to the FCFS-principle like before. The forwarder then checks whether a time window is advantageous for vehicle route planning. If this is not the case, the time window is entered into a central display interface where all offered time windows from all forwarders involved are entered. The insight into the display interface enables the forwarder to overview which and how many time windows are provided for exchange by other forwarders. Based on the outline, the forwarder can then decide whether there is a time window with which savings can be realized. If this is not the case, the already booked time windows can be taken out, and the vehicle route planning can be finalized. Is there at least one time window left with which savings in costs and emissions can be realized, the forwarder participates in the auction. After winning a more profitable time window in the auction, the own time window can be released for auction. After all time windows offered for the auction have been allocated, the warehouse operator receives the information about the outcome of the exchange process and can perform the resource allocation. The forwarder sends the truck on tour, therefore collects the goods from the shipper and delivers them to the warehouses.

5. Conclusion

In this extended abstract, a pickup and delivery process with an auction-based exchange mechanism for time windows was developed. It was shown that if the mechanism is implemented in the pickup and delivery process at the level of vehicle route planning, there can be a Pareto improvement for all the actors involved in the process. By exchanging unfavorable time windows, the forwarders can avoid driving additional miles, thus saving costs and emissions in the execution of the route. The incoming and outgoing goods processes of shippers and warehouse operators, which are optimized by TWMS, are not affected due to the implementation of the mechanism at the level of vehicle route planning. Due to the topicality of the subject matter, none of the requirements described could be taken directly from any source. Instead, it was necessary to derive the relevant actor's requirements on a process with an auction-based mechanism for time window exchange from current challenges. Caused by the selection of literature and the composition of the interview partners, it is possible that not all relevant requirements could be identified. Thus, the identification of requirements is not conclusive, and continuous and incremental improvement of the process should be sought. This topic offers a broad field for further research. The next important step is selecting a suitable auction-based mechanism for the exchange of time windows and the networking of the individual platforms of the TWMS-providers to enable cross-platform time window exchange.

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The Challenges of Textile Collection And Suggestions for an Innovative Data Framework Towards a Sustainable Textile Circular Economy

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Extended Abstract

Summary. With the EU Action Plan for the Circular Economy coming into force in 2025, textiles will have to be collected separately throughout the EU in the future. A massive increase in the quantities of used textiles is expected. The current situation already poses enormous logistical and financial challenges for municipalities, collectors and sorters of used textiles due to the increasing amount of textiles with mixed fibre content and falling prices. Against this background, a qualitatively and quantitatively improved collection and (pre-)sorting is necessary in order to develop new scenarios for the collection and sorting of the growing textile waste by means of both technical (e.g. smart containers) and process-related innovations (e.g. dynamic route planning), taking into account the requirements of the legislator and the demands of the stakeholders involved (e.g. citizens).

1. Background

The collection of secondary raw materials is always a challenge, and this applies just as much to used textiles. Complicating in this market is the fact that the collection is inhomogeneous, there are the commercial and municipal collections as well as charitable organizations that also carry out own collections. Although in most countries the collection of textiles is dominated by the municipal waste collection, the other forms of collection usually exist there as well. The material flows are therefore diverse, partly unrecorded and the qualities partly differ considerably. A common method in the United States and the United Kingdom is the singled-out kerbside collection. While Germany focuses mainly on the container collection, the collection in the United Kingdom is done also through home pick-up systems or drop-offs in charity shops. Newly forms of textile collection are the in-store collection of end-of-life clothing and the free mail-back option for consumers (Ellen MacArthur Foundation 2017). All collection variants have in common that logistics systems play an important key role in efficiently closing cycles and thus enabling circular and sustainable supply chains (Fennemann et al. 2018, 28).

The textile collection is influenced by various challenges. For example, the collection qualities are affected by different weather conditions or by impurities. In this context, moisture quickly develops degrading foxing that can develop into a health-threatening black mold. The proportion of obvious impurities is on average 5 % in Germany (Kietz et al., 2018, 9). However, this share has a significant negative impact on the remaining 95 %. Furthermore, it is of fundamental importance for the collection of used textiles that they are disposed of and transported in safe conditions to prevent damages.

The evolution of EU legislation in the area of sustainability is changing the dynamics in the collection of used textiles. In the past, the majority of this was mostly socially or economically driven in the near future it will become obligatory. The Waste Framework Directive of the EU requires for the first time a separated waste collection for textiles (Directive 2018/851/EC, deadline for implementation: 1 January, 2025). As elaborated in Brieger et al. (2021), to date, there has been a lack of a profound data basis both for the associated logistics processes and for improving the quality of the use garments and textiles collected.

As the high-quality textile collection, as a base for high-quality textile recycling, is hindered by various factors, this research deals with the challenges of textile collection, and describes and analyses the inherent logistics processes as an essential part of a textile Circular Economy. The overall research objective is a framework for an effective transition towards a textile Circular Economy. The need to collect more data to improve the logistical processes in used textiles collection and recycling arises at least from the EU directive but also from the overall social responsibility of the textile and logistics industry. These data are the basis for the improvement of the footprint in both industries and an increase of textile recycling.

In the waste management industry for used textiles, the usage of 5G-compatible level sensors with integrated hub for container management is steadily increasing and will soon be state of the art. With the help of the sensors and the "NarrowBand IoT" (NB-IoT) radio technology, central control and recording technologies for container management can be installed cost-effectively and with a long service life without excessive additional infrastructure. For further process optimisation, the data from the level sensors are integrated into (dynamic) route planning.

Nevertheless, it is evident that the container collection was discontinued in some cities by municipal waste management companies, e.g. in Hamburg and in Dortmund. Although large quantities of old textiles are collected with the help of the container collection, the supposedly poor quality of the delivered goods, the number of misthrows as well as external influences led to the decision to dismantle the containers. In the future, an adapted design and controlling sensor technology, e.g. level sensors for optimising the logistics by means of demand-oriented collection in combination with throw-in restrictions (in terms of time and material), should reduce the share of poor quality of the collected goods and misthrows. To this end, new concepts are to be created with container and sensor manufacturers in order to evaluate feasibility and develop and test prototypes.

2. Methods and Intended Results

For a better collection of used textiles, information about the properties concerning used materials, processed quantities or possible ways of utilisation of old textiles are required in order to ensure the highest possible utilization. It is not sufficient by just collecting textiles separately. Overarching general conditions are missing. Therefore, the resulting framework provides a reference model for future implementations of a textile Circular Economy approach, including both sample processes for an improved information logistics, as well as specific technical logistics solutions for e.g. reduce misthrows related to public container collection. In this context, logistical functions such as handling (loading, unloading and reloading) and transport are also taken into account, with regard to regular and damage free collections.

As one solution, throw-in restrictions for containers show a potential. With throw-in restrictions a take back to a certain time or for specific textiles is possible. The solution is based on processes that have already been established for the sale of used products, including textiles. In this context prominent online shops can be mentioned, where photos or the scanning of barcodes are used to determine values or to register a sale/shipment.

First potential process for the use of throw-in restricted used textiles containers:

1. Scan QR code / barcode on container with a mobile device
2. Confirm the action online at the relevant waste disposal company
3. Unlock the used textiles container
4. Insert (desired) used textiles correctly
5. Used textiles container locked

The research focuses on the feasibility of this system integration and the evaluation of the possible increase in collection quality through this approach. Furthermore, it is to be examined to what extent a presorting system close to the consumer, e.g. by means of additional containers, can be supplied with desired input material. Presorting close to the consumer can be a possibility, for example, to separate the mixed fibre content, for which only a few recycling processes are currently available, in order to relieve the sorting capacities of sorting companies.

These technical and procedural adjustments will initially be associated with additional costs. If the added value of the system will pay off over time due to improved collection and sorting processes, needs to be analysed. Moreover, with the involvement of other stakeholders, the acceptance of throw-in restrictions must be researched so that used textiles are not disposed of in residual waste. Appropriate concepts are being developed for this purpose. As listed in Brieger et al. (2021) the requirements for an effective presorting are:

- Easy-to-use: A low-threshold use must be possible to ensure a high utilization
- Clarity: To avoid the routing of textiles on wrong or not desirable routes clear additional guidance and education should be given
- Incentives: Support the separate collection with bonuses for other municipal or sustainable services.

Overarching improved information for logistics and transparency will enable the processes and contribute to successful collection systems in the future. To improve efficiency and transparency in the area of used textile collection, data exchange concepts system are necessary. So far, these data exchange concepts concentrate on efficiency and not on the Circular Economy and sustainability facts. The core challenge is therefore to integrate the sustainability dimension into such data exchange concepts in order to draw reproducible conclusions regarding the improvement of collection and sorting processes with the help of data to be collected.

A special focus is on business models and incentive systems. Since infrastructural adaptations are associated with investment costs, different perspectives and business models for economic and ecological operation are analysed. In addition, the acceptance of this new generation of used textiles containers, e.g. with throw-in restrictions, is being researched with the development of incentive systems so that suitable used textiles are collected in a high-quality manner in the future and not disposed of in residual waste.

3. Conclusion

The framework guides actors in the textile sector by implementing a Circular Economy. A further research result should show a new demonstrator of the next generation of used textiles containers with new potentials regarding collection quality and transfer of data as well as the simplification of administrative processes. The demonstrator can be seen as a starting point for further application-oriented research projects as well as system integrations to show the benefits in data driven decisions like:

- Selection of locations and number of containers
- Integration into transportation planning and dynamic route planning to improve fleet utilisation
- Improved forecasting of quantities for a better management of a Circular Economy

The topic of transparent data availability and efficient data processing is an essential prerequisite for the improvement of a textile Circular Economy. The tracking and networking of information, e.g. on used textiles and other products with textile components, provide information on the anthropogenic stock and necessary collection and disposal activities. An increased share of labelled products (digital product passport) can facilitate or promote adequate return to the value chain.

Furthermore, a Circular Economy requires the updating of previous approaches to the ecological assessment of textile products. In this context, logistics as a connecting element in the value chain fulfils an important enabler function for the flow of information. Innovative concepts such as “quick LCA” can be deepened with the help of the research approach in order to take sustainable product and process decisions into account as early as the design phase.

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