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### Proceedings

## Logistics 4.0 and Sustainable Supply Chain Management: Innovative Solutions for Logistics and Sustainable Supply Chain Management in the Context of Industry 4.0

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Carlos Jahn, Wolfgang Kersten and  
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# Logistics 4.0 and Sustainable Supply Chain Management



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# Logistics 4.0 and Sustainable Supply Chain Management

Innovative Solutions for Logistics and Sustainable Supply Chain  
Management in the Context of Industry 4.0

Prof. Dr.-Ing. Carlos Jahn  
Prof. Dr. Dr. h. c. Wolfgang Kersten  
Prof. Dr. Christian M. Ringle  
*(Editors)*

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# Preface

Digitalization is changing the way organizations manage their supply chain and their daily logistical processes. The development of digitalized solutions and industry 4.0 have created a completely new business ecosystem. Additionally, customers are demanding more innovative, more diverse and greener products. This creates numerous challenges for all actors in the supply chain; yet, they also present an opportunity to create solutions and practices that improve performance and productivity.

This year's edition of the HICL proceedings complements the last years' volume: Digitalization in Maritime and Sustainable Logistics. Companies are challenged to reengineer their supply chains to tackle logistics and sustainability issues that exist in such a complex environment, especially with the increased pollution and congestion in cities.

This book focuses on core topics of logistics 4.0 and sustainable supply chain management. It contains manuscripts by international authors providing comprehensive insights into topics such as environmental innovation, ecological assessment of port equipment, electric vehicles at public organizations or layout planning for logistics nodes and provide future research opportunities in the fields of logistics and sustainable supply chain management. All manuscripts contribute to theory development and verification in their respective research area.

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

Hamburg, September 2018

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



# Part I

## Maritime and Port Logistics



# Ecological Assessment of Port Equipment for Container Terminals

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*Environmental protection and energy efficiency are important topics for sea port management, which is characterized by long-term investments. To assess the environmental impact of port equipment, we investigate different equipment types with fossil, hybrid and electric drive technologies, in cooperation with our project partner Hamburg Port Consulting (HPC). An ecological assessment of port equipment will support terminal operators who aim to make sustainable investment decisions. We conduct a comparative life cycle assessment (LCA) of different port equipment types including the three above-mentioned drive technologies. Various LCA impact categories, such as climate change, terrestrial acidification and particulate matter formation, were calculated and compared. Thus, we aim to foster a more comprehensive understanding of the environmental performance of port equipment. The results show the contribution of each life cycle phase to the environmental performance of an equipment type within each impact category and thus allow for a comparison of different port equipment types. So far, little comprehensive research exists regarding sustainable port operations. Especially, port operators often lack knowledge about the environmental impact of port processes, whereof it is necessary to provide a good basis to fill in this gap.*

**Keywords:** Ports; Sustainability; LCA; Straddle Carrier

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## 1 Introduction

In order to mitigate further climate change, efforts are ongoing to curb Greenhouse Gas (GHG) emissions across business sectors. The transport sector accounts for about 23% of global GHG emissions (Creutzig et al. 2015). However, some technologies that are associated with lower GHG emissions are also disputed because they are considered harmful in other environmental categories, such as acidification, resource depletion or eutrophication. In general, four different approaches to address the environmental impact of transport can be distinguished: reducing the total amount of transport, shifting to less damaging modes of transport or forms of behavior, reducing the impact of specific modes of transport and improving the environment in terms of spatial planning (Hou and Geerlings 2016).

Before measures from any of these four approaches can be taken, it is important to identify the current environmental impact of transport and potentials for improvement with regard to a meaningful selection of environmental categories. Ports are central actors in the transportation and logistics sector, and their role in the sector's sustainability efforts receives increasing attention (Davarzani et al. 2016). Current legislative efforts targeting ports are e.g. aiming to curb emissions of sulphur and nitrogen oxides (Tichavská et al. 2017). Also, significant energy saving potentials can be exploited by improving operations, adopting energy efficient technologies and using renewable energy sources (Wang and Sarkis 2013). At the same time, ports and terminals may improve their "green" image by reducing emissions, which may be associated with direct and indirect benefits (Lam and Notteboom 2014).

While there is abundant research on the transportation to and from ports, only few studies focus on the role of port layout and equipment on the environmental impacts of entire supply chains. Stahlbock and Voß (2007) explain container logistics in ports and provide a comprehensive review on existing literature. Yang and Chang (2013) give an overview over different electric and diesel-electric Rail Mounted Gantry cranes (RTGs), with a focus on fuel consumption. They came to the conclusion that 68 % of carbon dioxide emissions and more than 80 % of energy can be saved through a substitution of diesel drive trains by electric drive trains. Also, Yang (2017) investigated carbon dioxide emissions in container terminals and received similar results as Yang and Chang (2013). He conducted a carbon footprint analysis of container handling in ports, which showed positive effects on time efficiency, carbon dioxide emissions and fuel consumption in

terms of electrification of power trains. Agrawal et al. (2017) studied the inventory of air emissions especially for the port of Los Angeles. They investigated various equipment types (like RTGs, Straddle Carrier, Yard tractor etc.) of the port of Los Angeles mostly powered by diesel. Gottwald Port Technology et al. (2011) compared the environmental impact of conventional diesel-electric Automated Guided Vehicles (AGVs) for container handling with battery-electric AGVs. Vujičić et al. (2013) conducted a similar study for RTGs and utility tractor rigs (UTR). In both studies, the use phase causes the highest environmental impact within the whole life cycle of the equipment. Replacing diesel-electric equipment by battery-electric equipment could therefore significantly reduce GHG emissions in the use phase, if the equipment is operated with renewable electricity. The results for RTGs and UTR show notable differences in the production phase (Vujičić et al. 2013). While the production of one UTR leads to lower GHG emissions compared to an RTG, the radioactive waste from the production of an RTG is supposed to be higher than for an UTR (Vujičić et al. 2013).

Despite the increasing importance of improving sustainability in ports, there is currently a high level of uncertainty amongst the terminal operators and port authorities to find the most promising measures to achieve this aim (Wilmsmeier and Spengler 2016, The European Sea Ports Organization (ESPO) 2012). This is of particular importance since terminal handling equipment requires substantial financial resources and is usually deployed for more than 20 years. Investments into such equipment influences the whole terminal layout configuration, this is why one can consider it as ultra-long-term investment (ULLI) (Breuer et al. 2013).

Therefore, it is necessary to further investigate the environmental performance of container handling equipment. The project “Simulation-based evaluation of measures for the improvement of energy sustainability in port operations” (SuStEnergyPort), which is carried out by the Georg-August-Universität Göttingen and the Hamburg Port Consulting GmbH (HPC), aims at developing a structured, model-based methodology to identify suitable measures that port operators can use to improve their energy efficiency and their usage of renewable energy. A selection of promising measures for the abatement of CO<sub>2</sub> and other emissions will subsequently be implemented in a simulation tool covering both logistic and energetic aspects as well as a life cycle assessment.

In this paper, the production and the use phase of exemplary equipment types are compared to find the most sustainable layout for specific container terminals. The

present study shows first results for the life cycle assessment (LCA) of a straddle carrier and also gives a first insight into results from the SuStEnergyPort project.

## 2 Structure, logistics and handling equipment of container terminals

This chapter gives a brief introduction to the structure and logistics processes of a container terminal. Furthermore, we point out which equipment is important for the logistic processes and should therefore be analyzed for potential improvement concerning environmental impact.

The main function of a seaport container terminal lies in handling of container arriving by truck, train or ship and in their temporary storage on the premises. A container terminal is an open and complex system which has two interfaces to the outside. First, there is the seaward interface (quayside) for loading and unloading of container ships and, second, the landside interface for loading and unloading trucks and trains. A container terminal always has container storage, the so called container yard, to store container after arrival. The intermediate storage is necessary to cope with different arrival and departure times of ships and land vehicles (Günther and Kim 2006).

The chain of operations for import container can be described as follows: After arriving at the port, the container ship is assigned to a berth equipped with quay cranes to unload or load container (ship operation area). Unloaded container are transported to the container yard by internal transportation equipment. Additional moves are performed inside the container yard before the container is loaded to a land side vehicle to leave the terminal (see Figure 1).

Several different types of cranes can be deployed on a container terminal. First of all, the quay crane or gantry crane for loading and unloading container from ships. Modern quay cranes can handle two 20ft container at the same time. They move the containers from ship to shore by putting them on the quay or on a vehicle and the other way around by moving the containers from the quay or vehicle onto the ship. Quay cranes can be powered by a diesel engine-driven generator located on top of the crane or by electric power from the dock. As a result, quay cranes can have different environmental impacts depending on their power supply.

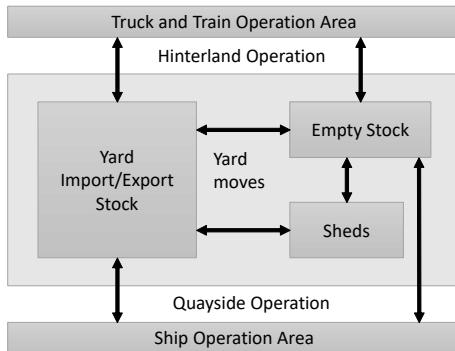


Figure 1: Operation areas of a seaport container terminal and flow of transports,  
see (Steenken et al. 2004)

Secondly, there are three different types of cranes with regard to yard management: The rail mounted gantry cranes (RMG), the RTG and the overhead bridge cranes (OBC). Gantry cranes usually span 8 to 12 rows in a yard and are able to stack up to 10 container. To improve operation speed, there can be up to three gantry cranes in one yard block (Steenken et al. 2004). All three types of cranes can be powered by either diesel engine-driven generator or by electric power. Since RTGs are not locally bound to one yard, they need a battery or a small diesel engine in addition to a static power supply. Depending on their power supply, the cranes can therefore have different environmental impacts locally and concerning their whole lifespan. In addition, changing the drive system of a crane can have a significant impact on the performance (Yang and Chang 2013).

Vehicles for horizontal transport can be divided into two categories: passive vehicles and active vehicles. Passive vehicles are not able to lift container by themselves. Loading and unloading of container is done by either gantry cranes or quay cranes. Typical vehicles in this category are trucks with trailers, multi-trailers and AGVs. Transport vehicles of the second category are able to lift container by themselves. Typical vehicles of this class are forklifts, reach stackers and straddle carriers (SC). The SC is a load carrying vehicle that carries its freight underneath (straddling) it, instead of carrying it on top. Concerning container

terminals, SCs can be seen as cranes that are not locally bound to a stack or the quay. When deploying SCs, the container terminal does not need yard cranes or other transport vehicles, since the SC can move, stack and manage container in the terminal. Concerning their power supply, there are SCs with diesel drives, diesel-electric drive and battery-electric drives which leads to different environmental impacts for each type of SC.

To conclude, most of the energy of container terminals is needed for handling equipment during the processes described above (Geerlings and van Duin 2011). In addition to the ensuing environmental impact of this energy demand, the production of equipment generates an environmental impact as well. A decision about choosing or replacing equipment is complicated by the fact that several different types of equipment can be used for the same operations at port container terminals. To gain a better understanding of the environmental impact of some equipment types and the resulting effects of their usage on the overall sustainability of port terminal operations, our research aim is to investigate and compare various port terminal equipment types with a LCA, starting with SC.

### 3 General methodology of Life Cycle Assessment

The LCA is a method to estimate the environmental impact of a product system through its whole life cycle. In the 1970 the Society of Environmental Toxicology and Chemistry (SETAC) developed a methodology for the ecological product analysis (Klöpffer and Grahil 2014). The International Organization of Standardization (ISO) implemented the international standard EN ISO 14040 for the assessment of environmental impacts in 2006. This norm only gives a general framework for conducting such analyses, as LCA can be applied in relatively different contexts. In addition to product-specific analyses, services or individual processes within a firm can be assessed with regard to their environmental impact. The DIN EN ISO 14040 divides a LCA into the four major phases: goal and scope definition, life cycle inventory analysis, life cycle impact analysis and interpretation (see Figure 2).

In the first phase, a definition of goal and scope is required. This phase also includes the identification of an audience for the analysis. Our study comprises multiple product life cycle assessments for different port container terminal equipment types and focuses on a comparative analysis of these types. The overall aim of our study is to investigate the environmental impacts of the respective

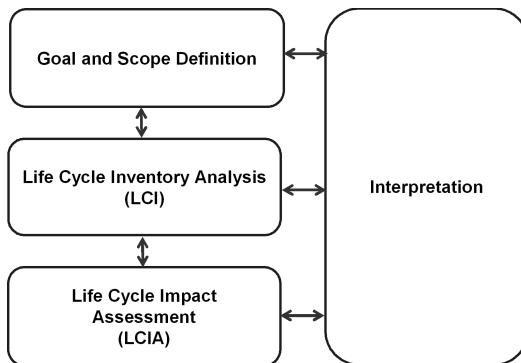


Figure 2: The four phases of life cycle assessments (DIN EN ISO 2006)

equipment types to advise port terminal operators regarding a sustainable port terminal layout.

The system boundaries should include all the input and output flows of material and energy that are relevant for the production system in question. Transparently communicating these system boundaries is of particular importance since the emission of certain parts of the life cycle will mean that these need to be attributed to other production systems in the course of a comprehensive analysis. In terms of our study, the boundaries include activities of selected equipment types for container movement within the gate of a port. Ideally, all energy and material flows needed to provide the equipment types with different drive trains and the infrastructure from ‘cradle-to-grave’ should be investigated. This means that the whole life cycle from the mining of raw materials, to production processes, transportation, use phase and the disposal of goods should be part of a proper LCA. E. g. in the container terminal case, it is important to consider the production phase, as the production of batteries may diminish the environmental benefits of electric drive trains in the use phase.

All results are expressed relative to a functional unit (FU) for comparison purposes. The FU should reflect the utility of the investigated products. The reference flow should correspond to the quantity of a product that is required to achieve this utility. Usually, multiple options for a FU exist. The major challenge within our

project was to decide on a suitable FU that serves to compare different equipment types and enables the implementation of emission factors into the simulation tool. This way, port terminal operators can be advised before realizing ULLIs. The FU in our project is defined as using equipment over one working hour. Note that in this assessment we use a different FU because we present preliminary results of one equipment type: using equipment over the life time of one SC.

Only few industrial processes exclusively produce a single product, or are based on a linear relationship between input and output. Because of this, energy and material flows and the associated emissions have to be allocated to several products. In such cases, the following priorities are recommended by DIN EN ISO 14040:

1. Avoid allocation
2. Find a sound scientific reasoning for an allocation approach
3. Find a sound economic reasoning for an allocation approach

With regard to the quality of the data used for the LCA, the data should be accurate, comprehensive, consistent, reproducible and representative. Due to high effort required to obtain such data, port terminal operators often lack detailed knowledge about port terminal processes like the actual energy consumption of equipment. Additionally, manufacturers usually provide data sheets with generalized information about equipment, which is not detailed enough for a comprehensive LCA. These facts constitute the importance and the challenge to further investigate port activities.

In the second phase of the LCA, a life cycle inventory analysis is created. This inventory analysis serves to properly identify and quantify all input and output flows and indicates their interdependencies. As mentioned above, the development of a LCA usually demands detailed process knowledge, which creators of LCAs often lack due to a limited access to process information. Therefore, it is recommended to use LCA software. These LCA software solutions are usually combined with access to databases containing data from completed life cycle assessments. In this way, modular datasets supply process knowledge about e.g. upstream chains.

In the third phase, the life cycle impact assessment, the results of the inventory analysis are interpreted with regard to specific impact categories, such as climate change (classification), and corresponding impact indicators (characterization),

such as carbon dioxide equivalents. Subsequently, the potential impacts of different port terminal equipment with different drive trains on the environment can be assessed.

In the fourth phase, the interpretation, the results from the inventory analysis are compared to the results from the impact assessment to allow for an interpretation concerning port terminal equipment as a whole. It should be kept in mind that a LCA is an iterative process, which requires a frequent review and reworking of initial phases whenever new insights are gained in the later phases of the process (DIN EN ISO 2006, Guinée et al. 2002).

## 4 Life Cycle Inventory Analysis of Port Terminal Transport Equipment

The assessment of environmental impacts of selected equipment types in container terminals is implemented in the software Umberto LCA+ using the ecoinvent database version 4.3 (IFU 2018). This model has been developed to quantify numerous categories of environmental impacts for a subsequent choice of the most fitting emission mitigation strategies for ports on the basis of the DIN EN ISO 14040 norm.

Following we conduct a simplified LCA-example of a SC (Christou 2012, Yang and Chang 2013) operating on port terminals. We model the SC with two different drive trains: diesel-electric and battery-electric. In the subsequent section, we compare the influences of these two drive trains on the overall LCA. The FU in this assessment is defined as using equipment over the life time of one SC. We will express all considered environmental impacts relatively to this FU.

### 1. Production:

The production of equipment includes all upstream parts of the supply chain, beginning from the cradle. Here, especially the production of raw materials and equipment parts like the diesel generator and electric diesel engines are modelled by customizing modular datasets (mostly so called 'unit processes') from the ecoinvent database. The main component of the SC is the steel-gantry with a hoist system and a driver's cabin. We assume that more than 90 % of the components of an SC are made of steel.

**2. Transportation:**

The equipment must be transported to the terminal before it can be used. These transport processes have not been included in our LCA so far.

**3. Use phase:**

An average use phase of an SC in port operation includes fuel/energy consumption for container transportation and empty driving and maintenance of the SC.

**4. End of life:**

This phase covers the disposal and recycling of equipment parts at the end of a SC's life cycle. Recycling of the battery of a battery-electric SC has not been included so far.

We model an SC with a total weight of 70 tons, which rank among the bigger ones (Kalmar 2017). The modelled SC can carry one 20ft, one 40ft or two 20ft container (Kalmar 2017). We assume an overall life span of 20 years.

The diesel-electric SC runs with a diesel-generator and four electric motors at the wheels, whereas the battery-electric SC has a battery (4 t) and four electric motors. Our calculations, which are based on the inventory data shown in Table 1, consider a replacement of the battery after 3,000 recharging cycles, which means that within a life span of 20 years 3.19 batteries are needed. We create two scenarios of a battery-electric SC to compare two different electricity mixes, the German and the Icelandic, for power consumption. The electricity mix of Iceland is chosen as a reference because it consists of nearly 100 % renewable resources (Loftsdóttir et al. 2017). An overview about further technical data on both SC models is given in Table 1.

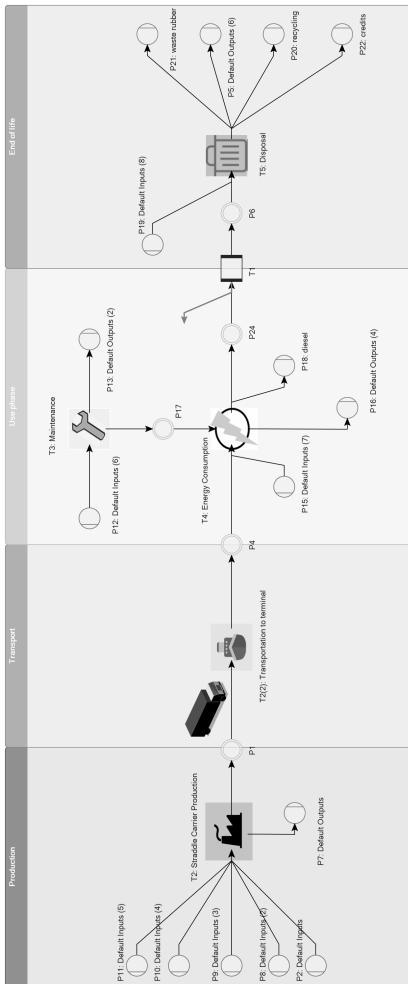


Figure 3: Life cycle phases of a straddle carrier

Table 1: Technical inventory data straddle carrier

	Diesel-electric	Battery-electric	Sources
Steel (gantry) [ton]	64.6	64.6	assumption
Life span [years]	20	20	assumption
Tires [number]	8	8	(Kalmar 2017)
Diesel-Generator [number]	1		(Kalmar 2017)
Electric motor [number]	4	4	(Kalmar 2017)
Working hours [h/y]	3,388	3,388	(Agrawal et al. 2017)
Fuel consumption [l/h]	20	-	(Froese et al. 2014)
Power consumption [kWh/h]	-	80	(Froese et al. 2014, Gottwald Port Technology et al. 2011)
Useful energy [kWh]	-	566	(Sterner and Stadler 2017)
Recharging cycles [number]	-	3,000	(Gottwald Port Technology et al. 2011)

## 5 Results of an Exemplary Environmental Impact Assessment for a Straddle Carrier

Most of the technical inventory data for our LCA (see Section 4) is derived from literature and research of other institutions. Therefore, our calculations are based on multiple assumptions and have to be treated as preliminary results. The planned future steps of our project with HPC will comprise a more comprehensive analysis of real data and conditions at Hamburg port terminals to produce more detailed results. Nevertheless, the LCA results already indicate the dimensions and interdependencies of port terminal equipment's life cycles to operate ports more sustainable.

### 5.1 Life Cycle Impact Assessment and Interpretation of diesel-electric and battery-electric Straddle Carriers

For a concise presentation of the most relevant results, we chose the three impact categories 'climate change', 'terrestrial acidification' and 'particulate matter formation'. These impact categories cover the most relevant emissions (greenhouse gases, sulfur dioxides and particulate matter) for the port transportation sector (Natururschutzbund Deutschland (NABU) 2015, International Maritime Organization (IMO) 2016).

Figure 4 to Figure 6 show the results of our LCA for the diesel-electric engine and the battery-electric engine with the German (ger) and the Icelandic (ice) electricity mix. In all impact categories, the diesel-electric SC causes the highest pollution. The greatest environmental impacts originate from the use phase in all impact categories. Within the use phase, the fuel consumption causes significant quantities of environmentally relevant emissions. The end of life treatment shows negative values in all impact categories, which come from credits for recycling of steel and treatment of rubber. We assume that 100% of steel can be recycled to low-alloyed steel. Meanwhile the end of life treatment of rubber in an incineration plant generates electricity. The electricity from waste incineration substitutes electricity from other resources.

In the impact category 'climate change' (see Figure 4), the electricity mix itself has a large influence on LCA results in the case of battery-electric engines. While the replacement of a diesel generator with an electric engine reduces the pollution

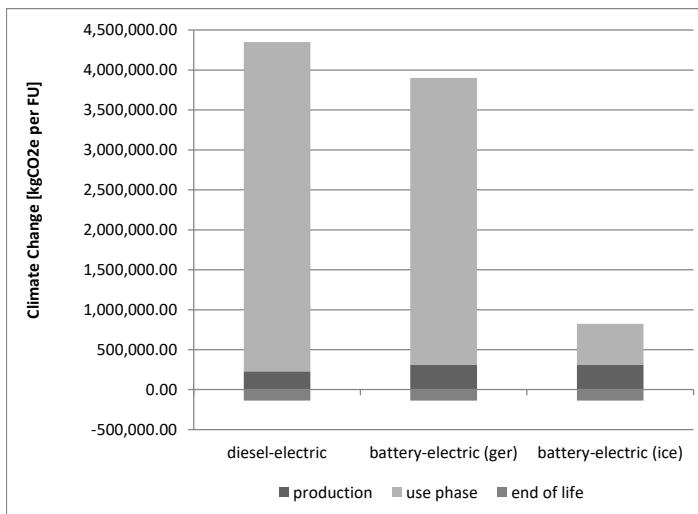


Figure 4: LCA results for the impact category 'climate change'

by about 13 % when assuming the German electricity mix, the green electricity mix of Iceland reduces the pollution by about 88 %.

A similar effect to the 'climate change' can be observed in the impact category 'terrestrial acidification' (see Figure 5). The diesel-electric SC has the largest influence on LCA results, while the battery-electric SC can significantly reduce emission from the use phase. Here again, the reduction potential depends on the electricity mix for power consumption in the use phase.

Foremost, the environmental impact of the production phase increases through the production of a battery for a battery-electric SC. The contribution of the use phase and the production phase to the 'particulate matter formation' (see Figure 6) by a battery-electric SC is very similar. Particularly for the battery-electric (ice) SC, the use phase causes only 13 % more emissions than the production phase. Nevertheless, emission reductions in the use phase switching from a

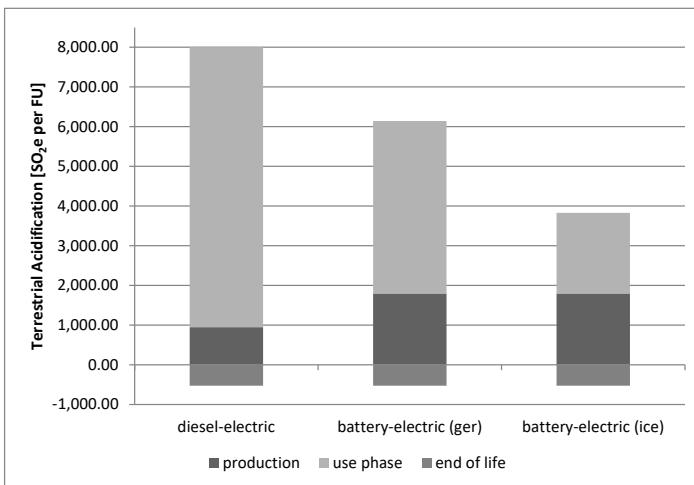


Figure 5: LCA results for the impact category 'terrestrial acidification'

diesel-electric to a battery-electric SC outweigh higher emissions caused by the production of the battery.

As battery recycling has not been modeled in our LCA, the end of life phase has no relevant effect on our results so far. As long as credits for recycling and impacts from disposal of rubber remain the same, there are no differences with regard to the disposal phase in the LCA results of our three SC models.

## 5.2 Conclusion based on findings

The scope of our project comprises a comparative analysis of feasible measures to improve the environmental performance of ports, especially with regard to the configuration and operation of equipment in the container terminal. The system boundaries have been set to enable a comparison of the relevant energy and material flows associated with specific types of terminal equipment. So far, we

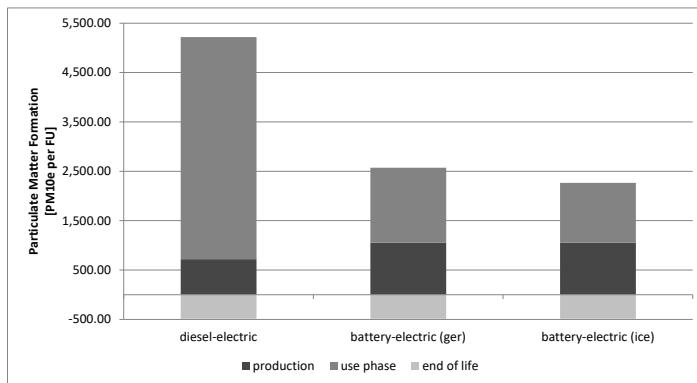


Figure 6: LCA results for the impact category 'particulate matter formation'

conducted one simplified LCA of an SC with a diesel-electric and one of an SC with a battery-electric drive train and two different electricity mixes.

Our preliminary results show the importance and the high impact of the use phase on the overall LCA results. Nevertheless, depending on the impact category, the production phase may also have an important impact on environmental pollution. The high relevance of the production phase confirms the findings of Vujičić et al. (2013), Agrawal et al. (2017) and Gottwald Port Technology et al. (2011). While it is not yet included in our LCA, it is likely that battery recycling will have an influence on the comparative LCA and may change our results in favor of battery-electric vehicles.

Further steps of our project will include a more detailed analysis of SC drive trains. A comparison of the SC with other equipment types for port terminal transportation like RTGs, RMGs and AGVs will also be taken into account to gain a better understanding of a sustainable port terminal layout. The overall aim is to develop emission factors for each equipment type and drive train per working hour. These factors will be implemented in a port operation simulation tool to serve as basis for further recommendations on sustainable ULLIs.

## Acknowledgements

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## References

- Agrawal, A., G. Aldrete, B. Anderson, R. Muller, and J. Ray (2017). “Inventory of Air Emissions for Calendar Year 2016: Prepared for: The Port of Los Angeles: Prepared by: Starcrest Consulting Group, L. L.C.” In:
- Breuer, W., H. Dyckhoff, A. Hüwe, P. Letmathe, O. Lorz, R. Madlener, P. Thomes, and G. Walther (2013). *Ultralangelebige Investitionen, Definition und Problembeschreibung*.
- Christou, I. T. (2012). *Quantitative Methods in Supply Chain Management: Models and Algorithms*. London: Springer Verlag.
- Creutzig, F., P. Jochem, O. Y. Edelenbosch, L. Mattauch, D. P. van Vuuren, D. McCollum, and J. Minx (2015). “Transport: A roadblock to climate change mitigation”. In: *Science* 350.6263, pp. 911–912.
- Davarzani, H., B. Fahimnia, M. Bell, and J. Sarkis (2016). “Greening ports and maritime logistics: A review”. In: *Transportation Research Part D: Transport and Environment* 48, pp. 473–487.
- DIN EN ISO (2006). *Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen (ISO 14040:2006)*. Berlin.
- Durrant-Whyte, H., D. Pagac, B. Rogers, M. Stevens, and G. Nelmus (2007). “Field and service applications - An autonomous straddle carrier for movement of shipping containers - From Research to Operational Autonomous Systems”. In: *IEEE Robotics & Automation Magazine* 14.3, pp. 14–23.
- Froese, J., S. Töter, and I. Erdogan (2014). *Green Efforts - Recommendations Manual for Terminals, Deliverable 12.1*.
- Geerlings, H. and R. van Duin (2011). “A new method for assessing CO<sub>2</sub>-emissions from container terminals: A promising approach applied in Rotterdam”. In: *Journal of Cleaner Production* 19.6-7, pp. 657–666.

- Gottwald Port Technology, HHLA, ifeu, and RWTH Aachen (2011). *Abschlussbericht B-AGV, Forschung und Entwicklung batteriebetriebener Schwerlastfahrzeuge (AGV) und deren Erprobung in einem Feldversuch im Container-Terminal Altenwerder in Hamburg, im Rahmen des FuE-Programms "Förderung von Forschung und Entwicklung im Bereich der Elektromobilität"*: Projektlaufzeit: 01.06.2010 - 30.09.2011: Gefördert durch das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Düsseldorf.
- Guinée, J. B., M. Gorrée, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. Wegener Sleeswijk, S. Suh, H. A. de Udo Haes, H. de Bruijn, R. van Duin, and M. A. J. Huijbregts (2002). *Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards*. Dordrecht: Kluwer Academic Publishers.
- Günther, H.-O. and K.-H. Kim (2006). "Container terminals and terminal operations". In: *OR Spectrum* 28.4, pp. 437–445.
- Hou, L. and H. Geerlings (2016). "Dynamics in sustainable port and hinterland operations: A conceptual framework and simulation of sustainability measures and their effectiveness, based on an application to the Port of Shanghai". In: *Journal of Cleaner Production* 135, pp. 449–456.
- IFU (2018). *Umberto LCA+: Institut für Umweltinformatik Hamburg GmbH (IFU); Institut für Energie- und Umweltforschung (IFEU)*. Hamburg/Heidelberg.
- Kalmar (2017). "Kalmar Straddle Carrier Data sheet". In:
- Klöpffer, W. and B. Grahl (2014). *Life Cycle Assessment (LCA): A Guide to Best Practice*. Weinheim: Wiley-VCH.
- Lam, J. S. L. and T. Notteboom (2014). "The Greening of Ports: A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe". In: *Transport Reviews* 34.2, pp. 169–189.
- Stahlbock, R. and S. Voß (2007). "Operations research at container terminals: A literature update". In: *OR Spectrum* 30.1, pp. 1–52.
- Steenken, D., S. Voß, and R. Stahlbock (2004). "Container terminal operation and operations research - a classification and literature review". In: *OR Spectrum* 26.1, pp. 3–49.
- Sternér, M. and I. Stadler (2017). *Energiespeicher - Bedarf, Technologien, Integration*. Berlin, Heidelberg: Springer Berlin Heidelberg.
- The European Sea Ports Organization (2012). *Green Guide - Annex 1: Good practice examples in line with the 5 Es*. Bruxelles.
- Tichavská, M., B. Tovar, D. Gritsenko, L. Johansson, and J. P. Jalkanen (2017). "Air emissions from ships in port: Does regulation make a difference?" In: *Transport Policy*.
- Vujičić, A., N. Žrnić, and B. Jerman (2013). "Ports Sustainability: A life cycle assessment of Zero Emission Cargo Handling Equipment". In: *Strojniški vestnik – Journal of Mechanical Engineering* 9.59, pp. 547–555.
- Wang, Z. and J. Sarkis (2013). "Investigating the relationship of sustainable supply chain management with corporate financial performance". In: *International Journal of Productivity and Performance Management* 62.8, pp. 871–888.
- Wilmsmeier, G. and T. Spengler (2016). "Energy consumption and container terminal efficiency". In: *FAL Bulletin* 350.6, pp. 1–10.
- Yang, Y.-C. (2017). "Operating strategies of CO<sub>2</sub> reduction for a container terminal based on carbon footprint perspective". In: *Journal of Cleaner Production* 141, pp. 472–480.
- Yang, Y.-C. and W.-M. Chang (2013). "Impacts of electric rubber-tired gantries on green port performance". In: *Research in Transportation Business & Management* 8, pp. 67–76.

# Integrating Layout Planning and Simulation for Logistic Nodes

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*When a new logistic node (e.g. a terminal) is planned or needs to be optimized, layout planning and simulation analysis are typically two separate tasks. While layout planning is an intuitive and visual but static approach, simulation is dynamic but more complex. Integrating both approaches would be highly beneficial. The idea of the integrated tool is to create first a static layout on a touchscreen planning table. After inserting relevant parameters and selecting preferred logistic strategies, the layout is converted directly into an executable simulation model. Based on the simulation, e.g. different layout or equipment variations can be tested.*

*Main challenges for a successful integration are the logistic processes and strategies on the terminal. Both are not included in the layout planning, but are essential for a valid and realistic simulation model. Therefore, relevant process and strategy variations as well as typical research questions are defined. The integrated approach is an innovative solution to optimize planned as well as existing terminals. Typically, conducting layout planning and simulation studies separately is a very time consuming task. Integrating both is more efficient, closer to reality and more cooperative by allowing to involve more stakeholders at an earlier stage.*

**Keywords:** Simulation; Layout Planning; Inland Waterway Container Terminal; Intermodal Transport

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## 1 Introduction

In order to meet the high demands for faster handling in a shorter time window and with higher quality, it is necessary that logistical nodes in ports and the hinterland continuously review their operational and administrative processes and adapt them if necessary. This applies in particular to container terminals (Stahlbock and Voß, 2008) and intermodal terminals due to the high transshipment numbers and the increasing requirements. Therefore, when planning new and existing logistic nodes, it is important to use space and technical systems for handling, transport and storage as efficient as possible. Simulation is becoming increasingly important for securing and optimizing solutions for planning processes in logistics in general (März and Weigert, 2011) and especially for container terminals. It is increasingly important to integrate the simulation in early planning phases and with little effort.

## 2 Problem Description

### 2.1 State of the art

Typically, terminal planning and terminal optimization by simulation studies are separate tasks. The terminal layout is planned statically using standard layouts, experiences, spreadsheets or other static tools. Afterwards, simulations studies can be conducted to evaluate and improve the terminal design. This would lead to adjustments in the terminal planning causing a high expenditure of time and high personnel costs. Furthermore, creating simulation models demands time and substantial soft knowledge.

Common simulation tools for material flow and logistics like AnyLogic, AutoMod, CLASS, Demo3D, Enterprise Dynamics, Plant Simulation, Simul8, or Witness base on object libraries that provide the foundation to create a simulation model. These objects are defined by a number of parameters. The amount of parameters has to be the higher the more realistic the simulation is supposed to be. This implies that modelling large sites containing various parameter constellations is a highly complex and time-consuming task.

Additionally, control mechanisms and algorithms have to be defined to manage the simulation runs. All common tools provide predefined procedures. Practically,

these procedures have to be adjusted by re-programming objects or programming new scripts. Target group of these tools are typically specifically trained users that intend to find answers to specific questions regarding an existing terminal layout.

In other areas of logistics, such as production planning (Toth et al., 2008) or conveyor system planning (Wurdig and Wacker, 2008), approaches have already been taken to integrate planning and simulation. However, these approaches cannot be directly transferred to the planning of logistical nodes due to a high number of organizational forms, many decision variables, static and dynamic side conditions and many sources of uncertainty, e.g. weather conditions or equipment failures. This is also the reason why many simulation models focus on defined area of seaport container terminals, e.g. automated storage blocks (i.a. Xin et al., 2014; Kemme, 2012; Canonaco et al., 2007), container gantry cranes (i.a. He et al., 2015; Guo and Huang, 2012; Dai et al., 2004; Liu et al., 2002) or horizontal transport (i.a. Garro et al. 2015; Tao and Qiu, 2015; Duinkerken et al., 2007). Other simulation models consider container terminals as a whole, but focus on medium to large seaport container terminals and do not offer the flexibility required for inland terminals or intermodal terminals.

## 2.2 Objectives

When layout planning and simulation studies for logistic nodes are conducted separately and decoupled, possible synergy effects (such as reducing the modelling time for a simulation model) are not realized. To approach these deficiencies, it would be beneficial to develop a soft *ware* solution that allows creating static terminal layouts and to transfer this layout directly to an executable dynamic simulation model including the relevant terminal processes and strategies. These processes and strategies are of utmost importance for a successful integration as they represent the essential link between layout planning and simulation. Therefore, they have to be defined beforehand. By integrating intuitive and cooperative layout planning together with dynamic process mapping within one soft *ware* solution, the strengths of both tools are combined while the weaknesses of both tools are eliminated at the same time.

In order to realize the integration of layout planning and simulation, two existing soft *ware* tools are chosen. Thereby, the planning soft *ware* visTABLE® by plavis and the simulation soft *ware* Enterprise Dynamics® by INCONTROL represent the

respective software are. The integration can reduce the required time to plan a logistic node significantly as simulation models have to be modelled otherwise by experts in extensive work based on the designed layout.

Therefore, this innovation directly supports an efficient and rapid planning phase of logistic nodes to support an extension of transport infrastructure suitable to the market needs. The integration of layout planning and simulation studies is - in a first step - developed for inland waterway container terminals and terminals for intermodal transport. This means that whenever the term 'terminal' is used in the following, these two terminal types are described. All other types of terminals such as e.g. seaport container terminals are not considered.

## 2.3 Methodology

### 2.3.1 Methodology to integrate both software tools

Baseline for such an integrated software tool are the *system specifications* that define all requirements for the tool. This comprises e.g. typical and relevant objects, processes and strategies to be implemented, but also relevant problems to be investigated with the tool and interesting output parameters of the tools for users later on.

Based on the system specifications, the *concept* is developed. A method needs to be described to define a systematic procedure how to implement the specifications. Basically, detailed use cases have to be described containing objects, processes, strategies, problems to be investigated and output parameters. This also includes e.g. describing core elements of a modular object kit and all selectable control strategies. Based on this method, detailed definitions of partial systems to be implemented later on are derived. Thereby, possible end users should be involved in this phase to ensure draftin user interfaces suitable for different types of users. Based on these results, a functional architecture of the planning environment can be derived.

If the concept is developed, the *implementation* phase begins. First, foundations have to be laid to allow for an integrated use of both software tools. There is a high number of interdependencies between results and restrictions from the layout planning and their transformation to an executable simulation model. These restrictions require adapting both software tools. The previously defined use cases have to be implemented together with the corresponding algorithms. Necessary

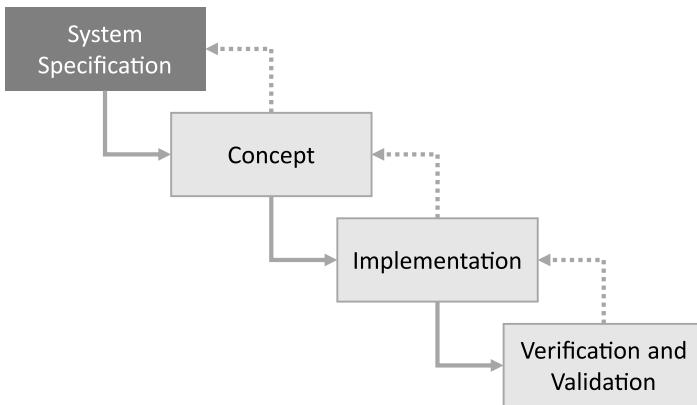


Figure 1: Methodology

interfaces and data structures that are defined in the system specifications need to be integrated in both software tools.

To verify the implemented software solution, extensive tests are conducted. First of all, the functional capability of the developed software tools is verified. This test bases on a test plan that contains all relevant test cases (e.g. choice of logistic strategies) based on systematic parameter variations. Afterwards, the functionality of the software is validated. Thereby, single specific test cases are considered. Afterwards, two exemplarily test applications show the comparability with real terminals.

Figure 1 displays the methodology. Thereby, the dotted arrows indicate that it might be reasonable to go back to the previous phase for some adjustments. The integrated software solution will be developed as a prototype within the German research project "ISI-Plan - Integration von ereignis-diskreter Logistiksimulation und Layoutplanung für logistische Knoten" which means "Integration of event-discrete logistics simulation and layout planning for logistics nodes". The project is funded by the German Federal Ministry of Education and Research (BMBF).

### 2.3.2 Methodology for the system specification

Based on this general methodology, the focus of this paper is on the first part, the system specification. Thereby, on the one hand scientific literature on terminal layout planning (e.g. Böse, 2011; Brinkmann, 2005) and terminal simulation (e.g. Dragovic et al., 2017; Angeloudis and Bell, 2011) is considered. On the other hand, the practical operational terminal processes are investigated in detail in order to validate the state of the art as well as to ensure the reference to recent terminal challenges.

First, a desk research is conducted to identify relevant publications in the field of container terminals. Thereby, not only inland waterway terminals and intermodal transport terminals are considered, but also seaport container terminals. This allows to include advanced technologies as well as storage and logistic strategies. Furthermore, websites of relevant logistic nodes as well as available studies and reports are analyzed to complete the findings with the state of technology. As there are sometimes significant differences between the functionalities and complexity of different logistic nodes, the findings are examined regarding their adaptability to inland waterway and intermodal transport terminals. This way, objects and strategies are considered as well that are less relevant at the moment but might become more important in the future.

Based on the desk research results, interview guidelines are developed that serve as a foundation for visits at two representative terminals. During these visits, detailed analyses of terminal operations, relevant parameters, planning issues and possible future topics are surveyed. Some interesting findings of both approaches (desk research and terminal visits) are presented in the following section.

## 3 Approach and functionalities

The goal of the research project ISI-Plan is the creation of a functional prototype consisting of the innovative integration of the planning table and the logistical process simulation. Therefore, that prototype will support the rapid and efficient planning and development of logistics hubs.

The tool will be tested in the project by the Institute of Maritime Logistics of the Hamburg University of Technology, the Fraunhofer Center for Maritime Logistics

and Services CML, the Studiengesellschaft für den Kombinierten Verkehr e.V. (German Promotion Centre for Intermodal Transport), an inland waterway terminal and an intermodal terminal using corresponding example scenarios. The tool mainly uses a map of the area to be planned as input data. Based on this map, the user inserts suitable superstructures (such as portal cranes or reach stacker (RS)) at the desired location in the planning software. Standard parameters such as vehicle speeds or energy consumption can be adjusted as required. The layout is created using the planning table.

Furthermore, the user can choose between different strategies for the logistics processes in the terminal (e.g. assignment of RS to specific tasks, which water and landside container input for the terminal is to be simulated in a specific time interval and on how many trucks, trains and passenger ships these are distributed). Afterwards, the prepared layout can be transferred directly to the simulation software with all parameters. The performance of the planned terminal layout can be tested using the generated simulation model.

In summary, the tool is characterized by the following functionalities:

1. Intuitive layout planning via "drag and drop" for logistics nodes (on a planning table)
2. Automatic creation of a simulation model based on the planned layout
3. Selection of different logistics strategies and parameters as well as input quantities of the logistics node
4. Execution of simulation tests to measure the performance of a layout alternative

To realize the prototype, both software tools visTABLE and Enterprise Dynamics will be linked bidirectional by special interfaces. One major issue is the implementation of logistics strategies and process flows in these logistics hubs.

Figure 3 displays the basic concept of that prototype with its characteristic functionalities. Using the ISI-Plan prototype, the layout planning is done with visTABLE by using the planning table. The user can create any terminal layout by using predefined logistics objects from the visTABLE library and drag-and-drop these to the modelling layout. Each object has a set of default parameters and a visual representation that can be modified by the user. Additionally to the modelling

of the layout in visTABLE the user also defines the logistics strategies and processes to be used later on in the simulation model and defines the target values to measure the performance of the layout.

When the modelling process is finished in visTABLE all data is transferred to Enterprise Dynamics. The simulation tool then automatically creates the simulation model with all applied objects, parameters and additional settings and automatically runs the defined simulation experiments. The defined target values are measured during each simulation run and are stored in a database. After the simulation experiments the result data is returned to visTABLE where the user gets these results presented in the form of e.g. diagrams and tables.

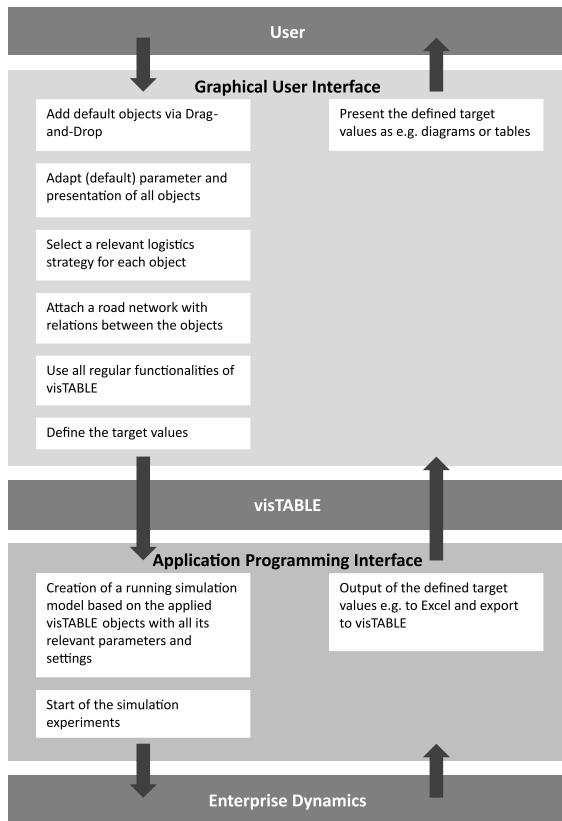


Figure 2: Overview of the functionalities of the prototype

## 4 System specification

As mentioned beforehand, the system specification defines which objects, processes and strategies, relevant problems and output parameters should be included in the new software tool. All of these issues are presented in the following section.

### 4.1 Objects

In the following, relevant objects and corresponding parameters for the integrated software are described. The objects are grouped in five categories: vertical transport, horizontal transport, external vehicles and means of transport, loading units (LU), terminal areas.

The category *vertical transport* comprises terminal equipment whose main function is to lift a LU from a horizontal transport vehicle or a storage area and to place the LU on another horizontal transport vehicle or a storage area. Although, technically, a certain horizontal transport takes place, this is neglected in this common classification. The pure vertical transport on terminals is carried out by cranes (e.g. gantry cranes, mobile harbor cranes).

Vehicles are assigned to the category *horizontal transport* if their main function is to transport LUs from one vertical transport equipment or storage area to another vertical transport equipment or storage area. However, some equipment types, such as RS, are capable of both vertical and horizontal transport and are used accordingly, e.g. for unloading a LU from a truck, transporting the LU across the terminal area to a storage area and stacking the LU on other LUs in this storage area. Within this classification, these hybrid forms are assigned to horizontal transport. A distinction is made within this group into active and passive vehicles. Active load carriers can independently receive LU, while passive vehicles must be loaded by another equipment type. Examples for vehicles in this category are empty container handlers, reach stacker, tractor-trailer-units and shunting engines.

While they are not classified as terminal equipment due to their deviating ownership, *external vehicles and means of transport* are nevertheless very important objects for the handling of goods at terminals. They are used to carry out the

incoming and outgoing volumes of LU to terminals as logistical transshipment nodes. Examples of external vehicles are trucks, trains and barges.

*Loading units* are transport containers through which various goods can be transported and handled in a standardized manner. The most important example of this are containers, which in turn can be divided into various subclasses such as standard, empty, reefer, open top, tank and flat racks. Other LUs can be swap bodies and trailers.

Within the category *terminal areas*, almost all terminals have a paved road area in common for the arrival and departure of trucks. Furthermore, a terminal has shunting and loading tracks. The track length for a so-called block train, i.e. a train with the maximum permissible length, measures 750 m in Germany. For tracks with half lengths, the block train must be divided and shunted. The loading and unloading tracks are usually straddled by gantry cranes handling the LUs between road and rail. In larger terminals, RS are often used to support the gantry cranes. The short-term storage area for LUs is located under the crane runway. Additional storage areas can be realized in the vicinity of the crane runway and must be operated by a RS. Administration buildings, entrance areas and fences are also part of the terminal area category.

## 4.2 Processes

Terminals in general serve as transshipment points between different modes of transport. Inland waterway container terminals and intermodal transport terminals are typically part of the pre- respectively post-carriage processes of maritime transports. This implies that, typically, containers and other LUs arrive at these terminals by train or barge from a seaport terminal, and they are picked up by trucks for further distribution (or vice versa). Intermodal transport terminals are also integrated in other transport chains such as e.g. CEP (courier, express and parcel) services.

Usually, all main cargo handling processes on the terminal begin when an external vehicle arrives at the terminal with a LU and end in the short-term storage area or vice versa. However, there is also the possibility that a LU is directly transferred from one external vehicle (e.g. train) to another (e.g. truck) without stopping in the storage area.

Figure 3 and Figure 4 show exemplarily the processes "pick-up by truck" and "delivery by train". The processes were mapped on terminals of project partners and afterwards generalized based on industry knowledge and scientific literature. They are displayed in swim lane diagrams. The darker boxes on the left show the respective actor, the medium grey boxes show the single process steps of the main process. The light grey boxes indicate the transition to other main processes. The arrows show the order of the single process steps.

*Pick-up by truck* - as displayed in Figure 3 - is quite similar in all terminals. The empty truck arrives, the driver registers either at a counter or on a self-service terminal, drives to a specified transfer position, is loaded with the LU by crane or RS, and afterwards leaves the terminal. In some cases, the loaded LU is checked whether it is the right one (if not, he LU has to be changed). Therefore, even if different equipment is used, the processes stay relatively constant.

In contrast, *delivery by train* varies widely depending on the equipment that is used in the train area (see Figure 4). When a train arrives, it registers, and the office generates an order list for the handling equipment based on the train load list. If a RS is used for unloading the train, the driver unloads an accessible LU, the checker checks the LU for damages and whether it is the right one, and then the RS transports it to the respective storage position and places it in the storage area (or on a truck that picks up the specific LU). If there are any restrictions regarding the accessibility of the train, a shunting engine is used to shunt the rail cars. If a crane is used in the train area, the checker first checks all LUs on the train before the crane starts unloading. If the LU is a trailer, the crane places it directly in the crane runway where it is picked up either by an internal tractor to be pulled to a trailer storage area or directly picked up by an external truck. If the LU is a container or a swap body, it is either placed in the storage area or directly on a waiting external truck. When all LUs are unloaded from the train, the order list is returned to the office together with remarks from the checker.

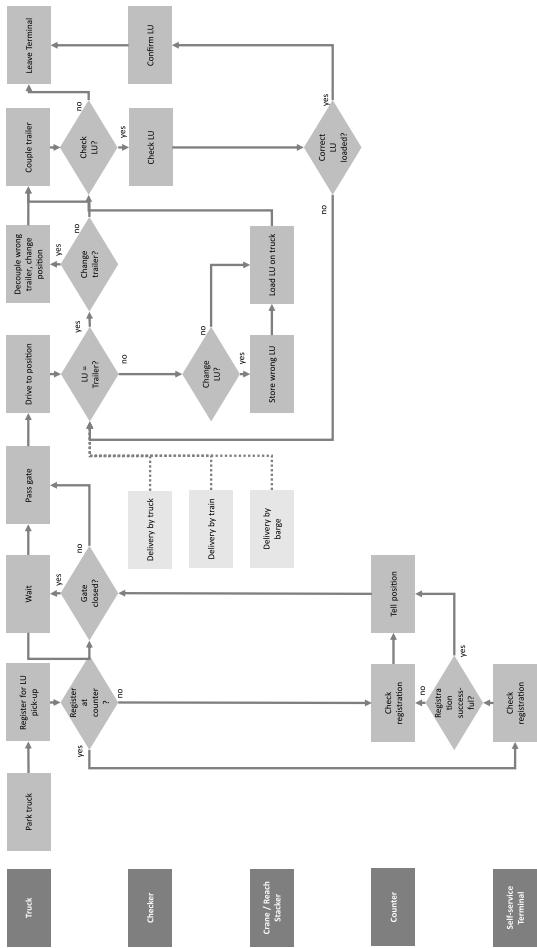


Figure 3: Process "Pick-up by truck"

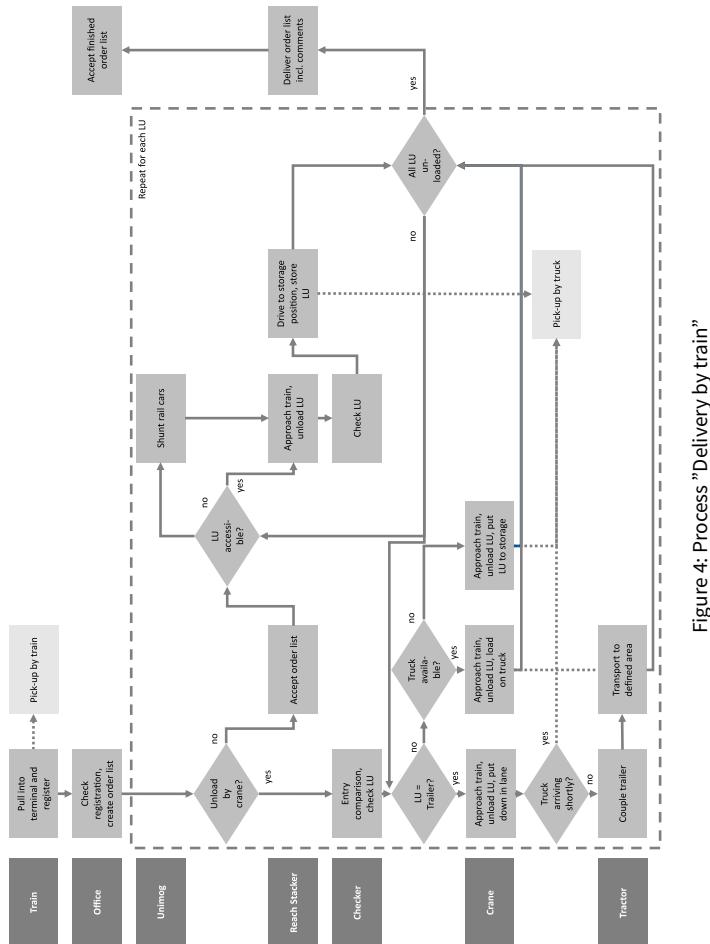


Figure 4: Process "Delivery by train"

These two process examples illustrate the challenges for a software tool that automatically generates a simulation model based on a static layout. The objects have to be connected to the respective process variations. However, implementing logistics strategies is another challenging topic.

### 4.3 Strategies

Various strategic and operational decision problems arise during the planning and operation of terminals. Strategic decision problems are of a longer-term nature and only arise infrequently, while operational decision problems occur in daily terminal operations. Figure 5 assigns strategic and operational decision problems to the respective terminal areas.

The strategic decision problems "layout" as well as "type and number of equipment" are essential research subjects of the software tool to be developed. The operational decision problems relate to the question of how a certain process step is carried out, e.g. how a decision is made, where exactly a LU is stored or to which transfer position a truck is steered to or which task a gantry crane performs next. The strategies can be used to make these decisions and are therefore solutions to the decision-making problems. For the tool to be developed, this means that for the relevant part of the decision problems, different variants of strategies that are typically used in terminals must be implemented. In the following, some exemplarily strategies are described.

*Prioritization or assignment of tasks* is about which gantry crane / RS / tractor performs which task next. Thereby, a task is to change the location of a LU (i.e. load, store, etc. the LU from the train/truck/barge). Possible strategies include: First-come-first-served, minimize distances, minimize travel time to job start location, select order with the longest waiting time, prioritization of task types (e.g. train before truck), scoring strategies, or restacking / presorting at low utilization (cf. Kaff et al., 2014; Clausen and Kaff et al., 2016; Eckert et al., 2013).

The *assignment of barges* to berths is only a relevant decision problem if there is more than one berth. One possible strategy, especially with a fixed weekly timetable, is that the assignment is always the same which means that a weekly arriving barge always gets the same berth.

The *transfer position* for an external truck refers to where on the terminal the truck hands over or receives the LU. The strategy depends among other things

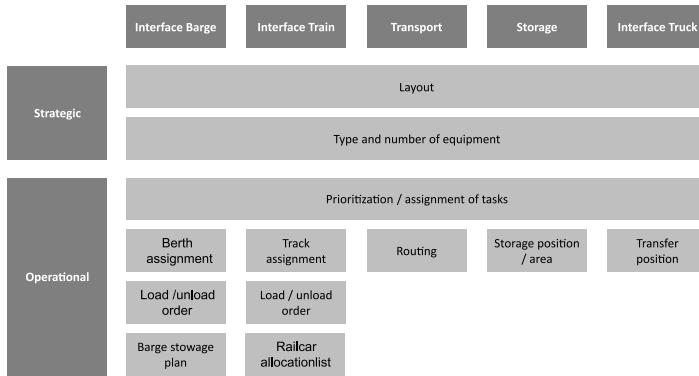


Figure 5: Decision problems on inland waterway and intermodal terminals

on the terminal size. For a small terminal, this can be one defined place. The following strategies are possible for larger terminals: minimize distance to planned storage position, minimize distance to current crane position, minimize distance to planned or current position on the train (during train loading or unloading), or minimize distance to an empty space in the storage area (especially at high storage area utilization).

These examples illustrate on the one hand that there are several similarities between seaport container terminals, inland waterway container terminals and intermodal terminals. On the other hand, the relevant strategies for inland waterway container terminals and intermodal terminals are rather simple, some seaport-related strategies are not relevant (e.g. berth assignment as most considered terminals have no or one berth), and there are other challenges as e.g. gantry cranes are used for several tasks in parallel (cf. e.g. Jaehn, 2013).

#### 4.4 Relevant questions

The questions that the prototype should be able to analyze are part of the decision problems mentioned in section 4.3. The most important questions relate to the

storage area as well as the barge and train handling. They were identified in discussions with different terminal experts.

Storage area-related questions are: How many storage lanes are required? How large (length, width, height) should the storage area be? Which equipment should be used and how much equipment is required by which equipment category? Which storage area organization respectively position assignment is best? Up to which storage utilization is terminal operation still productive? How do the dwell times of LUs affect the productivity of the terminal? Which order should the equipment process next?

Barge- respectively train-related questions are: What influence does the logic have on the occupancy of the tracks/ berths? Which equipment should be used and how much equipment is required by which equipment category?

#### 4.5 Output parameters

Eventually, the soft ~~are~~ tool has to provide output parameters that are important to decision makers to choose the best alternative for the specific terminal. Depending on the terminal and the question that is analyzed, different output parameters are important. In general, the following output parameter have a high priority to terminal decision makers: Number of LUs handled (per year/month/day/hour), equipment utilization, utilization of space, number of delayed train departures, distances travelled by vehicles (per LU), and moves/h per equipment. Output parameters with a medium priority are e.g. cycle time of (sub-)processes, duration of the train's stay at the terminal, fuel consumption, power usage, personnel expenses, equipment wear, and noise emissions.

### 5 Conclusion and Future Research

This innovative soft ~~are~~ tool directly supports efficient and fast planning of logistic nodes, which are necessary for a demand-oriented expansion of the transport infrastructure. In Germany alone there are more than 300 logistic nodes that can benefit directly from the integrated planning and simulation tool.

Further research could extend the scope of the prototype to other logistic nodes and even seaport container terminals. It could also include additional objects,

processes and strategies. Also new technologies could be tested more easily as well as time and cost efficient .

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## References

- Angeloudis, P. and M. G. Bell (2011). "A review of container terminal simulation models". In: 38,5, pp. 523–540.
- Böse, J. W., ed. (2011). *Handbook of Terminal Planning*. Operations Research/Computer Science Interfaces Series. New York, NY: Springer New York.
- Brinkmann, B. (2005). *Seehäfen - Planung und Entwurf*. Berlin: Springer.
- Canonaco, P., P. Legato, R. M. Mazza, and R. Musmanno (2008). "A queuing network model for the management of berth crane operations". In: 35,8, pp. 2432–2446.
- Clausen, U. and J. Kaff a (2016). "Development of priority rules for handlings in inland port container terminals with simulation". In: 10,2, pp. 95–102.
- Dai, J., W. Lin, R. Moorthy, and C.-P. Teo (2004). *Berth Allocation Planning Optimization in Container Terminals: Working Paper*. Atlanta, USA.
- Dangelmaier, W., C. Laroque, and A. Klaas, eds. (2013). *Simulation in Produktion und Logistik 2013: [Entscheidungsunterstützung von der Planung bis zur Steuerung ; 15. ASIM Fachtagung]* ; Paderborn, 09. - 11. Oktober 2013. Vol. 147. ASIM-Mitteilung. Paderborn: Heinz-Nixdorf-Inst. Univ. Paderborn.
- Dragović, B., E. Tzannatos, and N. K. Park (2017). "Simulation modelling in ports and container terminals: Literature overview and analysis by research field, application area and tool". In: 29,1, pp. 4–34.
- Duinkerken, M. B., R. Dekker, S. T. G. L. Kurstjens, J. A. Ottjes, and N. P. Dellaert (2007). "Comparing transportation systems for inter-terminal transport at the Maasvlakte container terminals". In: *Container terminals and cargo systems: design, operations management, and logistics control issues*. Ed. by K. H. Kim and H.-O. Günther. Berlin: Springer, pp. 38–61.
- Eckert, C., P. Teige, and D. Steinhauer (2013). "Bausteinbasierte Simulation des Ladungsumschlags in trimodalen Contain-nerterminals". In: *Simulation in Produktion und Logistik 2013*. Ed. by W. Dangelmaier, C. Laroque, and A. Klaas. Vol. 147. ASIM-Mitteilung. Paderborn: Heinz-Nixdorf-Inst. Univ. Paderborn, pp. 283–292.
- Garro, A., M. F. Monaco, W. Russo, M. Sammarra, and G. Sorrentino (2015). "Agent-based simulation for the evaluation of a new dispatching model for the straddle carrier pooling problem". In: 91,2, pp. 181–202.

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## REFERENCES

- Guo, X. and S. Y. Huang (2012). "Dynamic Space and Time Partitioning for Yard Crane Workload Management in Container Terminals". In: 46.1, pp. 134–148.
- He, J., Y. Huang, and W. Yan (2015). "Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption". In: 29.1, pp. 59–75.
- Jaehn, F. (2013). "Positioning of loading units in a transshipment yard storage area". In: 35.2, pp. 399–416.
- Kaff, J., U. Clausen, and S. Stein (2014). "Revealing gaps in the material flow of inland port container terminals alongside the danube with simulation". In: *Winter Simulation Conference (WSC), 2014*. Ed. by A. Tolk. Piscataway, NJ and Piscataway, NJ: IEEE, pp. 1807–1818.
- Kemme, N. (2012). "Effects of storage block layout and automated yard crane systems on the performance of seaport container terminals". In: 34.3, pp. 563–591.
- Kim, K. H. and H.-O. Günther, eds. (2007). *Container terminals and cargo systems: design, operations management, and logistics control issues*. Berlin: Springer.
- Liu, C.-I., H. Jula, and P. A. Ioannou (2002). "Design, simulation, and evaluation of automated container terminals". In: 3.1, pp. 12–26.
- Rabe, M., ed. (2008). *Advances in Simulation for Production and Logistics Applications*.
- Rabe, M., ed. (2012). *Advances in Simulation for Production and Logistics Applications*.
- Tao, J. and Y. Qiu (2015). "A simulation optimization method for vehicles dispatching among multiple container terminals". In: 42.7, pp. 3742–3750.
- Tolk, A., ed. (2014). *Winter Simulation Conference (WSC), 2014*. Piscataway, NJ and Piscataway, NJ: IEEE.
- Toth, M., A. Wagenitz, and S. Turgut (2008). "Ein Ansatz zur kollaborativen, modellbasierten Planung von Komponenten mit Hilfe von elektronischen Katalogen (eKAT)". In: *Advances in Simulation for Production and Logistics Applications*. Ed. by M. Rabe, p. 417.426.
- Wurdig, T. J. and R. Wacker (2012). "Generische Simulationslösung für Fördertechnik". In: *Advances in Simulation for Production and Logistics Applications*. Ed. by M. Rabe, pp. 12–20.
- Xin, J., R. R. Negenborn, and G. Lodewijks (2014). "Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control". In: 44, pp. 214–230.



# Influence of Drayage Patterns on Truck Appointment Systems

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*Truck appointment systems (TAS) are a well-recognized method to smooth the peaks in truck arrivals at seaport container terminals and thereby reduce operation costs for the terminals and waiting times for trucking companies. This study analyzes the influence of different drayage patterns on the success of a TAS at seaport container terminals by means of a discrete event simulation model. These drayage patterns vary in the percentages of transports between container terminals and container terminals and other logistics nodes. Past studies mainly focus on the general impact of TAS on container terminals or on trucking companies. Rarely different TAS' characteristics are analyzed regarding their impact on the performance. To the authors' knowledge, the influence of varying shares of different drayage origins and destinations have not been studied so far. The results show that the pattern of drayage transports has a considerable influence on the success of TAS. As the transport from terminals to logistics nodes and vice versa is bound to the opening hours of the logistics nodes, trucking companies often need to execute inter terminal transports at night.*

**Keywords:** Truck Appointment System; Port Drayage; Container Terminal; Simulation

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## 1 Introduction

Maritime transport has a high worldwide importance due to the large amount of global trade transported by ships and handled in ports, by volume 80 % and by value 70 %. In 2016, world seaborne trade grew 2.8 % in contrast to 2015 and reached a volume of 10.3 billion tons. The global containerized trade grew even faster at a rate of 3.1 % in 2016, with a volume of estimated 140 million 20-foot equivalent units (TEU). (UNCTAD, 2017) To deal with the rising amount of containerized goods, stricter ecological regulations and lower margins, shipping companies respond with rising ship dimensions. This leads to severe challenges for all stakeholders in the maritime supply chain, especially for the seaports. Seaports are essential interfaces in the overall maritime supply chain, connecting the main carriage via ocean carrier and the hinterland transportation via barge, train or truck. Container terminals, as the most important part of the maritime supply chain in seaports, aim to uphold the guaranteed handling times for their clients, even if these are not rising proportionally to the vessel sizes. Generally, container terminals consist of four functional areas: waterside, horizontal transport, container yard and landside (i.a. Brinkmann, 2011; Steenken et al., 2004). The strategies and processes in all of these functional areas need to be optimized to meet the challenges imposed by the growing vessel sizes.

Especially, container terminals struggle with the strain caused by peaks at land-side operations due to the arrival of large vessels and the related arrivals of many external trucks at the terminal gates. Due to the peaks, the right amount of personnel is hard to estimate and often the capacity of the terminal gate and the handling equipment on the container yard doesn't fit the demand imposed by the arriving trucks. This either leads to high waiting times at the terminal gate and on the terminal yard or to inefficient high labor costs for the terminals due to over capacities. Drayage transportation is accountable for a large share of container terminals' truck arrivals as well as for a high percentage of the overall transportation costs (Harrison et al., 2007; Shiri and Huynh, 2016). A well-established definition of port drayage is: "truck pickup from or delivery to a seaport, with the trip origin and destination in the same urban area" (Hartmann, 2004; Huynh et al., 2011). Drayage transports are mainly used for transports from one container terminal to others. In addition, they are used for transports between terminals and freight stations, empty container depots, customs stations located in the port and vice versa. The transports are executed by specialized trucking companies. They mostly employ truck drivers as owner operators, which get paid for every completed trip. These drivers rely on a minimal number of daily trips to cover the expenses.

Therefore, waiting times at terminals or other logistics nodes as well as congestion on public streets lead to less successful trips per day and, thereby, reduce the income per truck driver. Furthermore, waiting times and congestion also affect the accessibility of public streets and related port companies, e.g. forwarders, empty container depots or freight stations. In addition, the waiting times cause higher emissions due to running truck engines.

One popular solution to smooth truck arrival peaks in ports is to implement a truck appointment system (TAS). This is a vehicle booking system used by trucking companies to book time windows within the operating times of container terminals. The truck drivers have to arrive in these time windows for being handled. For late arrivals or missed time windows, penalties can be defined by the TAS operator. Furthermore, there can be penalties for the TAS operator for too long waiting times for trucks arriving at their time window. Due to the existence of (mainly mandatory) TAS at terminals, trucking companies lose part of their flexibility to dispatch their orders to trucks and risk executing less orders per day. Other logistics nodes might have to deal with changes in truck arrival times, affecting their opening hours and capacities.

This paper focuses on drayage transports and on the handling at all relevant stakeholders. Seaside and train operations are excluded in this analysis. For an extensive overview on general container terminal operations and optimization potential, please be referred to e.g. Vis and De Koster (2003), Stahlbock and Voß (2007) and Carlo, Vis and Roodbergen (2014a; 2014b). This paper aims to analyze the effects of different drayage patterns on the efficiency of TAS. A drayage pattern is defined as the share of transport relations between different kinds of sources and drains. Sources and drains of drayage transports can generally be divided in two main groups: container terminals with TAS and other logistics nodes without TAS. The drayage pattern can vary in the amount of sources and drains belonging to either of these groups. In section 2, the current state of research concerning port drayage transports and TAS is presented. The simulation study is described in section 3. Finally, the simulation results and the conclusion and outlook will be given in sections 4 and 5.

## 2 State of Research

Drayage transports often result from transhipment containers being unloaded from a vessel at one container terminal and needing to be loaded on a vessel at

another terminal. The transport between the two container terminals is mainly done by truck or to a minor degree by barge or train. Other causes for drayage transports are the transport of empty containers to specialized depots for long time storage, repairs or cleaning and the delivery of empty container to freight stations to be loaded with goods from one or several clients and afterwards the transport to a container terminal for shipping, vice versa. A special case is the transport of full containers to customs stations for checking. In this case, there are always two transports necessary, one for the way to the station and one back.

Depending on the size and the structure of the port, a truck driver manages three to twelve drayage transports per day. Container terminals are often either source or drain. Therefore, a lot of the truck arrivals at container terminals are drayage transports. Due to this, long waiting times at terminals (or other logistics nodes) have a high impact on drayage transports and, thereby, on the drayage trucking companies. Still, the main motivation for the implementation of improvement methods or systems is to reduce the congestion in front of the gates and thereby to enhance the productivity of the terminal. In the past, several different approaches have been studied. Analyzed approaches are *inter alia*: specialized gate lanes (Gracia, González-Ramírez and Mar-Ortiz, 2016), promoting the use of off-peak shifts (Bentolila et al., 2016), informing about congestion by the use of webcams at the gate (Huynh et al., 2011) and implementing and improving a truck arrival management (*i.a.* Huynh and Walton, 2011; Guan and Liu, 2009).

The first TAS was implemented in 2002 in the ports of Los Angeles and Long Beach with the aim to decrease CO<sub>2</sub>-emissions in the port area. Due to the fact that different TAS were implemented at the different logistics nodes in the port area and that most of the systems were voluntary, there were high barriers for trucking companies and as a consequence a low participation in the different systems. (Giuliano and O'Brien, 2007) Since then, other ports, e.g. Vancouver, Sydney and Southampton, implemented a TAS successfully with the lessons learned from their predecessors. Furthermore, studies aiming at improving these systems have been conducted (*i.a.* Huynh, Smith and Harder, 2016; Davies and Kieran, 2015).

Another research focus is the reduction of congestion in the port by optimizing drayage operations. In addition, the productivity of drayage companies can be enhanced. Diverse research methods are used: for example, the operations of drayage companies are studied and different dispatching and routing algorithms are developed (Namboothiri and Erera, 2008; Jula et al., 2005). In addition, possible benefits of cooperation between trucking companies and companies in

the port are studied (Caballini, Sacone and Saeednia, 2016). Other, broader approaches include using supply chain management instruments (Ascencio et al., 2014), implementing a new traffic control system (Rajamanickam and Ramadurai, 2015) or dry docks with concepts like a chassis exchange system (Dekker et al., 2013). An extensive literature classification about TAS and drayage transports can be found in Lange et al. (2017).

The focus of many papers lies on container terminals and their productivity. Drayage trucking companies are studied as well, but less extensively. Other stakeholders, as empty container depots or freight stations, are nearly never analyzed (Lange et al., 2017). Furthermore, the proportion of transports between the different stakeholders, here called the drayage pattern, is mostly kept static. Therefore, its impact has not been analyzed so far. It can be expected to have a high effect on the productivity of drayage trucking companies as well as on the arrival times of trucks at the logistics nodes and therefore, also on their benefits and costs.

## 3 Simulation Study

In the following sections, the simulation study will be described. In the first subsection, the relevant constraints are highlighted and the necessary assumptions are presented. Afterwards, the structure of the simulation model is illustrated in detail. In the last subsection, the experimental design is explained.

### 3.1 Constraints and Assumptions

A discrete event simulation model is used to analyze the mentioned effects of drayage patterns on the success of TAS. The model is built using the simulation software Tecnomatix Plant Simulation version 13. The success of a TAS is influenced by the traffic in the ports and by the productivity of the logistics nodes. As only port drayage transports are analyzed, the model is limited to the port area. The traffic in the port area was determined with a distance matrix application programming interface provided by Google Maps. With this API, the average transport durations at different times of the day between all considered stakeholders were calculated and implemented in the simulation model. Therefore, it was not necessary to model all single streets as the transport duration combined with

stochastic elements can be taken out of a distance matrix. This led to much lower run times for the simulation experiments.

Furthermore, five types of stakeholders are considered: trucking companies, container terminals, empty container depots, freight stations and other relevant logistics nodes. For trucking companies, a depot is implemented, where the dispatching of the trucks is located and where the trucks start and end their shifts. Between tours, the trucks are not required to return to the depot, except when they can't be assigned to another order or during shift breaks. To simplify the model, a truck can load only one container and therefore has only one loading and one unloading address. The distance between the unloading address of one tour and the loading address of the next tour is called empty transport and should be minimized. All logistics nodes have specified opening and closing hours. The container terminals are open 24/7. Furthermore, the queuing times at the gate and the handling times vary stochastically depending on the time of the day and the related demand.

The analysis is based on data of the port of Hamburg, obtained by different stakeholders in the port area. Transport data was generated by analyzing the orders and their execution of a medium sized trucking company in the port of Hamburg. Additional information was given by container terminals and other logistics nodes. This information includes data about truck arrival rates at different times of the day and also about handling times. The port of Hamburg is the third largest container port in Europe and handled 8.82 million TEU in 2017. 36 % are transhipment containers, which enter and leave the port of Hamburg via ocean carrier. All other containers either arrive or leave via train, barge or truck. For this simulation model, the four big container terminals in the port of Hamburg, six empty container depots, six freight stations and five other logistics nodes have been considered.

### 3.2 Structure of the Simulation Model

The analysis is based on previous work displayed in Lange et al. (2018), which was refined to answer the stated research question. The simulation model is divided into two main parts: (1) booking time windows at container terminals for specific transport orders and (2) dispatching transport orders to the different trucks (see Figure 1).

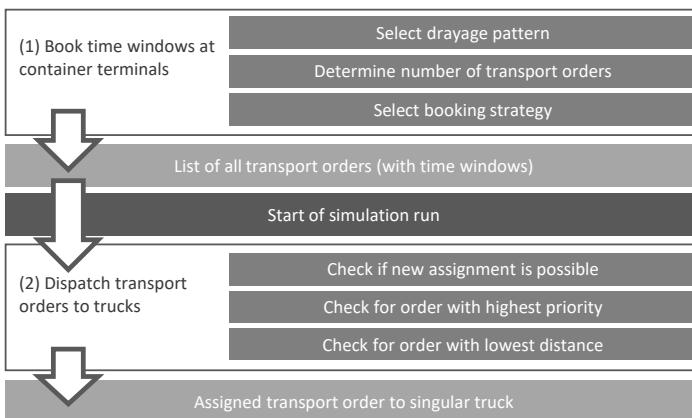


Figure 1: Structure of the simulation model

Before the start of a simulation run, the drayage pattern has to be selected to generate the order list. To do so, the user can decide about the share of transports between the different stakeholders. As there are different companies for every type of stakeholder, the defined shares are divided randomly on the corresponding companies. In the next step, the user has to decide about the amount of orders, which shall be generated in total for one day. Furthermore, the number of trucks, which is later imported by the simulation model, needs to be determined. The third important parameter is the booking strategy, defining for which orders a time window is booked with high priority. After selecting all these parameters, an order list, containing source and drain for every order, is generated. The specific time windows are added to this list in the next step.

Time windows are only required for loading or unloading of containers at container terminals. As a time window has the duration of one hour, there are 24 different time windows types per day. Container terminals are often operated 24/7. As a consequence, the time windows are assigned to three shifts (11 p.m. until 7 a.m., 7 a.m. until 3 p.m., 3 p.m. until 11 p.m.). There is the same capacity for all hours in one shift and therefore the same amount of potential time windows. It is assumed that the competitors of the considered trucking company book

their time windows in advance. Therefore, not all potential time windows are available to be booked. Furthermore, in the times with a higher demand, less time windows are available. The demand is calculated based on data of one container terminal in the port of Hamburg. For every booked time window, the free capacity is reduced. If no capacity is left, other times have to be selected. For the booking process, opening and/or closing hours of source and drain as well as already booked time windows for the source have to be considered. Furthermore, for every transport distance a triangular distribution based on Google Maps API data is considered. Only viable time windows are selected.

In part (2), the list with all transport orders and the required time windows is imported in the simulation model. In the simulation model, the dispatching of transport orders to trucks is done. If a truck has no order assigned, the order list is checked for the orders with the highest priority. Reasons for a high priority of orders are a soon expiring time window for this order or a soon closing source or drain. Furthermore, for orders with the same priority, the order with the lowest driving distance between the current location of the truck and the source of the order is selected. When the truck reaches the drain of the current transport and the container is unloaded, the next order is assigned to the truck. Exceptions are if a break is due for the driver or if no further order is viable at the moment. In these cases, the truck heads to the depot and stays there until the break is over or a new order is available.

### 3.3 Experimental Design

In the simulation model, the focus is on one trucking company. The size of this trucking company, especially the amount of transport orders and the number of trucks, is set to a medium level of 375 orders per day and 25 trucks. It is possible for a truck to manage up to 15 transport orders per day. In reality, trucking companies always aim at reducing the costs due to very low margins. Therefore, the minimal possible amount of trucks is often used. The same is done in this simulation model. With the 25 trucks used, every delay has a direct impact on the amount of successfully executed transport orders. The simulation horizon is one day. All orders that are not successfully executed at the end of the day are marked as failed and registered in the related statistics. All time windows are booked before the start of the simulation model. It is not possible to change a time window during the simulation run.

Six simulation experiments are considered. They vary in two criteria: the booking strategy and the drayage pattern. The booking strategy refers to the order in which time windows are booked for different transports. When the strategy is "Low Priority ITT", transports between container terminals with TAS, called inter terminal transports (ITT), have a lower priority than transports between a container terminal and the three other types of logistics nodes. Vice versa, if the booking strategy is "High Priority ITT", the transports between container terminals have a higher priority than all other transports. Furthermore, three different drayage patterns are examined. In the first drayage pattern, all transports are executed between container terminals. In the second, 50 % of all transports are ITT and all other transports are evenly distributed between all other relations. Lastly, in the third drayage pattern, no transports are executed between container terminals. All other transport relations have the same percentage. The overview of all experiments and their parameters is shown in Table 1.

Table 1: Plan of experiments (CT: Container terminal, ED: Empty container depot, FS: Container freight station,  
OL: other logistics nodes)

Exp.	Booking Strategy	CT-CT	CT-ED	CT-FS	CT-OL	ED-CT	FS-CT	OL-CT
1	Low Prio. ITT	100%	0%	0%	0%	0%	0%	0%
2	Low Prio. ITT	50%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
3	Low Prio. ITT	0%	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
4	High Prio. ITT	100%	0%	0%	0%	0%	0%	0%
5	High Prio. ITT	50%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
6	High Prio. ITT	0%	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%

## 4 Simulation Results

One of the main differences between the six experiments are the shares of the successfully executed transport orders (see Figure 2). A transport order is successfully executed if the source as well as the drain have been reached in the correct timeframe and the order has been handled correspondingly. Possible reasons and times of cancelations are shown in Figure 3.

Experiment 1 and 4 have the highest rate of successfully executed orders with nearly 100 %. Experiment 2 and 5 have a medium share of successful orders (70 to 90 %). The lowest success rate is visible for experiments 3 and 6 (less than 70 %). It is noticeable that experiments with the same drayage pattern result in similar success rates. In experiments 1 and 4, only transports between container terminals are considered while in experiments 3 and 6 only transports with one stop at a container terminal are relevant. Thereby, it can be concluded, that a higher share between container terminals leads to a lower rate of unsuccessful orders. This is most likely due to the limited opening hours of all other logistics nodes. Furthermore, it can be assumed that the booking strategy with a high priority on ITT has a slightly negative impact in comparison to the other booking strategy. This may be caused by the fact, that it favors transports with less restrictions and, therefore, leads to missing time windows for the non-ITT transports. This fact is analyzed in detail in Figure 3. There, the share of times when a transport order is canceled are shown. It is evident that experiment 3 and 6 have very high cancellation rates.

If an order is canceled before the start of the simulation run, it was not possible to book a time window for either source or drain fitting the requirements, especially the opening hours and the booked time window, of the other destination. Therefore, it is not possible to execute this specific order on the given day. A cancellation of an order before the start of the execution is due to an estimated late arrival of the truck at the source. Because it was assumed that the source will be either closed or the time window will be expired, the order was canceled before the beginning of its execution. A similar case is the cancellation of an order during the transport execution. Here, the truck arrived too late at the source or drain of its transport and, thereby, wasn't able to load or unload the container due to limited opening hours or a missed time window. If one order is not chosen by a truck for execution, it is canceled at the end of the simulation run. In this case the capacities of the trucking company are too low to execute all orders.

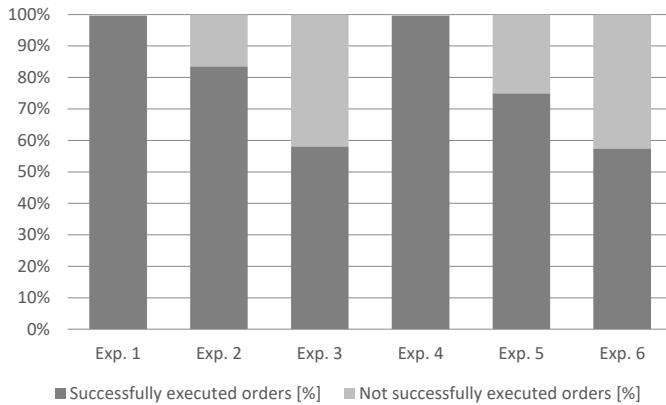


Figure 2: Successfully executed orders

The reasons for order cancelations in experiment 1 and 4 and in experiment 3 and 6 are quite similar. In experiment 1 and 4, some orders are canceled during the execution of the transport, because they arrived too late at the source or drain of the transport. No orders are canceled in the other two phases. As explained before, this is caused by the fact that all transports happen between container terminals, which are open 24 hours per day. Therefore, the transports can be evenly distributed over the day. The cancelations during a transport are similar for all other experiments. These cancelations are probably caused by transports happening at peak times. These transports face a lot of congestion in the port area and the variance of the transport duration is higher, causing truck delays and missed time windows. The source or drain of the transport has no or only a small impact on the delay. The high cancelation rates in experiment 2 and 5 and even higher rates in experiment 3 and 6 are also caused by a lower number of viable time windows fitting to the opening and closing hours of the logistics nodes. As some of the potential time slots are located in the off-peak hours at the morning and in the evening, it is harder for trucking companies to find a match if many of the transports need to happen in peak times. The difference in cancelation rates and times between experiment 2 and experiment 5 result from

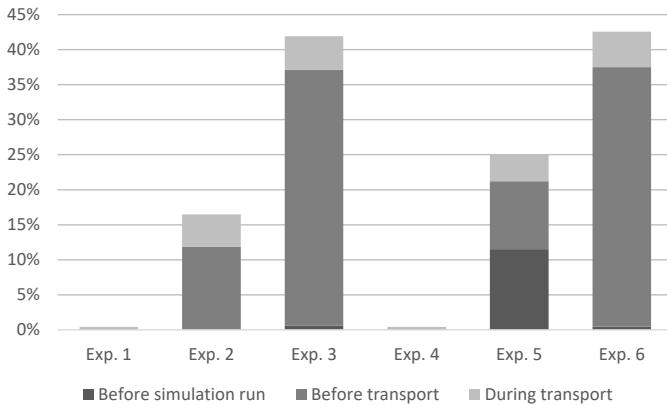


Figure 3: Times of transport order cancelations

the different booking strategies. In experiment 2, the non-ITT transports have a higher priority. Therefore, they are booked on the limited time windows at peak times. In experiment 5, these time windows with a high demand are given to the ITT orders. Thereby, less time windows in peak times are available for the non-ITT orders, which mostly cannot be executed in off-peak times. This leads to a higher number of cancelations before the start of the simulation run in experiment 5. To gain further insight, the times of booked time windows in experiment 1, 2 and 3 are shown in Figure 4 and the ones of experiment 4, 5 and 6 in Figure 5.

Figure 4 and Figure 5 show the amount of time windows booked during different phases of the day. One phase has a length of 4 hours. The amount of time windows is differentiated by the type of transport (ITT and non-ITT) and if the time window is booked for the source or the drain of the transport.

It is noticeable, that the booked time windows for experiment 1 and 4 are, as expected, distributed among all phases of the day. Furthermore, many transports happen during off-peak times due to the higher amount of bookable time windows. For experiment 3 and 6, nearly all booked time windows are located in the daytime hours. Again, this is consistent with the results shown in the figures

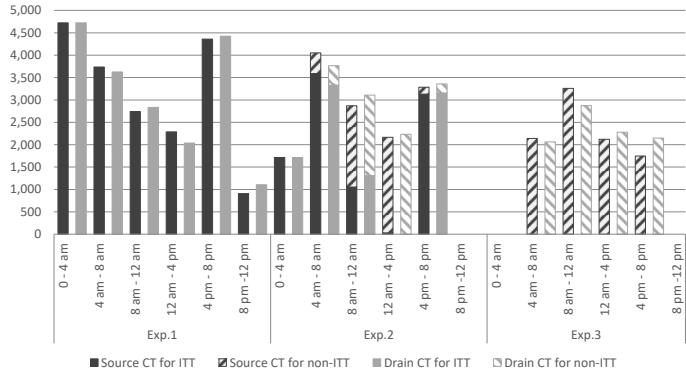


Figure 4: Booked time windows for experiments 1 to 3

above. As all transports in these experiments are non-ITT, the opening hours of the other logistics nodes limit the viable time windows at the container terminals. On the one hand, the delivery time of containers at container terminals depends on the opening time of the source. On the other hand, the pick-up of a container at a container terminal needs to happen before the closing hour of the drain. Furthermore, long waiting times for the trucks between picking up and delivering a container are discouraged in the model as well as in reality. In experiment 2, most ITT time windows are situated in the off-peak hours. The non-ITT orders have booked time windows in the peak times. This is vice versa for experiment 5.

In conclusion, the booking strategy of possible time windows has a high impact on trucking companies if they execute ITT orders as well as non-ITT orders. In this case, it is recommended to prioritize transports with higher constraints, in this case the transports to logistics nodes with limited opening hours.

The effect of the different strategies and drayage patterns can be seen as well in the working times and driven distances of the trucks. In Figure 6 the different states per truck per day are shown. The states are differentiated between driving, handling at logistics nodes, idle due to break and idle due to no available order. Due to the limited amount of trucks, the time spent idle due to missing executable orders is low especially for experiment 1 and 4. As more orders are canceled

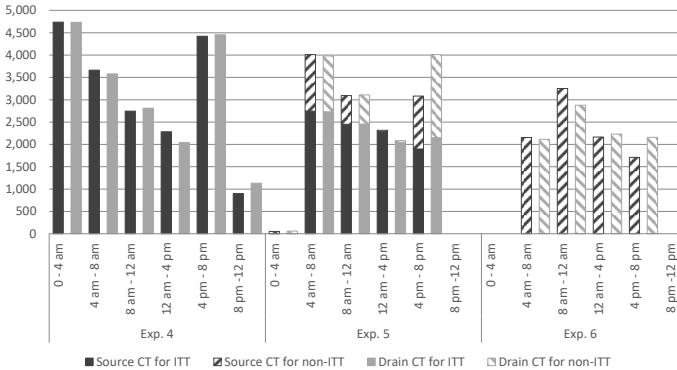


Figure 5: Booked time windows for experiments 4 to 6

early on, there is a higher share of idle time in experiments 2 and 5 and an even higher share of idle time in experiments 3 and 6. The driving time fits in inverse proportion.

In Figure 7, the driven distances per truck and day for every experiment are shown. The more transport orders a truck driver has to handle, the longer are the driven distances. As a truck driver executes more transports in experiment 1 and 4 than in the other experiments, the results also show higher driven distances. Nevertheless, the differences between the experiments are not as high as the differences shown before. This is caused by the fact that for experiment 1 and 4 there are more possible transport orders for the trucks. Therefore, a better fit, with less waiting time and/or empty travel distance can be selected. Furthermore, the container terminals in the port of Hamburg are situated in close proximity, whereas some other logistics nodes are located further away. This leads to longer driven distances especially in experiment 3 and 6.

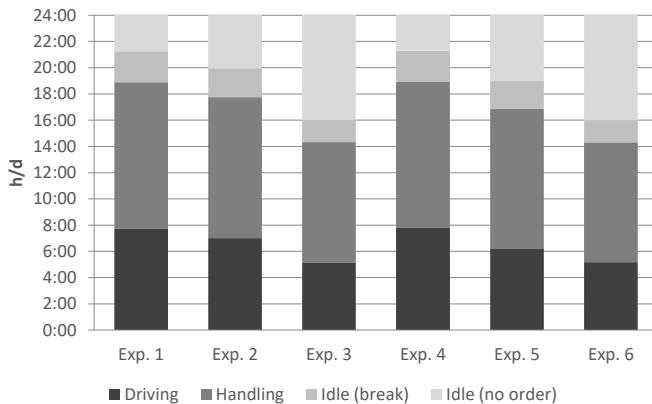


Figure 6: Truck states per day

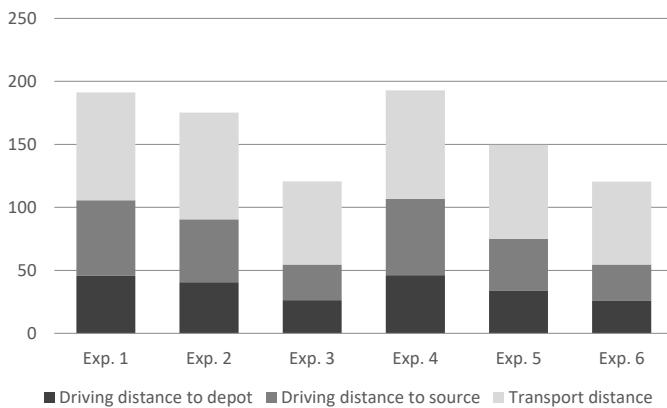


Figure 7: Driven distances per truck and day

## 5 Conclusion and Outlook

The focus of this study was to evaluate the impact of different drayage patterns and booking strategies of time windows on the productivity of a TAS at container terminals and on related stakeholders in the port. The analysis was conducted using a discrete event simulation model and data provided by different stakeholders in the port of Hamburg. The stakeholders were divided into container terminals and other logistics nodes. Transports between container terminals are called ITT. The results showed that the impact of the booking strategy of time windows is higher, when the drayage pattern is mixed between ITT and non-ITT orders. In the case of limited time windows during the opening hours of the logistics nodes in the port, the booking strategy should favor non-ITT transports to mitigate bottlenecks in the peak hours. Furthermore, the limited opening hours of some logistics nodes pose the biggest challenge for a successful implementation and use of a TAS. A possible strategy is to transfer many of the ITT orders in the off-peak hours to ensure enough capacity for the non-ITT orders during daytime.

This analysis is limited to a fixed number of free time windows per day, not flexibly considering the size of the trucking company or the amount of competitors. Furthermore, the time windows are booked before the dispatching process. In reality, these two parts are interwoven. In addition, trucking companies might be allowed to switch or cancel time windows. Due to these reasons, some flexibility is lost in the model, which might cause in a lower productivity.

In future research, the impact of the TAS on other logistics nodes, e.g. on the arrival rates of trucks or the required personnel, should be analyzed. Furthermore, different drayage company sizes could be studied in detail. It can be expected that larger trucking companies have advantages in the dispatching process due to a higher amount of possible orders and time windows and, therefore, due to a higher optimization potential. Furthermore, the booking and dispatching should be done simultaneously.

## References

- Ascencio, L. M., R. G. González-Ramírez, L. A. Bearzotti, N. R. Smith, and J. F. Camacho-Vallejo (2014). "A Collaborative Supply Chain Management System for a Maritime Port Logistics Chain". In: *Journal of Applied Research and Technology* 12 (3), pp. 444–458.

- Bentolila, D. J., R. K. Ziedenveber, Y. Hayuth, and T. Notteboom (2016). "Off-peak truck deliveries at container terminals: the ?Good Night? program in Israel". In: *Maritime Business Review* 1 (1), pp. 2–20.
- Brinkmann, B. (2011). "Operations Systems of Container Terminals: A Compendious Overview". In: *Handbook of Terminal Planning*. Ed. by J. W. Böse. Operations Research/Computer Science Interfaces Series. New York, NY: Springer New York, pp. 25–40.
- Caballini, C., S. Sacone, and M. Saeednia (2016). "Cooperation among truck carriers in seaport containerized transportation". In: *Transportation Research Part E: Logistics and Transportation Review* 93, pp. 38–56.
- Carlo, H. J., I. F. A. Vis, and K. J. Roodbergen (2014a). "Storage yard operations in container terminals: Literature overview, trends, and research directions". In: *European Journal of Operational Research* 235 (2), pp. 412–430.
- Carlo, H. J., I. F. A. Vis, and K. J. Roodbergen (2014b). "Transport operations in container terminals: Literature overview, trends, research directions and classification scheme". In: *European Journal of Operational Research* 236 (1), pp. 1–13.
- Davies, P. and M. E. Kieran (Oct. 23, 2015). *Port Congestion and Drayage Efficiency*. Paper presented at the METRANS International Urban Freight Conference. In collab. with Metrans Transportation Center. Long Beach, USA.
- Dekker, R., S. van der Heide, E. van Asperen, and P. Ypsilantis (2013). "A chassis exchange terminal to reduce truck congestion at container terminals". In: *Flexible Services and Manufacturing Journal* 25 (4), pp. 528–542.
- Giuliano, G. and T. O'Brien (2007). "Reducing port-related truck emissions. The terminal gate appointment system at the Ports of Los Angeles and Long Beach". In: *Transportation Research Part D: Transport and Environment* 12 (7), pp. 460–473.
- Gracia, M. D., R. G. González-Ramírez, and J. Mar-Ortiz (2016). "The impact of lanes segmentation and booking levels on a container terminal gate congestion". In: *Flexible Services and Manufacturing Journal* 244 (3), p. 675.
- Guan, C. and R. Liu (2009). "Container terminal gate appointment system optimization". In: *Maritime Economics & Logistics* 11 (4), pp. 378–398.
- Harrison, R., N. Nutson, J. West, and J. Wilke (2007). "Characteristics of Drayage Operations at the Port of Houston, Texas". In: *Transportation Research Record: Journal of the Transportation Research Board* 2033, pp. 31–37.
- Hartmann, S. (2004). "Generating scenarios for simulation and optimization of container terminal logistics". In: *OR Spectrum* 26 (2), pp. 171–192.
- Huynh, N., F. Harder, D. Smith, O. Sharif, and Q. Pham (2011). "Truck Delays at Seaports". In: *Transportation Research Record: Journal of the Transportation Research Board* 2222, pp. 54–62.
- Huynh, N., D. Smith, and F. Harder (2016). "Truck Appointment Systems". In: *Transportation Research Record: Journal of the Transportation Research Board* 2548, pp. 1–9.
- Huynh, N. and C. M. Walton (2011). "Improving Efficiency of Drayage Operations at Seaport Container Terminals Through the Use of an Appointment System". In: *Handbook of Terminal Planning*. Ed. by J. W. Böse. Vol. 49. Operations Research/Computer Science Interfaces Series. New York, NY: Springer New York, pp. 323–344.
- Jula, H., M. Dessouky, P. Ioannou, and A. Chassiakos (2005). "Container movement by trucks in metropolitan networks. Modeling and optimization". In: *Transportation Research Part E: Logistics and Transportation Review* 41 (3), pp. 235–259.

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## REFERENCES

- Lange, A.-K., F. Branding, T. Schwenzow, C. Zlotos, A. K. Schwientek, and C. Jahn (2018). "Dispatching Strategies of Drayage Trucks at Seaport Container Terminals with Truck Appointment System". In: *Dynamics in Logistics. Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany*. Ed. by M. Freitag, H. Kotzab, and J. Pannek. Lecture Notes in Logistics. Cham: Springer International Publishing, pp. 162–166.
- Lange, A.-K., A. Schwientek, and C. Jahn (2017). "Reducing truck congestion at ports – classification and trends". en. In: *Digitalization in maritime and sustainable logistics. City logistics, port logistics and sustainable supply chain management in the digital age*. Ed. by C. Jahn, W. Kersten, and C. M. Ringle. Ed. by TUHH Universitätsbibliothek. TUHH Universitätsbibliothek. epubli, pp. 37–58.
- Namboothiri, R. and A. L. Erera (2008). "Planning local container drayage operations given a port access appointment system". In: *Transportation Research Part E: Logistics and Transportation Review* 44 (2), pp. 185–202.
- Port of Hamburg (2018). *Port of Hamburg Press Conference 2018*.
- Rajamanickam, G. D. and G. Ramadurai (n.d.). "Simulation of truck congestion in Chennai port". In: *2015 Winter Simulation Conference (WSC)*. (Huntington Beach, CA, USA), pp. 1904–1915.
- Shiri, S. and N. Huynh (2016). "Optimization of drayage operations with time-window constraints". In: *International Journal of Production Economics* 176, pp. 7–20.
- Stahlbock, R. and S. Voß (2007). "Operations research at container terminals: a literature update". In: *OR Spectrum* 30 (1), pp. 1–52.
- Steenken, D., S. Voß, and R. Stahlbock (2004). "Container terminal operation and operations research - a classification and literature review". In: *OR Spectrum* 26 (1), pp. 3–49.
- UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (2017). *Review of maritime transport 2017*. New York and Geneva: UNITED NATIONS. xiii, 114.
- Vis, I. F. A., de Koster, René B. M., and M. W. P. Savelsbergh (2005). "Minimum Vehicle Fleet Size Under Time-Window Constraints at a Container Terminal". In: *Transportation Science* 39 (2), pp. 249–260.



# Exploring congestion impact beyond the bulk cargo terminal gate

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*Bulk cargo terminal congestion management approaches have tended to be almost exclusively focused on the sea side of bulk terminals. To-date there has been very limited work on land-side approaches to mitigate congestion in bulk terminals. This research aims to address these gaps by considering the effectiveness of multiple congestion management methods across a range of throughput scenarios. This paper develops a discrete event simulation model based on data collected from an Australian bulk wood chip export maritime terminal and analyses the effect of infrastructure and process improvements on gate congestion and hinterland logistics chains. The improvements include: variations of terminal configurations, a terminal appointment system and gate automation technology. This paper argues that traditional efficiency and utilization measures fail to capture the impact of these alternatives over the whole hinterland logistics chain. Results indicate that the gate automation technology and the introduction of an appointment system can reduce average turnaround times by approximately 20%. Interestingly additional unloading capacity has a relatively small influence (<10%) on the average turnaround time under the initial truck arrival frequency. Significantly, findings highlight how the range of alternatives that improve efficiency and utilization can be impaired when organizations do not plan and negotiate impacts with other terminal users along the hinterland logistics chain. The impact of these alternatives needs to be evaluated in the broader hinterland perspective to enhance stakeholder 'buy-in' and resilience over time of solutions implemented.*

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**Keywords:** maritime logistics; truck appointment system; coordination; marine bulk terminal

## 1 Introduction

Research on bulk cargo terminals congestion management has tended to be limited to approaches that improve sea-side and yard capacity to minimize vessel delays and associated costs. On the land-side, there is an inherent logic, from a terminal perspective, that a certain level of congestion is beneficial to maintaining a high level of equipment efficiency and utilization. Terminals may therefore have little incentive to address congestion, particularly when no financial penalties are applied for exceeding turnaround time thresholds. Counterintuitively, congestion can reach levels where it creates difficulties for terminals to evaluate strategic development options and, more prosaically, to plan maintenance works. From a terminal user and hinterland logistics chain perspective, the impact of congestion and mitigation methods is also typically neglected.

In this context, this research introduces a discrete event simulation model based on a case study of a bulk maritime terminal in Australia and investigates the effect of multiple approaches on mitigating congestion and the terminal and the hinterland logistics chains. Previously, the potential impact of a terminal appointment system and automation technology under existing throughput conditions was explored (Neagoe et al., 2018). This paper extends the investigation with updated data, additional development options and an evaluation of hinterland logistics impact and approaches' robustness under increased throughput conditions.

### 1.1 Case Description

The bulk cargo terminal on which the case study is based operates in a medium sized Australian port and is open 24-hours per day. The terminal is an export facility for wood chips, a processed timber product. Wood chips are the raw material input in paper production or used as biofuel.

The terminal receives deliveries of wood chips regularly from three processing facilities located at various distances from the terminal. Logs from the forest harvesting sites are delivered to the three facilities. The logs are processed into wood chips at the mills and then stockpiled. Dedicated trucks are loaded with

wood chips from the milling site and then drive to the terminal in a cyclical delivery operation. Approximately 60% of trucks have an average delivery cycle (excluding the terminal unloading) of 40 minutes, 35% drive and load in approximately 90 minutes and the rest of 5% drive and load in 300 minutes. Trucks operate in 12 hour shifts during which they try to maximize the number of deliveries to the terminal. The relatively close proximity between the processing mills and the terminal means significant changes in the terminal turnaround time can impact on the efficiency and utilization of the transporters' equipment and the chain as a whole.

Two types of wood chips are delivered to the terminal. These are stored in separate stockpiles and cannot be mixed. Wood chips are delivered to the terminal and stockpiled, until sufficient volumes are available to fill a wood chip vessel bound for export markets. On average, between 1,500 and 2,000 truck loads are required to reach the volume capacity of a vessel.

The terminal unloading process starts at the weighbridge where the trucks are weighed. Drivers are then directed to the wharf area where they wait until an unloading ramp is available. Two unloading ramps operate at the terminal. Wood chips are unloaded from truck trailers using hydraulic ramps that lift the entire body of the truck, forcing the product out the trailer doors. Concurrent unloading can take place if the bin in which product is unloaded has sufficient space available, and if two trucks carry the same product. A conveyor belt system connected to both unloading ramps moves the product from the bin to the stockpile. Once unloading is finished, drivers weigh their trucks once more at the weigh-bridge. The difference between the first gross-weight reading and the second empty-weight reading is the net weight of the product delivered. The time between weight readings is the truck turnaround time. Upon completing unloading, trucks return to the milling facilities and, the delivery cycle is restarted.

On average, trucks arrive at the terminal every 10 minutes. Figure 1 shows the observed arrival distribution of trucks. The distribution is right-skewed. Approximately 60% of arrivals are less than 10 minutes apart and more than 30% are less than 5 minutes apart. Although the average terminal turnaround time of trucks is approximately 22 minutes per truck, 40% of the turnaround times are larger than the average and can reach 120 minutes in some cases. The clustering of truck arrivals at the terminal therefore introduces significant inefficiencies in the system, although the terminal enjoys a relatively good capacity utilization. Partly due to irregular and clustered arrivals, the terminal is currently experiencing severe congestion at the gate and unloading facilities.

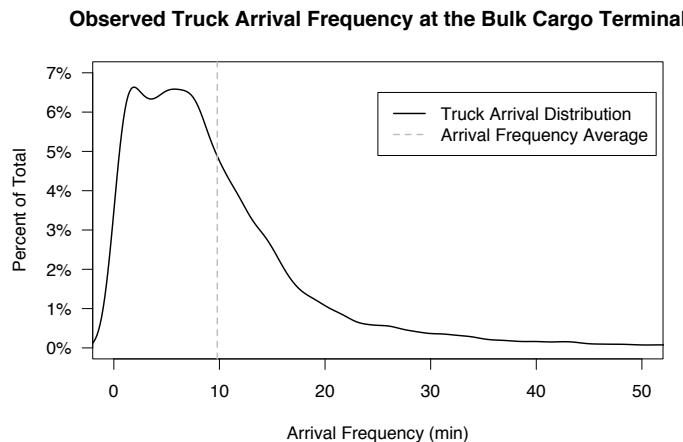


Figure 1: Observed truck arrival frequency at the bulk cargo terminal

## 2 Literature Review

Research on bulk terminal gate congestion applications is relatively limited. Considerably more effort has gone in research on congestion management in container terminals. Bulk cargo terminals modelling literature, together with modelling and applications of congestion management techniques in marine container terminals are briefly reviewed below.

### 2.1 Bulk Cargo Maritime Terminals

Dry bulk terminals can be split into two categories: export and import terminals (van Vianen, Ottjes and Lodewijks, 2014) and generally serve only one of the two functions. Much of the dry bulk terminal research reviewed focused on commodities such as: coal (Wadhwa, 1992, 2000), iron (Van Vianen et al., 2012; Bugaric and Petrovic, 2007; Bugaric, Petrovic and Jeli, 2015) or bauxite (Cimpeanu

et al., 2015; Cimpeanu, Devine and O'Brien, 2017). The main issues explored in the dry bulk terminal literature reviewed are regarding vessel handling and yard capacity of the terminals (Cimpeanu, Devine and O'Brien, 2017; Dahal et al., 2003; Bugarić and Petrović, 2007).

Bugarić and Petrović (2007) investigate the effect of vessel unloading mechanization at an iron and coal river terminal. Their results, obtained using a discrete time simulation model, indicate that this approach can improve unloading times and therefore reduce the penalties associated to vessel waiting times (demurrage). Wadhwa (2000) investigate deploying additional vessel loaders at a bulk export facility to improve the vessel handling capacity of the terminal. Findings from the discrete event simulation model indicate that an additional vessel loader can increase the terminal's capacity by more than 20%. The deployment of an additional loader is motivated by vessel loading time requirements and penalties associated with waiting times. Financial penalties are one of the most frequently mentioned reasons for optimizing and improving the loading or unloading process at terminals.

Timber products, such as logs or wood chips, can also be transported in bulk. Munisamy (2010) analyzed the capacity of a timber products export terminal in Malaysia and found that balancing the available equipment capacity in each stage of the loading process at the terminal is crucial to maintaining a consistent throughput and utilization. Their research focuses on yard management and vessel loading processes and made little mention of the terminal gate and product deliveries. The authors were unable to identify research centered on wood chip export terminals from a logistics perspective.

Throughput capacity increases on the sea side are not always met with a similar approach on the land side. Several reasons can be identified: (1) export dry bulk terminals are commonly supplied by train (van Vianen, Ottjes and Lodewijks, 2011); (2) import terminals are typically closely located to production facilities (such as steel mills) or power plants and provide continuous supply of raw materials via conveyor belts; (3) some authors hypothesize that terminal gate operations, although important, are simpler to handle logically and cost-wise as long as the main performance indicator, vessel waiting time, is satisfactory (Bassan, 2007).

This paper however argues that the land-side interface is just as important as the sea side. The incoming throughput of a terminal equals the outgoing volumes. Therefore, one of the main factors determining a terminal's throughput is the lowest common denominator between the terminal gate, berth and storage capacity.

Furthermore, the task of coordinating multiple stakeholders with multiple, often diverging interests, is similarly complex on the land as on the sea side.

A limited number of papers deal with terminal gate congestion in the context of bulk terminals and particularly for wood chips. The container terminal literature is significantly richer and identifies and evaluates a number of approaches to mitigate terminal gate congestion. As both containerized and bulk transportation share a number of similarities (Bugarić, Petrović and Jelić, 2015), the insights gained in containerized terminals are of relevance in the context of bulk goods.

## 2.2 Terminal Gate Congestion Management

Terminal gate congestion mitigation approaches can be distinguish on two planning and control levels. On the strategic level, capacity can be increased over time. On the tactical and operational levels, gate operating hours can be extended and terminal appointment systems (TAS) can be introduced (Maguire et al., 2010). Additional alternatives that can facilitate and support the introduction of congestion management tools include gate automation technologies via Optical Character Recognition (OCR) or Radio-Frequency Identification (RFID) systems (Heilig and Voß, 2017) and congestion pricing.

Extended gate working hours increase the number of available delivery times for trucks (Giuliano and O'Brien, 2007) and can help smooth truck arrival peaks. TAS define delivery or pick-up slots for transporters and aim to manage arrival patterns of trucks. This approach requires limited capital and human resources expenses and has the potential to improve terminal and gate operations, decrease roadway congestion and reduce green-house gasses emissions (Maguire et al., 2010). Congestion pricing introduces incentives for delivering at less busy times (Bentolila et al., 2016) or disincentives for deliveries during peak hours (Holguín-Veras et al., 2011) in an attempt to shift traffic patterns. Gate automation technologies can be used in combination with other congestion relief methods to reduce manual input from drivers and enhance terminal security.

A common feature of the literature surveyed is that the perspective of the terminal is frequently taken when reporting results, whereas the impact of the method on transporters or the logistics chain is often disregarded (Huynh, Smith and Harder, 2016). Huynh (2009) use discrete event simulation to investigate the impact of different scheduling rules of TAS and maximize the utilization of unloading equipment in the terminal. Their results indicate that an individual appointment

system leads to lower equipment utilization and a reduction truck turnaround times. Similarly, the impact of variations of TAS rules on yard efficiency are evaluated by Zhao & Goodchild (2013) using simulation and queuing theory. Their findings indicate that system performance can be significantly improved even with imperfect information on truck arrival times. This finding is supported by Chen, Govindan and Golias (2013). The authors use a queuing model to optimize truck waiting times and find a reduction of approximately 50% in congestion when arrivals during peak times are spread (Chen, Govindan and Golias, 2013). Huynh & Walton (2008) and Ambrosino and Caballini (2015) use simulation to reduce yard congestion in order to meet service level requirements of trucks. This means however that the waiting times of trucks outside the terminal gates are not considered. Terminals actively sought to reduce vessel waiting time prior to loading or unloading to avoid penalties. For trucks, waiting times outside terminal gates are often times disregarded. While outside the terminal, trucks are on the public domain and their waiting time may not be as easily quantified. Furthermore, the unique inter-organisational relation between terminals and drayage companies where, often times, no contractual arrangement exists between the two parties (Jaffee, 2016), can lead to a lack of focus on the efficiency of the overall land transport task and terminal interface cost.

One attempt of combining the perspectives of terminals and transporters was taken by Guan and Liu (2009). Terminal operations were represented by a queuing model and an optimization model was used to minimize the truck waiting and gate operating costs. The optimal arrival pattern produced 35% less congestion than the initial situation. The largest cost reduction resulted from a decrease in truck waiting times. Zehendner and Feillet (2014) modelled a TAS and included delay costs for trucks, trains and barges in their optimization model of a container terminal. Their results indicate an average reduction of approximately 14 minutes in the optimal solution. One disadvantage of pooling terminal and truck costs together into one cost measure is that the optimization model solution may be sensitive to variations in cost ratios. In their study, Guan and Liu (2009) used an hourly gate-truck operating cost ratio of approximately 4 to 1. If a broader perspective on supply chain costs is taken, the ratio is likely to decrease.

One explanation for the strong preference for TAS in the research literature is that this approach is "less disruptive and less costly than extended gate hours" (Giuliano and O'Brien, 2007). However, this argument fails to account for the decreased flexibility for truck operators and the impact on their fleet productivity and utilization (Ramírez-Nafarrate et al., 2017). It also further highlights the terminal-centric approach to managing gate congestion. Noticeably, studies

evaluating variations of appointment systems or congestion pricing, few if any, have compared the impact of different congestion mitigation techniques. Spreading arrivals at terminals helps reduce delays, however scenarios and benefits of mechanisms to tackle congestion that affect multiple port users do need to be analysed prior to implementation (Ramírez-Nafarrate et al., 2017).

### 3 Bulk Cargo Terminal Simulation Model

Simulation is one of the most frequently used modelling techniques, along with queuing and optimization models, for investigating congestion management. Simulation can be an effective tool to understand the impact of a limited number of variables on the system modelled (Manuj, Mentzer and Bowers, 2009) and allow researchers to develop and analyse "what-if" scenarios (Crainic, Perboli and Rosano, 2017). This research utilizes a discrete event simulation approach to model a bulk terminal gate and the implementation of congestion management measures adapted from container terminal literature. The measures impact on the terminal and the logistics chain is evaluated, as well as their performance when the terminal throughput increases.

#### 3.1 Model Specification

The model's **input data** originates from two sources: the weigh-bridge software generates reports containing truck arrival and departure times, gross and net weight readings and products delivered. A sample containing 9 months of truck arrivals was used for this model. The duration of each stage of the unloading process (weighing, unloading, drive times and final weighing) was determined by geo-fencing the location of each stage and measuring the visit duration. This was achieved using GPS data from one trucking company. The GPS information covering approximately 15,000 truck trips spread over 3 months were analysed.

The simulation model is based on the following **assumptions**: (1) Two products are delivered concomitantly at the terminal and cannot be mixed during unloading or during storage; (2) Two types of trucks deliver product at the terminal; (3) The terminal operates non-stop during the simulation, no breakdowns or terminal closures are modelled; (4) Two unloading ramps with the same capacity operate at

the terminal; (5) Truck turnaround times are measured from weigh-bridge (gross-weight reading) to weigh-bridge (empty-weight reading); (6) The weighing-in stage is the entrance of the truck in the system therefore, the weighing-in duration and queuing time are excluded from the turnaround time calculation. The simulation **model logic** follows the unloading process described in the introduction and is detailed in Figure 2.

The model was implemented in Python. Arena Input Analyzer was used to fit the input data to distributions. The distributions that best fit the empirical data were used as the **model's parameters**: (1) One truck type can load maximum 32-tons of product and the payload distribution is described by a +19 shifted beta distribution with parameters  $\alpha = 9.77$ ,  $\beta = 6.55$ ; (2) The second truck type can load a maximum of 45 tons and its payload distribution is described by a normal distribution with parameters  $\mu = 38.7$ ,  $\sigma = 1.18$ ; (3) The inter-arrival time is described by a gamma distribution with parameters  $k = 1.49$ ,  $\theta = 6.97$ ; (4) Unloading the same product at two different ramps can take place if one ramp has completed more than 60% of its unloading cycle before the other begins. A different product can be unloaded if one ramp has completed more than 80% of its unloading cycle before the other begins; (5) The unloading times are described by a lognormal distribution with  $\mu = 5.16$ ,  $\sigma = 3.97$ ; (6) The driving time between the weigh-bridge and the unloading ramps is held constant at 1 minute on arrival and 2 minutes on departure; (7) The weigh-bridge operation time is described by a normal distribution with parameters  $\mu = 3.46$ ,  $\sigma = 1.68$ ;

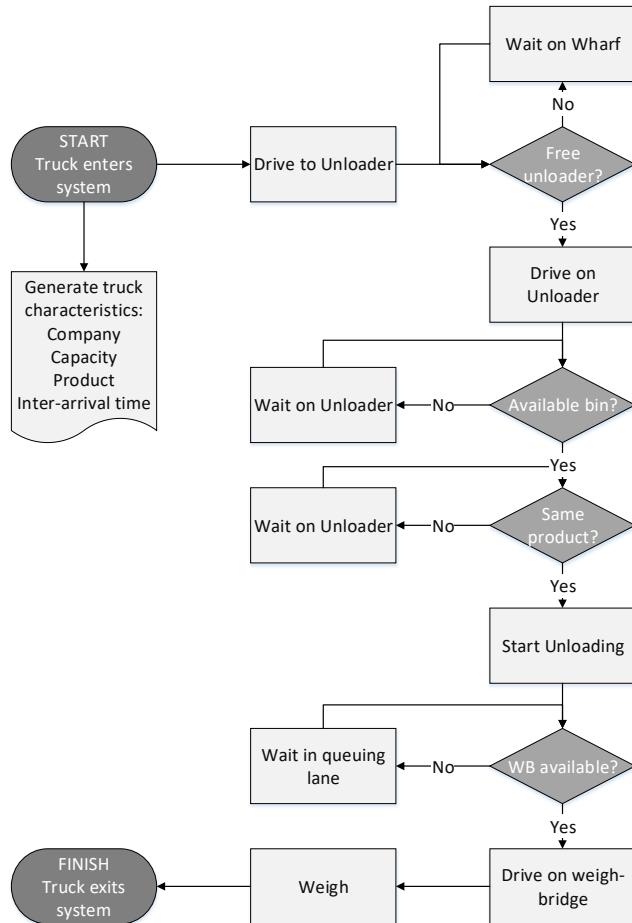


Figure 2: Terminal simulation model logic

## 3.2 Simulation Results

Four congestion management methods were explored under four truck arrival frequency scenarios. The starting arrival frequency was a gamma distribution with parameters  $k = 1.49$ ,  $\theta = 6.97$  with an average of one truck arrival every 10 minutes. Subsequent scenarios applied decreasing multipliers: 0.9, 0.8 and 0.7 respectively to simulate increased traffic under the same distribution. The terminal appointment system (TAS) included slot intervals equal to the average arrival frequency of trucks for other methods (10 minutes in the base case). Slot intervals were scaled down as traffic increased. The congestion management methods considered include two tactical approaches and two strategic level capacity improvements:

**Terminal appointment system (TAS).** Trucks currently arrive unscheduled at the terminal. Arrivals can be more evenly distributed using individual slot appointments for each truck. Trucks are scheduled to arrive at regular intervals and, should arrive between the last arrival and the next slot. A stochastic component drawn from a normal distribution with  $\mu = 0$ ,  $\sigma = 2.5$  modelled delays or early arrivals of truckers compared to their scheduled arrival time.

**Gate automation technologies** simulate the reduction of weighing processing times. Currently all trucks delivering at the terminal are weighed after delivery to calculate the net weight of the payload. The automation technology eliminates this stage by using digitally stored truck tare weights.

**Extend the unloading system** with an additional ramp with the same characteristics as existing unloading equipment is added to the existing conveyor belt system.

**Expand the unloading system** with a separate unloading ramp and conveyor system for one stockpile. This separates the two products flows and eliminates the risk of product contamination. It also substantially increases the system capacity, as unloading can now take place concomitantly irrespective of the products delivered.

For comparison purposes, the alternative of **not intervening** with a congestion management approach is also presented.

Each arrival frequency scenario and congestion management approach combination is simulated 1,000 times. The values presented are the averages over the iterations. Each iteration represents 365 days of operations.

Table 1: Simulation model outputs for 10-minute average arrival frequency scenario

Model Output	TAS	Automation Tech.	Expand Unload System	Extend Unload System	No Intervention
T. Time (min)*	17.47	18.00	20.22	21.78	22.12
W. Time (min)**	1.59	5.68	4.49	5.99	6.31
Throughput(t)	1,604,131	1,598,892	1,599,670	1,599,782	1,599,389
Trucks	52,559	52,389	52,415	52,414	52,402

\*T. Time = turnaround time, \*\*W. Time = waiting time

Table 1 illustrates the simulation model results for **the first scenario** which simulates a 10-minute average truck arrival frequency. Two methods stand out as particularly effective, the automation technology and the TAS. Both can reduce average turnaround times by approximately 20% (from 22 to 18 minutes) compared to no intervention. While the reduction in turnaround times is similar, the ways the two methods achieve this reduction are different. The automation technology reduces operational time, while the TAS substantially reduces the truck waiting time. Additional unloading capacity has a relatively small influence, less than 10% reduction of the turnaround time.

Figure 3 illustrates that, while differences in averages may not be substantial, the turnaround time distributions are significantly different. The reduction in average turnaround times with the TAS and the expanded unloading system is caused by a reduction in variance. The automation technology reduces operational times and therefore shifts the turnaround time distribution to the left, leaving its structure intact. The extended unloading system is excluded from Figure 3 because it substantially overlaps with the no intervention case.

**Subsequent arrival frequency scenarios** included average arrival frequency times of 9, 8 and 7 minutes. To conserve space, only the 7-minute case is pre-

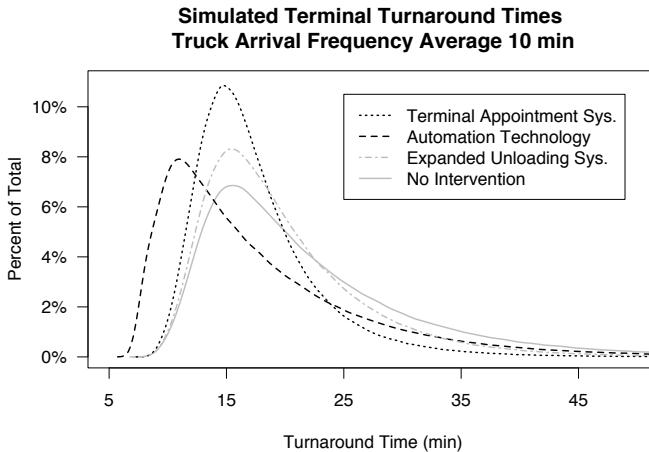


Figure 3: Simulation model turnaround times distribution for 10-minute average arrival frequency scenario

sented in table 2. The no intervention and automation technology approaches evolve in a similar manner. The 4-minute difference in turnaround time is maintained, however waiting times remain very similar. Until a throughput of 2 million tons is reached, the unloading system expansion also follows a similar trend in terms of turnaround times, showing little impact on turnaround times. At a 2.3-million-ton yearly throughput, waiting times increase dramatically. Likely, capacity utilization reaches a level where additional trucks can destabilize the system and increase waiting times dramatically. At the same time, both the TAS and the expanded unloading systems are more robust to changes in throughput. In the 7-minute average arrival frequency scenario, both methods are 65% more effective on average than the no intervention case.

Figure 4 shows a similar pattern of distribution variance reduction for the TAS and the expanded unloading system as in previous examples. In contrast, the automation technology and extended unloading system maintain the shape of the turnaround times distribution while shifting its peak. Clearly, increased vol-

Table 2: Simulation model outputs for 7-minute average arrival frequency scenario

Model Output	TAS	Automation Tech.	Expand Unload System	Extend Unload System	No Intervention
T. Time (min)	30.12	78.51	26.26	62.62	83.52
W. Time (min)	14.41	66.22	10.73	46.94	67.83
Throughput(t)	2,291,889	2,311,094	2,312,181	2,312,982	2,311,706
Trucks	75,082	75,722	75,756	75,787	75,731

umes put a strain on the terminal, however, the effectiveness of the approaches modelled in reducing average turnaround times differs significantly.

An evaluation of the impact of congestion management approaches on terminal users and the logistics chain is a more complex task. If the average delivery cycles and average terminal turnaround times are considered, the truck productivity decreases by almost 45% in the no intervention approach between the 10 and 7 minutes arrival frequency scenarios. In the 10-minute arrival frequency scenario, the TAS and automation technology approaches could improve truck productivity by up to 15% compared with no intervention. In the 7-minute arrival frequency scenario, the TAS and expanded unloading system could improve productivity by up to 40% compared with no intervention. However, average values do not provide an accurate picture of the actual impact on the users, as they fail to account for the variables' distributions and should only be used as trend indicators rather than predictors.

A central argument of this research is that efficiency and utilization measures may fail to capture two important aspects: first, the congestion management approaches' robustness to changing traffic and second, the congestion management intervention or lack thereof impact on the hinterland logistics chains. The implications of this narrow lens are explored in the next section.

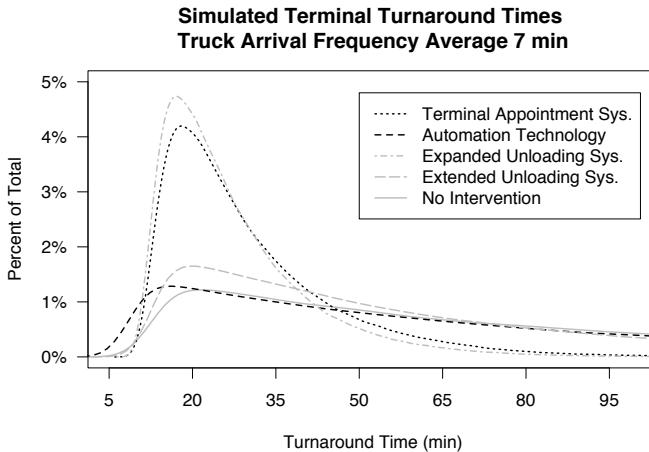


Figure 4: Simulation model turnaround times distribution for 7-minute average arrival frequency scenario

## 4 Discussion

The search for operational efficiency and capacity improvements is an ever-present theme in the terminal modelling and applications literature. This research suggests that a unidimensional measurement of congestion management techniques impact may be an oversimplification. Automation technologies can eliminate process or cargo handling time. In the 10-minute average arrival frequency scenario, the reduction was approximately 20% compared to the no intervention. At the same time however, *this improvement exhibits decreasing returns with increased traffic*. As terminal asset utilization increases, waiting times follow a similar trajectory therefore reducing the relative benefit of operational improvements.

*A terminal appointment system (TAS) is clearly one of the lowest cost and potentially highest impact congestion mitigation solution. This approach requires the high-*

est degree of coordination and collaboration between users and terminals. The modelled impact of the TAS is based on a series of assumptions on the technical feasibility, stakeholders' willingness to collaborate and the static nature of the environment (Neagoe et al., 2018). This research has partly relaxed the assumption of static nature by evaluating the TAS robustness under various throughput scenarios. The technical feasibility may not pose significant difficulties however, attracting support from stakeholders may prove challenging. Evaluations of TAS usage in previous studies have shown lower than expected usage if the solution is deemed incompatible with transporters' business requirements (Morais and Lord, 2006) or the system is perceived as an attempt to take advantage of the transporters (Davies, 2013).

The congestion management methods introduced appear to have limited impact for the terminal's costs or efficiency, particularly when no penalties are imposed for exceeding a set turnaround time threshold. *Terminals have little incentive to address congestion as it can be perceived as an alternative to maintain high levels of equipment utilization. Issues arise when strategic investments for capacity expansion or maintenance works planning are considered.* High asset utilization may create a perceived urgency to expand capacity to accommodate demand. However, the effectiveness of additional equipment to mitigate congestion issues is highly dependent on whether it addresses the actual operational bottleneck. Furthermore, maintenance planning becomes increasingly problematic with sustained levels of congestion as high utilization implies high demand and little downtime. Postponed maintenance can increase the probability of catastrophic failures which can severely impact both the terminal and its users.

Terminal users also experience a set of challenges related to congestion. Terminal service time uncertainty may translate into an upstream 'bullwhip effect' (Lee, Padmanabhan and Whang, 1997). Symptoms of uncertainty may include forecast inaccuracy, excessive inventories and high inventory turn times (Maleki and Cruz-Machado, 2013). Ultimately the effects of a high uncertainty environment can impact the supply chain's profitability. At an individual driver level, the risk of fatigue may increase as the flexibility to choose breaks decreases (Perttula, Ojala and Kuosma, 2011). Furthermore, congestion effects may not be equally spread amongst port users. Consequently, transporters may attempt to find alternatives to improve their efficiency, often at the expense of the other users. Conversely, decreased turnaround times may facilitate the chain's resilience. At a transporter level, schedule and fleet management can be improved (Huynh, 2009).

The range of impacts and behaviours discussed cannot be easily encompassed in existing methods of measuring efficiency and utilization. As links in the logistics chain are studied in isolation, the intricate interdependencies between them are obscured. The modelling approach only allows for the subset of behaviours that can be captured, quantified and geo-located to be modelled. Consequently, a broader lens that acknowledges multiple stakeholder perspectives and objectives and, the impact of interdependent links in the logistics chain is required to best optimize synergies between the various components in the chain.

## 5 Conclusion

This research adapted gate congestion management methods from container terminal to a bulk cargo marine terminal. A discrete event simulation model based on a wood chip export terminal in Australia was developed to evaluate the different methods' impact on terminal turnaround times and on the hinterland logistics chain.

Simulation results indicate that both automation technologies and a terminal appointment system can reduce average turnaround times by approximately 20% (from 22 to 18 minutes) compared to no intervention. Additional unloading capacity has a relatively small influence, less than 10%, on average turnaround times. With increased volumes, automation technologies and unloading capacity extension generate fewer benefits. The terminal appointment system and the unloading capacity expansion appear to have a significant impact in managing terminal gate congestion.

Automation technologies and additional infrastructure that target improvements in terminal efficiency may fail to yield expected results if they do not address the actual operational bottleneck. The lowest cost option, the terminal appointment system, may come with the highest requirements, in terms of stakeholder collaboration, that need to be satisfied to achieve its full potential.

The range of impacts and behaviours discussed cannot be easily encompassed in existing methods of measuring efficiency and utilization. As links in the logistics chain are studied in isolation, the intricate interdependencies between them are obscured. Consequently, a broader lens that acknowledges multiple stakeholder

perspectives and objectives and, the impact of interdependent links in the logistics chain is required to best optimize synergies between the various components in the chain.

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<http://www.utas.edu.au/arc-forest-value>

## References

- Ambrosino, D. and C. Caballini (2015). “Congestion and truck service time minimization in a container terminal”. In: *Maritime-Port Technology and Development - Proceedings of the International Conference on Maritime and Port Technology and Development, MTEC 2014*, pp. 1–10.
- Bassan, S. (2007). “Evaluating seaport operation and capacity analysis - Preliminary methodology”. In: *Maritime Policy and Management* 34.1, pp. 3–19.
- Bentolila, D. J., R. K. Ziedenveber, Y. Hayuth, and T. Notteboom (2016). “Off-peak truck deliveries at container terminals: the “Good Night” program in Israel”. In: *Maritime Business Review* 1.1, pp. 2–20.
- Bugaric, U. and D. Petrovic (2007). “Increasing the capacity of terminal for bulk cargo unloading”. In: *Simulation Modelling Practice and Theory* 15, pp. 1366–1381.
- Bugaric, U. S., D. B. Petrovic, and Z. V. Jeli (2015). “Optimal utilization of the terminal for bulk cargo unloading”. In: *Simulation: Transactions of the Society for Modeling and Simulation International* 88.12, pp. 1508–1521.
- Chen, G., K. Govindan, and M. M. Golias (2013). “Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern”. In: *Transportation Research Part E: Logistics and Transportation Review* 55.X, pp. 3–22.
- Cimpeanu, R., M. T. Devine, and C. O’Brien (2017). “A simulation model for the management and expansion of extended port terminal operations”. In: *Transportation Research Part E: Logistics and Transportation Review* 98, pp. 105–131.
- Cimpeanu, R., M. T. Devine, D. Tocher, and L. Clune (2015). “Development and analysis of a port terminal loader model at RUSAL Aughnish”. In: *Simulation Modelling Practice and Theory* 51, pp. 14–30.
- Crainic, T. G., G. Perboli, and M. Rosano (2017). “Simulation of intermodal freight transportation systems: A taxonomy”. In: *European Journal of Operational Research*.

- Dahal, K., S. Galloway, G. Burt, J. McDonald, and I. Hopkins (2003). "A port system simulation facility with an optimization capability". In: *International Journal of Computational Intelligence and Applications* 3.04, pp. 395–410.
- Davies, P. (2013). "Container terminal reservation systems design and performance". In: *METRANS International Urban Freight Conference Long Beach CA*, pp. 1–24.
- Giuliano, G. and T. O'Brien (2007). "Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach". In: *Transportation Research Part D: Transport and Environment* 12.7, pp. 460–473.
- Guan, C. and R. Liu (2009). "Container terminal gate appointment system optimization". In: *Maritime Economics and Logistics* 11.4, pp. 378–398.
- Heilig, L. and S. Voß (2017). "Information systems in seaports: a categorization and overview". In: *Information Technology and Management* 18.3, pp. 179–201.
- Holguín-Veras, J., K. Ozbay, A. Kornhauser, M. Brom, S. Iyer, W. Yushimoto, S. Ukkusuri, B. Allen, and M. Silas (2011). "Overall impacts of off-hour delivery programs in New York city metropolitan area". In: *Transportation Research Record: Journal of the Transportation Research Board* 2238, pp. 68–76.
- Huynh, N. (2009). "Reducing truck turn times at marine terminals with appointment scheduling". In: *Transportation Research Record: Journal of the Transportation Research Board* 2100, pp. 47–57.
- Huynh, N., D. Smith, and F. Harder (2016). "Truck appointment systems". In: *Transportation Research Record: Journal of the Transportation Research Board* 2548, pp. 1–9.
- Huynh, N. and C. M. Walton (2008). "Robust scheduling of truck arrivals at marine container terminals". In: *Journal of Transportation Engineering* 134.8, pp. 347–353.
- Jaffee, D. (2016). "Kink in the intermodal supply chain: interorganizational relations in the port economy". In: *Transportation Planning and Technology* 39.7, pp. 730–746.
- Lee, H. L., V. Padmanabhan, and S. Whang (1997). "Information distortion in a supply chain: the bullwhip effect". In: *Management Science* 43.4, pp. 546–558.
- Maguire, a., S. Ivey, M. M. Golias, and M. E. Lipinski (2010). "Relieving congestion at intermodal marine container terminals: review of tactical/operational strategies". In: *Proceedings of the 51st Annual Transportation Research Forum* 1, pp. 631–645.
- Maleki, M. and V. Cruz-Machado (2013). "An empirical review on supply chain integration". In: *Management and Production Engineering Review* 4.1, pp. 85–96.
- Manuj, I., J. T. Mentzer, and M. R. Bowers (2009). "Improving the rigor of discrete-event simulation in logistics and supply chain research". In: *International Journal of Physical Distribution & Logistics Management* 39.3, pp. 172–201.
- Morais, P. and E. Lord (2006). "Terminal appointment system study". In: *Transportation Research Board* 1.March, p. 123.
- Munisamy, S. (2010). "Timber terminal capacity planning through queuing theory". In: *Maritime Economics and Logistics* 12.2, pp. 147–161.
- Neagoe, M., M. S. Taskhir, H.-O. Nguyen, and P. Turner (2018). "Exploring the role of information systems in mitigating gate congestion at a wood chip export terminal through simulation". In: *IFIP International Conference on Advances in Production Management Systems, submitted*. Springer Berlin Heidelberg, pp. 1–11.
- Perttula, P., T. Ojala, and E. Kuosma (2011). "Factors in the fatigue of heavy vehicle drivers". In: *Psychological reports* 108.2, pp. 507–14.

- Ramírez-Nafarrate, A., R. G. González-Ramírez, N. R. Smith, R. Guerra-Olivares, and S. Voß (2017). “Impact on yard efficiency of a truck appointment system for a port terminal”. In: *Annals of Operations Research* 258.2, pp. 195–216.
- Van Vianen, T. A., J. A. Ottjes, R. R. Negenborn, G. Lodewijks, and D. L. Mooijman (2012). “Simulation-based operational control of a dry bulk terminal”. In: *Proceedings of 2012 9th IEEE International Conference on Networking, Sensing and Control, ICNSC 2012*, pp. 73–78.
- Vianen, T. van, J. Ottjes, and G. Lodewijks (2011). “Dry bulk terminal characteristics”. In: *Bulk Solids India*, pp. 1–10.
- Vianen, T. van, J. Ottjes, and G. Lodewijks (2014). “Simulation-based determination of the required stockyard size for dry bulk terminals”. In: *Simulation Modelling Practice and Theory* 42, pp. 119–128.
- Wadhwa, B. L. C. (1992). “Planning operations of bulk loading terminals by simulation”. In: *Journal of Waterway, Port, Coastal and Ocean Engineering* 118.3, pp. 300–315.
- Wadhwa, B. L. C. (2000). “Optimizing deployment of shiploaders at bulk export terminal”. In: *Journal of Waterway, Port, Coastal and Ocean Engineering* December, pp. 297–304.
- Zehendner, E. and D. Feillet (2014). “Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal”. In: *European Journal of Operational Research* 235.2, pp. 461–469.
- Zhao, W. and A. V. Goodchild (2013). “Using the truck appointment system to improve yard efficiency in container terminals”. In: *Maritime Economics and Logistics* 15.1, pp. 101–119.

# Digitalization Potentials in Supporting Offshore Wind Logistics

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*Digitalization complementing offshore wind energy is a topic of interest for both researchers and practitioners. As part of a broader research on offshore wind logistics optimization, this paper focuses on how digitalization can be further developed to support logistics in the particular domain of offshore wind farm construction, as well as Operations and Maintenance (O&M). This paper analyzes five major digitalization potentials: the use of unmanned systems, 3D printing, motion sensors, big data techniques and LiDAR usage. The term Industrial Digitalization Technologies (IDT) summarizes these potentials. This contribution provides an initial mixed method analysis on enhanced offshore wind efficiency. Initial frameworks based on in-depth literature analysis on the one hand and on experimental break-even calculations on the other, are provided. This paper's outcome shows that unmanned systems provide the by far largest cost-saving potential.*

**Keywords:** digitalization; offshore wind logistics; optimization; LCOE

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## 1 Introduction

Offshore wind is a promising renewable energy source. Its main challenge however is its profitability, which is a key driver for any industry especially in the energy sector. Logistics could represent a large share of offshore wind farms costs and be consequently an important contributor to improve profitability. Moreover, wind turbines are increasing in size and wind parks tend to be installed further away from coast in less favorable weather conditions, leading to more difficult vessel operations and higher risks. It seems then appropriate to find ways to improve logistics for better offshore wind profitability.

As described by Made Smarter (2017), different industrial revolutions had great influence on industries productivity and consequently on their profitability: first industrial revolution, originating from the textile industry, was driven by transition from manual production methods to manufacturing using machinery in the 18th century. Later on in early 20th century, mass production and Fordism brought the second industrial revolution. The third industrial revolution arose as computers were introduced in production process. With support of Internet, fourth industrial revolution is currently initiated and related to digitalization. In this last revolution, called as well Industry 4.0, technologies used are referred to as "Industrial Digitalization Technologies" (IDTs).

Øydegard (2017) suggested future research on the digitalization of offshore wind that could be done within several areas and pointed out logistics as one of them. On the industrial side, MHI-Vestas (2018) indicated that digital transformation has started improving the capabilities to collect, sort and analyze data, and also combined it with machine learning and artificial intelligence. Siemens (2018) recently indicated that digital intelligence is a differentiating factor against its competitors, while E-ON (2018) is using data to increase the accuracy of actions. Furthermore, Statoil (2018) is investing to secure a global leadership position within digitalization.

As an interest from researcher and practitioners is identified, this paper intends to highlight and analyze potentials of digitalization processes that support offshore wind logistics leading to possible cost reduction.

This study addresses the following research questions:

Q1: Which IDTs could support offshore wind logistics in order to reduce costs?

Q2: How could such processes relevance be evaluated and compared?

Q3: What are the limitations of digitalization in offshore wind logistics industry?

## 2 Methodology

Research on innovative digitalization opportunities in the offshore wind industry is accompanied by a scarcity of existing literature and quantitative data. In order to cope with this aspect, this paper applies mixed method concepts of qualitative literature analysis, initial framework introduction and a case study of quantitative break even analysis to provide a valuable basis for future research on IDTs in the offshore wind sector.

Chapter three provides an in-depth qualitative literature analysis on the three main areas of Levelized Cost Of Energy (LCOE) definition, LCOE reduction potentials and IDT integration in the offshore wind industry. The literature review was conducted using Google Scholar between March and May 2017 focusing on a variety of key words such as 'LCOE reduction', 'LCOE in offshore wind', 'off-shore wind digitalization', 'offshore wind innovations' and 'offshore logistics digitalization'. Technical aspects were disregarded for the sake of this paper's limitation to digitalization in the offshore sector. Furthermore, contributions and discussions among experts on the 6th International Conference on Dynamics in Logistics in February 2018 were taken into account for this paper's literature review.

This analysis findings are processed and presented within conceptual frameworks (following the definitions of Miles and Hubermann, 1994 and Maxwell, 2013). Quantitative aspect of this paper is founded on a break-even scenario analysis of IDTs in chapter 4 which aims at ranking and discussing such approaches using limited but real-life data. Limitations of this paper's research are pointed out in detail in chapter 5. Finally, in chapter 6, paper contributions and further research opportunities are presented and discussed.

### 3 Introduction of research areas

Limited numbers of studies have, so far, been conducted on digitalization in the offshore wind business. First contributions focused on big data integration to improve offshore wind farms' maintenance (see Viharos et al., 2013; Brinch, 2015; Nabati and Thoben, 2017) but these studies did not cover the logistics during construction of offshore wind farms. Øydegard (2017) already pointed out the necessity of additional research when investigating new digital technologies to improve logistics in the offshore wind industry. First business-related sources provide roadmaps for digitalization (Made Smarter, 2017) and cost-reduction potentials (WindEurope, 2017) while academic contributions in that area are scarce. In the following, this paper's focus areas are introduced and qualitatively evaluated.

#### 3.1 LCOE

LCOE reflects the 'lifetime cost' of an energy source 'per unit of energy generated' (The Crown Estate, 2012). LCOE as a cost metric provides valuable insights, allowing normalizing costs into a consistent format over time and technologies (Rhodes et al. 2017). Using LCOE as profitability estimation for renewable energy sources is widely accepted among existing literature. However, LCOE evaluation on offshore wind energy is, as of now, quite limited (see Levitt et al. 2011; Ioannou et al. 2015; Duan 2017). Levitt et al. (2011) developed a pro-forma cash flow analysis for 35 offshore wind projects in Europe, China, and the United States, in planned or operation phases. Ioannou et al. (2015) expanded LCOE to account for stochastic inputs via Monte Carlo simulations. Furthermore, Duan (2017) introduced cost components for offshore wind energy and analyzed influencing factor for various markets. Due to the limitations of this paper, only locally installed offshore wind farms and their LCOE structures are evaluated. The area of floating wind farms is therefore not taken into consideration.

Calculating and combining LCOE among various energy sources is a challenging task as it is affected by various regional and external factors. Among these factors are political orientations (such as tax reduction or subsidies) or weather factors of the plant's region. Rhodes et al (2017) provides a more detailed view on LCOE dynamics. Table 1 gives a brief survey on different LCOE sources in order to

identify a general ranking of offshore energy expenses compared to other energy sources.

Table 1: Median LCOE prices of common US energy sources

	Range for total system levelized costs in \$/MWh (2017)	Min	Median	Max
<b>Dispatchable technologies</b>				
Geothermal	42	45	50	
Advanced combined cycle gas	44	49	77	
Conventional combined cycle gas	45	50	79	
Advanced combined cycle gas with CCS	67	75	85	
Advanced combustion turbine	75	85	129	
Advanced nuclear	90	93	98	
Biomass	74	95	111	
Conventional combustion turbine	87	99	145	
Coal with 90% CCS	111	119	140	
Coal with 30% CCS	117	130	191	
<b>Non-dispatchable technologies</b>				
Wind, onshore	41	59	77	
Hydroelectric	50	62	74	
Solar photovoltaic	42	63	114	
Wind, offshore	122	138	169	
Solar thermal	145	165	188	

CCS= Carbon capture and sequestration

Source: U.S. EIA (2018)

As LCOE calculations vary, the outcome among different studies also differs for each individual energy source. In order to avoid a locally biased European point of view concerning offshore digitalization effects on LCOE expenses, Table 2 compares various US sources with European values for the six largest conventional energy sources.

Table 2: Comparison of US and UK LCOE

System levelized costs in \$/MWh (2017)			
	US EIA (2018)	Bifera (2017)	Siemens (2014)
	US Median I	US Median II	UK Median
Onshore Wind	59	64	71
Combined cycle gas	50	70	67
Utility scale solar PV	63	83	130
Coal	125	108	77
Nuclear	93	126	79
Offshore wind	138	141*	123

\*Source: NREL (2018)

Bifera (2017) compared the five major US sources in his study while US EIA (2017) referred to the data provided in Table 1. Recent European LCOE values for conventional energy sources were not found during this paper's literature review. The values, provided by a study of Siemens (2014) reflect the linear median of outlook values between 2013 and 2025. The authors are aware of the limited accuracy of these values but decided to integrate them in this study because the intention to briefly compare LCOE values was met. Nevertheless, offshore wind industry is still under great pressure to reduce costs in order to improve competitiveness with other energy sources.

### 3.2 LCOE reduction potentials

In order to properly analyze digitalization potentials towards their reduction effects on LCOE, one must understand how the costs of an offshore wind park are allocated among the park's lifetime. Figure 1 is a key driver matrix concerning LCOE with regards to its cost factors. Digitalization in offshore wind construction mainly affects capital expenses (CAPEX) in the beginning while digitalization in operations further affects long-term operation expenses (OPEX). Turbine expenses regarding CAPEX can be reduced using IDT in the construction process. A long term integration of IDT in the wind farm operation further enhances the farm's productivity, therefore positively affecting LCOE. On the OPEX side, regular maintenance is a key aspect of wind farm operations. Transformers, switches, breakers,

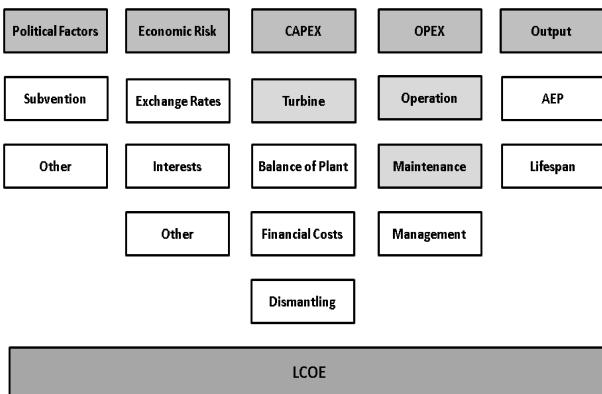


Figure 1: Key LCOE Driver Matrix

Source: Adapted from Lüthi and Prässler (2011), Prässler and Schaechtele (2012), Duan (2017)

relays, etc. are subject to regulatory protocols that determine the schedule for inspection ensuring safety to both farm and the personnel (Dovorak 2016). Using IDT in operations might also positively affect LCOE outcome by gathering and applying larger scales of data for optimization purposes.

The aspect of LCOE drivers becomes more complex as offshore wind farms themselves evolve and do not follow the same universal calculation patterns. As turbines increase in size and wind farms get installed further away from shore in harsher weather conditions, it becomes more and more difficult to operate vessels and, consequently, accessibility of offshore wind farms can be considered a major factor that escalates expenses and risks of offshore wind projects. These cost-increasing aspects were already identified by Van der Zwaan et al. (2012).

Tables 1 and 2 show the still high energy costs of offshore wind compared to other energy sources. At the same time cost-saving opportunities in offshore wind are presented throughout the literature. Offshore wind development will also benefit from cost reductions due to technological developments as well as learning and scaling effects (Van de Zwaan et al., 2012 and Chartron and Haasis 2018).

While the above mentioned sources remain rather general in their expression, recent contributions provide a more detailed view on the cost distribution and their cost reduction potential. Bloomberg (2017) predicted a reduction of offshore wind expenses by 71% by 2040 due to competition, experience and economies of scale. These predictions were complemented by Hobohm et al. (2015) indicating a 68% reduction of costs from 2010-2020 among German offshore wind farms. According to Hobohm et al. (2015), external factors would reduce offshore expenses by 13%. Technological developments would account for 38% whereas 30% can be attributed to more modern and larger turbine sizes. Excellence and maturation in processes finally account for another 40% of cost reduction that sums up to an overall reduction of 68% from base- to future case scenarios. It is worth mentioning that OPEX reductions only account for 5% while logistics improvements are not separately mentioned. According to other contributions, off-shore wind farm logistics costs range from 15% (Windenergy, 2009) to 19% (Ahn et al., 2016). Poulsen and Bay Hasager (2016) even provided a more detailed evaluation, in which logistics represents 18% of LCOE.

#### 4 IDTs applicable to offshore wind logistics

In order to answer research question [Q1], the following chapter introduces and evaluates five major IDTs for the offshore wind logistics industry as a means of reducing LCOE. Assumptions used for break-even calculations (see chapters 4.1, 4.2, 4.3 and 4.4) are listed in Table 2. Estimated values from different sources or authors assumptions have been indicated in order to compare quantitatively presented IDTs (see chapter 4.6).

Table 3: Assumptions for break-even analysis

Symbol	Assumptions	Estimated Value used	Source
Bunk Cost	MGO bunker cost	0.45 € / liter	Ship & Bunker (2018)
CTV Max	Crew Transfer Vessel (CTV) consumption at maximum speed	500 liters / hour	Opus Marine (2018)
CTV Rate	CTV day rate	3,500€	Based on Phillips, et al. (2015), average for CTV with availability over 50%
CTV Red	CTV consumption at reduced speed 20 knots	380 liters / hour	Opus Marine (2018)
CTV Serv	CTV consumption at service speed	400 liters / hour	Opus Marine (2018)
D	Distance to shore in nautical miles	40	
Day	Ratio of day when a technician works less than 12 hours per day	65%	BMO offshore (2016)
less12h	Ratio of day when a technician works less than 12 hours per day		
H	Vessel net working hours per day	5	
IV Rate	Installation vessel day rate	220,000€	Based on Dalgic, et al. (2013), average spot market rate
Improv Dep CTV	Improvement in CTV deployment	25%	BMO offshore (2016)

*Continued on next page*

Table 3 – continued from previous page			
Bunk Cost	MGO bunker cost	0.45 € / liter	Ship & Bunker (2018)
M	Marginal weather window	30%	BMO offshore (2016)
N	Number of vessel hire days	Variable	
nI	Number of interventions to bring a component from deck to nacelle on installation vessel	1 per vessel hire day	
nT	Number of trips to transport a spare part from onshore to offshore	1 per vessel hire day	
Speed Serv	CTV service speed in knots	26.5	Opus Marine (2018)
T Climb	Duration in minutes to climb from installation vessel deck to nacelle	20'	
T Lift Prep	Duration in minutes to prepare lifting equipment on the installation vessel crane hook	20'	

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#### 4.1 Motion sensors

Øydegaard (2017) argued that an increased implementation of sensors on the support vessels would result in a higher level of autonomy to improve workability, availability of turbines and fuel saving. Offshore wave conditions generally result in a ‘grey’ area in the operating window between 1.2m and 2m of significant wave heights for Crew Transfer Vessels (CTV). According to BMO offshore (2016), the probability of that marginal weather window occurring is estimated at 30%.

External vessels are hired to perform in this marginal operating window, but lack of vessel performance data for marine control results in a best practice 'no-go' decision at significant wave heights above 1.2m. It is estimated to realize a 25% improvement in deployment in this weather window.

Moreover, BMO offshore (2016) indicates that vessels are often sailing at full-speed to maximize technicians' work time. It is estimated that in 65% of days, technicians are returning to port having worked less than 12 hours. Those instances allow reducing vessel speeds from 25/26 knots to 20 knots. The resulting fuel consumption can only be saved on the inbound and return legs; not on the outbound leg. Hence, a display indicating to the crew when to reduce speed, may reduce fuel costs.

Cost savings associated with implementation of such sensors could be evaluated by calculating the vessel's additional active operation time due to more accurate evaluation of wave height marginal weather windows ("CTV Rate x M x Improv Dep CTV ") and fuel saving due to an optimization of vessel speed according to technicians working time ("H x (CTV Max - CTV Red)x Bunk Cost x Day less 12h /2"). These savings are factored by the number of vessel hiring days (N).

BE sensor cost for such sensor can then be broken even as follow

$$BE\ Sensor = N \times (CTV\ Rate \times M \times Improv\ Dep\ CTV + H \times (CTV\ Max - CTV\ Red) \times Bunk\ Cost \times Day\ less\ 12h/2) \quad (1)$$

## 4.2 3-D Printing

3-D printing as a newly available technology in different industries and has so far not been introduced in the offshore wind sector. This promising technology could reduce storage efforts and avoid unnecessary cargo transfer of small parts. 3D printing in offshore areas was highlighted by Øydegard (2017) to ideally have components 3-D manufactured instead of having high-volume storage. A qualitative assessment on sustainability by Gebler et al. (2014) quantified changes in life-cycle costs, energy and emissions. Mohr and Kahn (2015) already identified seven key areas of logistics that will be affected by 3D printing technologies in the near future.

Cost savings associated with implementation of 3-D Printing could be evaluated by calculating the vessel charter rate ( $D/\text{Speed Serv} \times CTV \text{ Rate}/24$ ) and bunker ( $CTV \text{ Serv} \times Bunk \text{ Cost} \times D/\text{Speed Serv}$ ) savings. These savings are factored by the number of events ( $nT$ ) and a factor 2 due to return trips.

BE 3D cost for 3D printer (installed onboard a ship or a platform) can be amortized as follows:

$$BE\ 3D = (D/\text{Speed Serv} \times CTV \text{ Rate}/24 + CTV \text{ Serv} \times Bunk \text{ Cost} \times D/\text{Speed Serv}) \times 2 \times nT \quad (2)$$

#### 4.3 Unmanned Systems (US) for access and inspection

Made Smarter (2017) foresaw benefits of using specialized robotics for maintenance on wind turbine blades as example as they are difficult to access. Øydegaard (2017) evaluated autonomous vessels and drones for access and inspection as well. Stein (2018 I) analyzed the approach of using Unmanned Systems (US) for inspection works in the maritime domain. He argues that this innovation reduces costs and improves operations efficiency and safety. Another contribution by Stein (2018 II) further integrated the use of US in maritime and port security operations.

Inspection that would avoid transfer of personnel on the wind turbine, hence avoiding traditional transfer by CTV or helicopter, would reduce cost significantly. The same accounts for transfer of small spare parts or tools from the installation vessel deck to turbine nacelles. There are instances in which a missing tool or spare part during installation slows down operations. In order to bring a spare part or a tool to the top of a turbine, a technician needs to climb from installation vessel deck to nacelle which takes around 20 minutes in an elevator or a minimum of 30 minutes climbing. US can conduct such operations within few minutes.

Cost savings associated with implementation of US could be evaluated by calculating the vessel charter rate ( $D/\text{Speed Serv} \times CTV \text{ Rate}/24$ ) and bunker ( $CTV \text{ Serv} \times Bunk \text{ Cost} \times D/\text{Speed Serv}$ ) savings. These savings are factored by the number of events ( $nT$ ) and a factor 2 due to return trips. Savings on Installation vessel due to reduced downtimes on installation critical path ( $T_{Climb} \times IV \text{ Rate}/24$ ), factored by number of events ( $nI$ ), are also considered.

BE US cost for US can be broken even as follows:

$$BE\,US = (D/\text{Speed Serv} \times CTV\,\text{Rate}/24 + CTV\,\text{Serv} \times \text{Bunk Cost} \times D/\text{Speed Serv}) \times 2 \times nT + T\,\text{Climb} \times IV\,\text{Rate}/24 \times nl \quad (3)$$

#### 4.4 LiDAR

LiDAR (Light Detection And Ranging) is a surveying method that measures distance to a target using lasers. It can be used to accurately measure wind speeds and wind turbulences (Hasager, et al., 2007). For instance, there is potential application during wind turbine installation phase: before lifting components, it is necessary to accurately check actual wind speed at a certain height to prevent exceeding Marine Warranty Surveyor (MWS) or vessel capability limits. For such verification, installation vessels usually use anemometer on their cranes to decide whether or not to proceed. Hence, instead of preparing and attaching the component to be lifted to the crane, the crane is up in the air, determining wind speeds. The installation vessel is then systematically losing a conservatively estimated 20 minutes. Installing a LiDAR on the other hand could prevent this crane operation by providing an accurate wind situation at the component height lift level.

Cost savings associated with implementation of LiDAR could be evaluated by calculating savings on installation vessel hire due to reduced time of lift preparation ( $T_{lift\,prep}$ ), factored by probability of such situation (M) and number of vessel hire days (N).

BE LiDAR cost for LiDAR can be broken even as follow

$$BE\,LiDAR = T_{lift\,prep} \times M \times N \times IV \times Rate/24 \quad (4)$$

#### 4.5 Big Data and Digitally-based Decisions

Use of data sources collected by proper instruments and analyzed using software embedded mathematical models already allows for a logical cost-effective decision-making process in the maritime domain. Jahn and Scheidweiler (2018)

have developed an algorithm that analyzes ship movements from AIS and environmental data to calculate the ships' estimated time on arrival for optimized port calls. According to Vestas (2018) data about wind, weather and the real-time performance of almost 25,000 turbines worldwide, is currently being gathered and evaluated. Vestas considers that digitalization will help to get more precise weather forecasting. This aspect was highlighted by IRENA (2016) where improvement in weather forecasting and analysis is one of the main opportunities for O&M offshore wind cost reductions before 2025. Villani (2018) encourages research collaboration projects on weather forecasts and artificial intelligence in terms of risk assessments. Digitalization and big data analysis can help to monitor critical key performance indicators as well. Chartron and Haasis (2018) proposed a tool to collect relevant information to identify logistics inefficiencies during offshore wind park constructions and analyzed these inefficiencies to point out improvement opportunities.

In order to better plan offshore logistics activities, several researches have been conducted and constitute a blueprint for big data and real time decision making analysis: during the installation phase, several decision support and simulation tools have been developed (see Scholz-Reiter et al., 2010; Lange et al., 2012; Ritter, 2016; Vis and Ursavas, 2016). Further studies have been conducted to optimize vessel fleet during O&M phase (see Endrerud, et al. 2014; Dewan, A. 2014; Stalhane, et al. 2016) and additionally, on big data to improve offshore wind farms maintenance (see Viharos et al., 2013; Nabati and Thoben, 2017).

As big data is certainly a benefit for offshore logistics operations, it is complex to evaluate. Both economically a prospectively positive impacts cannot be evaluated without proper data so that no break-even analysis can be proposed on this specific aspect. According to the author's opinion, this topic is even without break-even information worth mentioning, as it already points towards future research on offshore wind digitalization.

#### 4.6 Break even analysis comparison

In order to answer to research question [Q2], it is proposed in this sub-chapter to evaluate and compare selected IDTs.

The number of Vessel hire days (N) has been considered a common variable for the previously presented 4 IDTs, and break-even savings have been evaluated over one year (365 days) of operation. Using functions (1), (2), (3) and (4) and

implementing estimated values from Table 2, we obtain results presented in Figure 2.

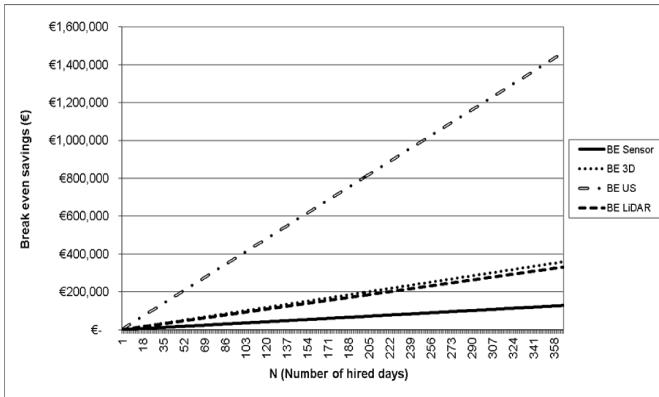


Figure 2: Break-even savings comparison between four different IDTs in offshore wind logistics

Figure 3 shows US IDT with the highest positive slope, reflecting the highest saving potential. This can be attributed to the fact that it can both save time on installation vessel as well as prevent travels of support vessels. With increasing payloads of US, the operability for spare part movement also increases. Nowadays a liftin capacity up to 5 kg is common around industrial US and this is likely to increase. Some limitations to consider may be authorizations to use US off-shore and having qualified personnel to pilot such systems.

3D printing IDT has the second highest saving potential. This IDT would be also particularly relevant in O&M phase were spare parts are sometimes needed urgently. Some limitations to consider may be the type of parts that can be produced, quality requirements, duration to create the part and skill to create the part offshore. Furthermore patent rights on specific parts or aspects might affect certain 3D printing procedures on specific parts.

LiDAR is the third highest saving potential IDT. It is applicable to installation vessel and would make sense on an installation campaign that requires the installation of several turbines. Some limitations to consider may be the reluctance of the

offshore wind industry to use such alternative systems and having the necessary skilled personnel to use this new technology.

The last and in comparison lowest potential is coming from sensors IDT. This technology is applicable in the particular domain of CTVs. It can represent a high potential in O&M phase where this kind of vessels are used during several year periods. Some limitations to consider may be the cost of the technology and capability to analyze the data accurately.

Based on the above, Table 4 presents an evaluation of the potential impact on LCOE and investment for each IDT.

Table 4: IDT evaluation LCOE impact and investment

IDT	LCOE (Construction)	LCOE (O&M)	Impact	Investment
Un-manned systems	High		High	High- Medium
Big Data	Medium		High	Medium
3D printing	Medium		Medium	High
LiDAR	Low		Medium	Medium

#### 4.7 Research barriers

In order to study research question [Q3], limitations on LCOE reductions via IDTs are evaluated in this chapter.

Since offshore wind projects are tending to be installed beyond the range limit of mobile phones and Wifi, connectivity is one of the key challenges. Splitting bandwidth and allocating it to specific tasks can be a solution to share limited connection capabilities.

Today, most of the vessel's information is coming from reports written by onboard employees. As technologies allow for better understanding of the vessel's activity (i.e. data coming from motion sensors and cameras) the amount of data to be processed increases. Figure 3 displays an infrastructure proposal of the integration

of current offshore data into the communication architecture. Such cloud-based scheme, using multiple data inputs aggregated in databases, however, requires advanced modes on data processing and storage.

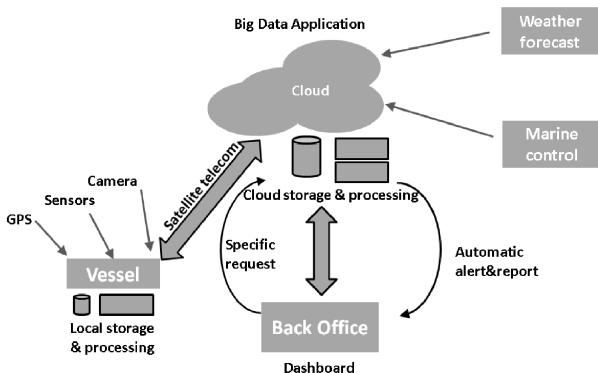


Figure 3: Architecture data processing and communication architecture

As high quantities of data are collected by physical sensors, on-board cameras, and human activity, concepts of edge-computing (see Carlini, 2016) are required to cope with current bandwidth limitations in remote offshore areas. Data management in remote offshore areas remains a considerable threshold to industrial digitalization technologies that requires additional research.

Made Smarter (2017) saw a need to adapt some digital technologies from more advanced sectors (nuclear or aerospace) to the offshore wind industry. Made Smarter (2017) further recommended more comprehensive and shared storage of geological or environmental data to reduce risks in the offshore wind industry. A2SEA (2018) for example implemented a turbine database in order to collect information such as vessels used, cables routes or seabed investigations. However, such databases are still rare in the offshore wind industry and not publically shared.

#### 4.8 Discussion and conclusion

Even though it appears to be obvious that the fourth industrial revolution is now on its way and will hit the offshore wind industry sooner or later, several precautions need to be considered.

For instance, marine coordinators are key for offshore logistics' smooth operations and cannot currently be replaced by computers or advanced artificial intelligence since a lot of events are not predictable and communication or authorizations are still conducted manually. Moreover, according to Made Smarter (2017), offshore wind industry is still in an early development phase with a need to improve in integration and standardization. It was also highlighted by Chartron and Haasis (2018) that productivity techniques still need to be implemented offshore. In that case, it seems to be relevant to explore improvements brought by the third industrial revolution. A number of barriers and limitations need to be overcome, and before the fourth revolution receives the total focus of attention, offshore wind industry needs to properly complete its third industrial revolution.

Nevertheless; it is observed that the wind industry actors try to instill digitalization as a new topic to better serve customers and their specific markets. This contribution provides an initial mixed method analysis on enhanced offshore wind efficiency expressed by LCOE reductions through the use of IDT. Five IDTs have been identified as potential support for offshore wind logistics (research question [Q1]). Experimental break-even calculations have been proposed in order to answer research question [Q2]. Unmanned systems provide by far largest cost-saving potential regarding offshore wind LCOE. Concerning research question [Q3], limitations identified for IDTs in offshore wind context are connectivity, data management and cross-sector cooperation. Therefore, further research on improved information sharing or collaboration tools to support real time decision-making would be beneficial. Furthermore, this academic field would benefit from applied quantitative analysis and economic benefit investigations.

### References

- A2SEA (2018). In:  
Administration, U. E. E. I. (2018). "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018". In:

- Ahn D., e. a. (2017). "Comparative evaluation of different offshore wind turbine installation vessels for Korean west south wind farm". In: *International Journal of Naval Architecture and Ocean Engineering* 9.1, pp. 45–54.
- Bifera, L. (2018). "Levelized cost of energy survey shows wind, natural gas cementing economic edge". In: *S&P Global Market Intelligence*.
- Bloomberg (2017). "New Energy Outlook 2017". In:
- Brinch, M. (2015). "Big Data and Operation and Maintenance in Offshore wind". In:
- Bunker, S.
- bibinitperiod (2018). "World Bunker Prices, Rotterdam price". In:
- Carlini, S. (2016). "The Drivers and Benefits of Edge Computing". In:
- Chartron, S. and H. Haasis (2018). "Improving Logistics Efficiency in Offshore Wind Farms Construction. Dynamics in Logistics". In: *Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany*, pp. 139–144.
- Dalgic, Y., I. Lazakis, and O. Turan (2013). "Vessel charter rate estimation for offshore wind O&M activities". In:
- Dewan, A. (2014). "Logistic & Service Optimization for O&M of Offshore Wind Farms - Model Development & Output Analysis". In:
- Dovorak, P. (2016). "A wind farms balance of plant also needs an inspection". In:
- Duan, F. (2017). "Wind Energy Cost Analysis -CoE for offshore Wind and LCOE financial modeling". In: *Helsinki Metropolia University of Applied Sciences*.
- E-ON (2018). "Digitization". In:
- Enderrud, O., J. Liyanage, and N. Keseric (2014). "Marine Logistics Decision Support for Operation and Maintenance of Offshore Wind Parks with Multi Method Simulation Model". In: *Proceedings of the 2014 Winter Simulation Conference, IEEE Press*, pp. 1712–1722.
- Energy, S. G. R. (2018). "L3AD2020 program 3-year strategic plan". In:
- Estate, T. C. (2012). "Offshore Wind Cost Reduction, Pathways Study". In:
- Gebler, M., A. Uiterkamp, and C. Visser (2014). "A global sustainability perspective on 3D printing technologies". In: *Energy Policy* 74.158–167.
- Hasager, C., A. Pena, T. Mikkelsen, M. Courtney, I. Antoniou, S. Gryning, P. Han-sen, and P. Sorensen (2007). "12MW Horns Rev Experiment". In: *Riso National Laboratory*.
- Hobohm, J., L. Krampe, and F. Peter (2015). "Cost Reduction Potentials of Offshore Wind Power in Germany. A joint report from Fichtner and Prognos". In:
- Ioannou, A., A. Angus, and F. Brennan (2017). "Stochastic prediction of offshore wind farm LCOE through an integrated cost model". In: *Energy Procedia* 107, pp. 383–389.
- IRENA (2016). "The Power to Change: Solar and Wind Cost Reduction Potential to 2025". In: *International Renewable Energy Agency, Abu Dhabi*.
- Jahn, C. and T. Scheidweiler (2018). "Port Call Optimization by Estimating Ships' Time of Arrival. Dynamics in Logistics". In: *Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany*.
- Laboratory, N. N. R. E. (2017). "Offshore Wind Power Plants". In:
- Lange, K., A. Rinne, and H. Haasis (2012). "Planning Maritime Logistics Concepts for Offshore Wind Farms: A newly developed Decision Support System". In: *HU, H, et al. (Eds.): Computational Logistics, Berlin, Springer*, pp. 142–158.
- Levitt, A., W. Kempton, A. Smith, W. Musial, and J. Firestone (2011). "Pricing offshore wind power". In: *Energy Policy* 39.10, pp. 6408–6421.

- Luthi, S. and T. Prassler (2011). "Analyzing policy support instruments and regulatory risk factors for wind energy deployment - A developers' perspective". In: *Energy Policy* 39(9), pp. 4876–4892.
- Marine, O. (2018). "28m CTV Class MV PRESTO / VIVACE Vessel specification". In:
- Maxwell, J. (2013). "Qualitative Research Design, An Interactive Approach". In: *3rd ed., Thousand Oaks, CA: Sage*.
- Miles, M. and A. Huberman (1994). "Qualitative Data Analysis: A Sourcebook of New Methods". In: *Beverly Hills, CA: Sage*.
- Mohr, S. and O. Khan (2015). "3D printing and its disruptive impacts on supply chains of the future". In: *Technology Innovation Management Review* 5(11), p. 20.
- Nabati, E. and K. Thoben (2017). "Big Data Analytics in the Maintenance of Off-Shore Wind Turbines: A Study on Data Characteristics". In: *Dynamics in Logistics Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany*.
- offshore, B. (2016). "Testimonial Business Cases". In:
- Oydegard, P. (2017). "Digitalization of Offshore Wind Farm Systems". In: *University of Stavanger, Norway*.
- Phillips, S., I. Shin, and C. Armstrong (2015). "Crew Transfer Vessel Performance Evaluation". In: *Design & Operation of Wind Farm Support Vessels, 28-29 January 2015, London*.
- Poulsen T., B. H. C. (2016). "How Expensive Is Expensive Enough? Opportunities for Cost Reductions in Offshore Wind Energy Logistics". In:
- Prassler, T. and J. Schaechtele (2012). "Comparison of the financial attractiveness among prospective offshore wind parks in selected European countries". In: *Energy Policy* 45 (2012), pp. 86–101.
- Rhodes J.D., e. a. (2017). "A geographically resolved method to estimate levelized power plant costs with environmental externalities". In: *Energy Policy* 102, pp. 491–499.
- Ritter, K. (2016). "Comparison between different transport scenarios during weather dependent processes of an offshore wind park in the Baltic Sea". In:
- Scholz-Reiter, e. a. (2010). "Planning and control of logistics for offshore wind farms". In:
- Siemens (2014). "What is the real cost of offshore wind?" In:
- Smarter, M. (2017). "Review 2017". In:
- Stalhane M., e. a. (2016). "Vessel fleet optimization for maintenance operations at offshore wind farms under uncertainty". In:
- Statoil (2018). "Digitalisation". In:
- Stein, M. (2018a). "Conducting Safety Inspections of Container Gantry Cranes Using Unmanned Aerial Vehicles". In: *Dynamics in Logistics, Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany*.
- Stein, M. (2018b). "Integrating Unmanned Vehicles in Port Security Operations: An Introductory Analysis and First Applicable Frameworks". In: *Oceans Yearbook* 32, pp. 556–583.
- Van der Zwaan B., e. a. (2012). "Cost reductions for offshore wind power: Exploring the balance between scaling, learning and R&D". In: *Renewable Energy* 41 (2012), pp. 389–393.
- Vestas (2018). "Energy system digitalisation". In:
- Vestas, M. (2018). "MVOW Smart". In:
- Viharos Z.J., e. a. (2013). "Big Data. Initiative as an IT Solution for Improved Operation and Maintenance of Wind Turbines". In: pp. 184–188.
- Villani, C. (2018). "Donner un sens l'Intelligence Artificielle - Pour une strategie Nationale et Europeenne". In:

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*REFERENCES*

- Vis, I. and E. Ursavas (2016). "Assessment approaches to logistics for offshore wind energy installation, Sustainable Energy Technologies and Assessments". In:
- Windenergy (2009). "Wind farm design offshore". In:
- WindEurope (2017). "Wind in Power 2017- Annual combined onshore and offshore wind energy statistics". In:



## Part II

# City Logistics



# Logistical Preconditions for Economical Reuse of End-of-life Textiles

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*The importance of textile recycling has long been highlighted and extensively covered in the literature. More recently, tightening waste regulations have forced household waste management organizations to seriously consider different alternatives for reducing the amount of textiles in mixed waste. To date, the high logistical costs associated with collecting, sorting and treating of end-of-life (eol) textiles has prevented the use of recycled textiles in production. The particular challenges of organizing these operations cost-effectively include small batch size, material diversity, and complex sorting and treatment processes. Finding economical alternatives for the reverse logistics of eol textiles will help companies that use recycled textile materials in large-scale production to evolve. This paper addresses the issue through mixed methods research combining a quantitative and qualitative approach. The paper is based on a case study of organizing the eol textile ecosystem in Finland. The material was obtained primarily from interviews with stakeholders and workshops. The economic impacts of different alternatives are compared using a designed cost model. Based on the study, local collection of eol textiles should be carried out at regional level using the expertise of local municipal waste companies. Centralized sorting and treatment enables adequate volumes to justify investment in automation and paves the way for economies of scale benefits.*

**Keywords:** Reverse logistics; Textiles; Recycling; Cost model

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## 1 Introduction

In the developed world, most end-of-life (eol) textiles end up in municipal waste collection as mixed waste, meaning that they will end up in energy burning plants or landfills. In almost every country, charity organizations collect apparel in good condition either for sale in their own retail stores, as relief aid to e.g. areas suffering from natural disasters, or for sale in underdeveloped countries. However, a considerable share of donated eol textiles are in such poor condition that they cannot be sold to other consumers in the country of origin, and transporting them to underdeveloped countries is ethically questionable (Norris, 2015). Reusing the material from eol textiles in new products therefore makes sense and is an important tool for increasing recycling rates. From an environmental point of view, recycling textile material is important as it can take more than 20,000 liters of water to produce 1kg of cotton (Bärlocher et al., 1999), but the reuse of 1 tonne of cotton clothing only uses 2.6% of the energy required to manufacture it from virgin material (Woolridge et al., 2006).

Charity organizations compete in the second-hand clothing business, which means there are good procedures for getting users of reusable clothes. In addition, some textile items no longer fit for purpose can be reused as raw material for other products without the need for fiber-level recycling, such as cast-off hotel bedding. However, once the recycling process moves to material and fiber-level, processing costs shoot up and the cost of recycled material can quickly exceed that of the corresponding virgin material. This is because a number of problems arise with the reuse of eol textiles as raw material for new products. First, the collected textile contains several types of material that need to be separated. To make matters worse, today's apparel seldom comes in a single material but rather as mixture of materials that somehow need to be recognized and sorted. Second, eol textiles usually include built-in parts such as zips and buttons that need removing before the recycling process. Third, used textiles may have dirt that interferes with the recycling process difficult. Further issues may arise if the textile material is wet or contains mold or pests.

A further challenge related to the reuse of eol textile material in developed countries such as Western Europe and North America is that their own textile industry has largely been shifted to other continents, notably South and East Asia. Thus there is only a limited number of industrial companies that could use collected textile material locally. One option could be to transport collected textile materials to countries with a large textile industry, but that has its own problems: Countries

like China have recently prohibited the import of waste material, including eol textiles (Davies and Ding, 2018), and transporting material that is relatively cheap but vulnerable to e.g. humidity to the other side of the world has its own costs and lessens the environmental benefits of recycling.

This paper examines the supply network of eol textile recycling. The aim is to find different alternatives for organizing operations within the network, because when there is enough information on available alternatives, it becomes easier to select the most functional ones and cut recycling costs to a reasonable level. Reasonable costs and an ensured supply of materials encourage the use of eol textiles as raw material for textile products as opposed to virgin material. This paper also aims to model the costs of recycled textile material, to help users evaluate their raw-material costs when planning a business related to the use of recycled textiles

## 2 Theoretical Background

Waste Framework Directive 2008/98/EC (European Commission, 2008) outlines how waste is defined in the European Union and how it should be treated. The Directive not only makes recommendations on the treatment of eol waste but also recommends a ‘waste hierarchy’ that is applicable across all member states. In the hierarchy, the primary aim is to avoid waste. The hierarchy has four waste categories in order of desirability: Reuse, recycling, other recovery, and disposal. (European Commission, 2008; Gharfalkar et al., 2015).

When the general aim is to reduce especially the amount of disposal waste, textile waste is one category that should be taken into consideration. Even if textiles normally represent a share of around 2.5% of all the household solid waste in Europe (e.g. Edjabou et al., 2015), it usually ends up in mixed waste; a study carried out in the Helsinki metropolitan area noted that the share of textile waste was 5.0% of all mixed household solid waste (HSY, 2013). Asaadi et al. (2017) also note poor recycling rates of eol textiles; they report that in the UK, the Nordic countries and the Netherlands, 61% of textiles end up in waste after only one cycle, and in the US the rate is as high as 85%. Textiles therefore represent a waste category that is poorly recycled and requires attention if the ambitious aims to reduce the amount of disposal waste overall are to be met. In addition, producing textile items from virgin materials is energy and resource consuming (Bärlöcher et al., 1999). Increasing the share of textile recycling will help to achieve

other environmental targets such as reducing CO<sub>2</sub> emissions and use of natural resources (Woolridge et al., 2006).

Based on Waste Framework Directive 2008/98/EC (European Commission, 2008), the primary way to recycle textiles is to use them according to their original purpose, or then as a raw material for new products without additional treatment (e.g. use the material of ripped cloth for a new cloth). If this is not feasible, the three most common ways to recycle fabrics are: 1) mechanical, 2) chemical, and 3) thermal treatment.

In mechanical recycling, the textile is handled mechanically by e.g. tearing and recycled at fiber level. However, this is only suitable for products made from a single material. In chemical recycling for cellulose-based materials, the textile waste, such as cotton, is dissolved in a way that its raw materials are returned to fibers and hence a usable textile raw material. Chemical recycling varies depending on the fiber type, and synthetic fibers can be recycled via the chemical repolymerization route. Chemical treatments can be also used to separate raw materials from a textile made from different materials. Chemical treatment can also be used to some extent for dirty material. In thermal treatment, the fibers are heated and can be melt-spun again into new fibers. However, textile fibers lose some of their features during this process; thus the resulting material can be used for producing plastics but is not suitable for recycling textile material.

Jahre (1995) lays out a framework for household waste collection as a reverse channel, analyzes different waste collection and sorting alternatives by using postponement speculation concepts (Boone et al., 2007), and suggests ten different propositions related to the issue. Based on the paper by Jahre (1995), increasing the number of fractions separated by collection level leads to higher collection costs but smaller sorting costs than where the numbers of separated fractions are smaller. However, increasing the number of fractions also creates more work for the consumer and heightens the risk that the material will not be suitable, as consumers may not properly separate the fractions. Nevertheless, when the number of fractions is smaller, there is greater risk of contamination with different materials, which complicates sorting in later phases of the supply chain. (Jahre, 1995)

In summary, recycling eol textiles offers significant environmental benefits but is difficult to organize cost-effectively. Therefore, the eol textile recycling network should be considered as an entity in order to get the total costs for recycled textile material. In addition, a holistic view requires operations planning to be widely applicable and to support the general target of creating a functioning recycling

ecosystem. Therefore, solutions that offer benefits locally but are problematic in a network perspective should not be adopted. (Bing et al., 2016).

### 3 Methodology

The paper is based on a single case study (Yin, 2013) of designing a countrywide eol textile recycling ecosystem in Finland.

The data collection methods used in the paper are literature searches and mixed methods research (Johnson et al., 2007). In mixed methods research, a researcher or team of researchers integrates qualitative and quantitative research approaches within a single study or a set of closely related studies (Johnson et al., 2007; Creswell, 2009; Bryman and Bell, 2011). The main qualitative methods used were observation of the processes, interviews and workshops, while quantitative modelling (Bertrand and Fransoo, 2002) was mainly used to employ and analyze the data obtained from qualitative sources. The actual collection of qualitative and quantitative data was mostly conducted during the same stage, thus the approach of this study is concurrent triangulation design (Castro et al., 2010). The use of mixed methods is encouraged in supply chain management (SCM) research, because SCM phenomena are often complex and dynamic (Golicic and Davis, 2012). Finding functional and cost-effective processes for collecting, sorting and handling eol textiles is just this type of SCM phenomenon, as the relevant literature is scarce and existing textile recycling systems are limited. Therefore, different methods were combined to obtain reliable answers to the research question instead of building an expensive textile recycling system that might fail.

The literature search examined all kinds of electronic material related to eol textile recycling (scientific papers, research and project reports and other articles). In addition, figures on the costs, speed and capabilities of related technological solutions were sought by probing the web pages of equipment manufacturers and organizations running used textile collection pilots, among others. The search used keywords such as 'textile recycling' and 'used textile collection'. It emerged that there is very little literature on the logistics of organizing eol textile recycling. As the technology related to sorting and reusing textiles is still in its infancy, the technological questions lean heavily on the current literature.

The authors visited three plants that use recycled textile as a raw material for new products: two in France and one in Estonia. The visits gave an idea of the criteria

required by eol textile raw material to make it eligible. The authors also visited two textile sorting centers: one in Germany and one in Estonia. In the semi-automated eol textile sorting center in Germany, human workers do the actual sorting but conveyor belts move the material. In the Estonian sorting center, which is run by a charity organization, human workers do all the sorting manually. These visits provided information on the costs and speed of different sorting systems.

Interviews with ten representatives from six organizations provided information on current processes and figures that could help design an eol textile recycling system, as well as expert input on various aspects of the recycling. The organizations were a charity organization collecting funding by selling used textiles, two regional house-hold waste management companies, an environmental service company, the Finnish Solid Waste Association, and an agent selling equipment for recycled textile material handling and treatment. The interviewees worked as logistics managers or experts in textile recycling. The organizations were also involved in projects related to eol textile recycling and gave valuable insight into their experiences. The interviews were semi-structured, with prepared questions intended not only to obtain specific answers and figures, but also to lead open discussions on the organizations' viewpoints and activities.

Stakeholders related to eol textile recycling were also invited to a workshop. The 18 participants included representatives of a regional waste management company, two charity organizations that collect funding by selling used textiles, two universities, a research institute, an organization representing textile and fashion commerce, the Finnish Solid Waste Association, and four organizations that sort used textiles and/or use them as raw material for new products. The purpose of the workshop was to evaluate different scenarios designed for organizing eol textile recycling in Finland and to estimate the related figures.

The first version of a process model for eol recycling was developed based on the literature research, then further elaborated based on the process observations, interviews and workshop. The process model worked as a basis for the cost model, which was designed to give numerical values for different options and scenarios for organizing eol textile recycling in Finland and to respond to research questions. The cost model was built using activity-based costing (Cooper and Kaplan, 1991) and typical components of investment cost-profit analysis (Drury, 2015). The model consists of the following process phases:

- 1) Collection of eol textile material. The potential volumes of recyclable textile waste were based on figures from Statistics Finland. The organization of eol textile collection was planned together with experts from a regional

household waste management organization. To get cost figures related to textile collection, the authors interviewed the representatives of another regional household waste management organization, which was running an eol textile collection pilot. In addition, the clothes-collection manager of a charity organization shared insight on how they have organized their countrywide used-clothes collection in Finland. Different eol textile collection alternatives and the related costs were discussed in a workshop.

- 2) Sorting of eol textiles. Different alternatives for organizing the sorting of eol textiles were discussed in interviews and a workshop. The cost model enables comparison of the following alternatives: First, the collected textile material is sorted in the regional collection centers of regional household waste management organizations. Second, the textile material is perhaps quickly presorted in these centers, but most of it is transported to centralized sorting that deals with all the textile material collected in Finland. The cost model also enables comparison of the costs of manual, automation-assisted, and fully automated sorting with different parameters.
- 3) Treatment of sorted textiles. Based on previous studies related to the content of eol textile material, the model gives the amounts of different textile raw materials (e.g. cotton, polyester etc.). The model then offers different alternatives for treating the sorted material in such a way that it can be used as raw material for new products. In addition, the cost model calculates all the costs of the selected previous process phases to offer production costs per kilogram for usable textile raw material.

The designed cost model was validated by presenting the cost model to Finnish eol textile related stakeholder organizations and asking for their expert feedback on the credibility of the figures.

## 4 Case Findings

### 4.1 Background Information

In Finland, consumers and institutional households discarded around 71 million kilograms of textiles in 2012. It is estimated that around 77% (54.7 million kilograms) of these textiles ended up as municipal waste and roughly 23% (16.4 million kilograms) was passed to charity organizations. Around 20% of the textiles received by charity organizations ended up as municipal waste. (Dahlbo et al., 2017). Given that there are around 5.4 million inhabitants in Finland, this means that 10.6 kilograms per capita of eol textiles ended up as municipal waste and thus in landfills or as part of energy production. Even though 58.5 tons of eol textiles is not a large share of the total 1,800 tons of municipal waste that ended up in landfills and energy production in 2012 (Statistics Finland, 2018), there is increasing pressure to improve the reuse of textile material; eol textiles are poorly suited to energy production and almost all landfill sites in Finland have been closed since 2012 (Statistics Finland, 2018).

Municipalities representing over 95% of the Finnish population have joined their waste management under 33 municipal bodies or similar organizations. These 33 organizations are members of the Finnish Solid Waste Association. The association shares the latest information on the effects of new regulations and best practices concerning e.g. separately collected material collection. Depending on the organization, private companies or entrepreneurs can handle different tasks such as waste collection, treatment or energy production. Especially smaller organizations also cooperate in certain areas of waste treatment, such as collection of certain separately collected materials, or they have common treatment or waste burning plants.

### 4.2 Recommendations for Eol Textile Collection and Sorting Operations in Finland

Based on the expert interviews and workshops, the collection and sorting of eol textiles should be organized as follows in Finland:

Cooperation is desirable between charity organizations that collect reusable clothes and regional municipal waste collectors that collect eol textiles primarily

for material recycling. The waste hierarchy model encourages the reuse of textiles by processing these as little as possible (Gharfalkar et al., 2015). Thus used textile collection processes by charity organizations should be encouraged to separate reusable textiles from other textile material. To minimize contamination of reusable material with other eol textile material, the best option would be for reusable textile material to be collected by charity organizations and other eol textile material by regional house-hold waste management organizations. In practice, consumers would deliver their eol textiles to specially allocated containers situated in recycling centers, where other waste categories are also collected separately. Neighboring regional household waste management organizations could of course cooperate and have joint facilities for eol textile handling, but the concluding idea was that every organization would first transport their collected textile material to their own handling center.

There are several alternatives for defining the role of a regional handling center and thus how its operations should be organized. The alternatives are either to sort the collected textiles locally in a handling center or pack them tightly in full trucks for transport to centralized handling. The benefits of local handling include a reduced need for transportation and local availability of the sorted raw material. The challenges of this alternative are that because textile volumes are small, manual sorting might be the only alternative if investments in automation are not economically justified. The benefits of centralized handling are bigger volumes that e.g. make investments in automation more economically feasible, but the transport costs are higher.

Based on the experiences of charity organizations with textile collection and of regional household waste management organizations with eol textile collection pilots, textile collection faces a number of challenges that affect the sorting process. To begin with, most consumers do not have the expertise to sort clothes as reusable or non-reusable.

This makes cooperation between charity and household waste management organizations important. Charity organizations already deliver unwanted textiles to waste management organizations. In the future, most of that material will be passed on to textile recycling and only a small non-recyclable portion will end up as mixed waste. Consumers also hand over reusable clothes to eol textile collection by waste management organizations. Stakeholders in current eol textile collection pilots are therefore interested in studying the content of collected textiles to determine whether it makes sense to sort through them man-

ually to separate reusable clothes before contamination happens in later process phases.

Another challenge related to collection is the presence of harmful content among collected textile material such as moldy, wet or oily clothes. This should be separated out as early as possible to avoid spoilage of a larger batch of textiles. During the workshop, the experts from stakeholder organizations proposed the following for eol textiles: generally, they were in favor of centralized sorting, which makes automation economically viable. However, they suggested that workers of e.g. charity organizations would manually presort textiles at regional sorting centers by separating out both reusable clothes and harmful material. If the quantity of reusable clothes is reasonable, their value will offset the costs of presorting. And if the sorters manage to separate out harmful material, the sorting organizations may get some rewards, as this presorting will smoother phases later in the process.

#### 4.3 Treatment of Sorted Textile Material

Depending on how the sorting is organized, other operations may be needed before or after sorting. In general, any treatment raises costs and is preferably avoided. However, some treatment is needed depending on the material and the needs of users:

- 1) Components, such as zips and buttons, must be removed.
- 2) The fibers must be opened and cut up into relatively small pieces.
- 3) The textile material may need washing depending on the need of the end-user. However, this raises the costs of the material, as drying requires both space and energy.

#### 4.4 Cost Estimations for Organizing Eol Textile Recycling in Finland

Based on the cost model, it seems that sorting of textiles is the most expensive phase of eol textile recycling, if mechanical recycling is used. Another expensive phase is collection of materials. The operations of regional handling centers incur costs, but these are much smaller than the costs of collection and sorting. Textile

material treatment can also be expensive, but these costs depend on the required treatment. Transport costs of packed collected textiles between regional handling centers and centralized sorting represent only a small share of the total costs of recycling.

The purpose of the cost model created during the research is to get an estimation of the costs per kilogram of recycled ready-for-use textile material in Finland. This cost has several uncertainties, but based on the research, the following estimations can be offered:

Some estimations for eol textile collection can be made based on the experiences of charity organizations, and on discussions during the workshop. The authors estimate that adding eol textile collection containers to existing recycling centers (one collection place per 10,000 inhabitants on average) could during the first phase enable collection of some 40% of potential eol textile that currently goes to mixed waste. This would entail annual collection costs of around two million Euro, derived from the estimated costs of refuse trucks and containers.

The authors also estimate that with cooperation between regional household waste management companies, the number of local handling centers could be roughly equivalent to the number of administrative regions in Finland (18). If the annual costs of a single local handling center are around 50,000 Euro, the total costs would be of the order of one million Euro. This would include the costs of presorting, if charity organizations are willing to this without substantial costs and the amount of harmful content remains small.

The costs of transport between regional handling centers and centralized sorting can be estimated fairly accurately if textile volumes and the place of sorting are known. Currently, the regional household waste management organization in Southwest Finland has the most advanced plans to build eol textile sorting and treatment facilities. If centralized sorting is situated in Turku, the weighted average transport distance between regional handling centers and centralized sorting will be around 270 km and the transport costs around 300,000 Euro.

The costs of centralized sorting vary widely depending on the sorting methods and technologies used. The most cost-efficient way to handle sorting would be to use automation as much as possible. Based on the experiences of charity organizations' manual sorting efficiencies the authors estimate that manual sorting would cost around 4.5 million Euro annually. The figure is roughly the same whether manual sorting is centralized or decentralized, but in decentralized

manual sorting, presorting may not be needed. The second alternative, automatic-assisted sorting, would double the effectiveness of one sorter but incur additional costs over manual sorting to make up around three million Euro annually. For the third alternative, different technological solutions exist for automated sorting, but given the limited number of automated sorting lines in production use it is difficult to estimate the performance. Also, since the technology is still young, the performance will probably improve and the costs drop significantly in the near future. Based on the figures from an advanced European technology provider, the authors estimate that the annual costs of automated sorting would be around two million Euro.

The costs of treatment will depend on the treatment needs. If the purpose is to use mechanical recycling, adding a cutting machine to the end of automated sorting lines would be a relatively small cost. There are also technological solutions for removing non-textile material from textiles. However, other treatments like washing will increase treatment costs. For chemical recycling the costs are substantially higher than for mechanical recycling, but using chemical treatment allows the use of mixed and somewhat dirty materials that could not be used after mechanical treatment. Thus the output volumes of chemical recycling could be higher than with mechanical recycling — depending of course on the content of the processed textile material.

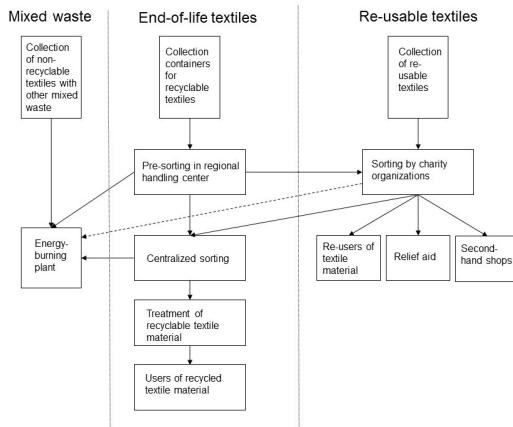


Figure 1: Suggested process for organizing reuse and recycling of excess textiles of households.

In summary, depending especially on the quality and volumes of collected material but also on the availability and costs of technological solutions for sorting textile material, the cost of usable recycled fiber raw material will be between 0.7-1.3 Euro/kg if mechanical recycling is used. Figure 1 shows the suggested process for organizing the reuse and recycling of excess textiles from households.

## 5 Conclusions

When considering the creation of an eol textile ecosystem from an SCM perspective, the most obvious challenge is to similarly create demand and enable an adequate supply of raw material. There is currently a limited demand for recycled textile material that might be more expensive than the corresponding virgin material. On the other hand, if an organization decides to invest in production using recycled textile material on a large scale, supply will quickly become a problem.

Therefore, by involving stakeholders such as raw material collectors, potential end-users and technology developers in joint development projects, the ecosystem has better possibilities to evolve. One essential precondition for ecosystem development is cost-effective logistics, which requires information about the costs and volumes of raw material when the recycling system is in production use. The developed cost model aims to contribute to this challenge.

Based on the results of the study, it seems possible to produce recycled textile raw material at a reasonable cost. However, achieving this requires the latest automation technologies and willingness on the part of consumers to spend some time separating their old textiles from other waste and taking them to collection containers. Once the ecosystem is in use, however, the processes involved will be further developed and the technology become cheaper.

For an SCM point of view, the organization of sorting is a key issue. Based on the study, two-phased sorting was recommended as follows: First, presorting where usable clothes and harmful material are separated from other eol textile material. Second, actual sorting where different textile materials are separated based on their material into 10–20 different fractions. Even if this kind of sorting was seen as the most workable, it is not the most effective. The best alternative would be automated sorting without presorting. The main motivation for presorting is that the collected material probably includes harmful content, which should be separated out as early as possible. When eol textile is collected using containers in unmanned sorting stations, it is difficult to avoid this kind of harmful content. However, if the collection system could be different, for example by getting apparel stores to organize the collection of used textile material, the amount of harmful content would probably remain minimal. If separating reusable textile becomes the only reason for presorting, it could be arranged to be more focused. Different collection methods and places most likely comprise different shares of reusable textiles. Presorting could then be focused on places where the share of reusable textiles is large. Where the amount and quality of reusable textiles are low, it is probably environmentally and ethically more sustainable to recycle these textiles as new raw material than to try to separate potentially reusable textiles and find users for those textiles in developing countries.

The study presented here has the following limitations: First, the figures are based on approximations using the best available information, as to our knowledge large-scale eol textile collection and a recycling ecosystem have not yet been developed. In addition, especially the figures related to collection rates and the share of non-recyclable textiles are only estimations based on expert opinions,

eol textile pilot tests and recycling of other types of material such as plastics. Therefore, the presented cost estimations have a fairly wide margin of error. Second, the results of the paper are not fully generalizable to other countries, as there are big differences within a single country. For example, people living in the countryside and in metropolitan areas use different types of clothes, which affects the composition and quantity of the collected material. Collection costs are also higher in sparsely populated communities. Because some figures of the cost model are based on experiences from local pilot experiments, the figures could have been different if the pilot has been carried out elsewhere. Therefore, before generalizing the results to other countries, the circumstances in Finland need to be considered first.

Related to almost every other waste category, appropriate management of textile waste requires further division of different types of processes. Depending on the textile item it may end up for reuse, recycling or as energy waste. Usually the reverse logistics process for separately collected waste categories has two destinations: If the collected batch meets the standards, it is passed on to recycling; if not, it is sent to energy waste or for disposal depending on the material type. In contrast, the reverse logistics process for items like wooden pallets has two options: either the pallet will be eligible for reuse (some fixing can be done if needed) or it will become energy waste. Thus the conducted research related to eol textile processes can offer novel viewpoints for diversifying reverse processes of other waste and recyclable item categories.

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## References

- Asaadi, S., M. Hummel, S. Hellsten, T. Härkäsalmi, Y. Ma, A. Michud, and H. Sixta (2016). "Renewable High-Performance Fibers from the Chemical Recycling of Cotton Waste Utilizing an Ionic Liquid". In: *ChemSusChem* 9.22, pp. 3250–3258.
- Bärlocher, C., R. Holland, and B. Guija (1999). "The impact of cotton on freshwater resources and ecosystems: A preliminary synthesis". In: *WWF Background Paper*.
- Bing, X., J. M. Bloemhof, T. R. P. Ramos, A. P. Barbosa-Povoa, C. Y. Wong, and J. G. van der Vorst (2016). "Research challenges in municipal solid waste logistics management". In: *Waste management* 48, pp. 584–592.
- Boone, C. A., C. W. Craighead, and J. B. Hanna (2007). "Postponement: an evolving supply chain concept". In: *International Journal of Physical Distribution & Logistics Management* 37.8, pp. 594–611.
- Bryman, A. and E. Bell (2011). *Business research methods*. Oxford University Press, USA.
- Castro, F. G., J. G. Kellison, S. J. Boyd, and A. Kopak (2010). "A methodology for conducting integrative mixed methods research and data analyses". In: *Journal of mixed methods research* 4.4, pp. 342–360.
- Commission, E. et al. (2008). "Directive 2008/98/EC of the european parliament and of the council of 19 november 2008 on waste and repealing certain directives (waste framework directive)". In: *LexUriServ. do*.
- Cooper, R. and R. S. Kaplan (1991). "Profit priorities from activity-based costing". In: *Harvard business review* 69.3, pp. 130–135.
- Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.
- Dahlbo, H., K. Aalto, H. Eskelinen, and H. Salmenperä (2017). "Increasing textile circulation & Consequences and requirements". In: *Sustainable Production and Consumption* 9, pp. 44–57.
- Davis, B. and L. Ding (2018). "China's waste import ban upends global recycling industry". In: DRURY, C. M. (2015). *Management and cost accounting*. Andover.
- Edjabou, M. E., M. B. Jensen, R. Götze, K. Pivnenko, C. Petersen, C. Scheutz, and T. F. Astrup (2015). "Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation". In: *Waste Management* 36, pp. 12–23.
- Finland, O. S. of (2018). "Municipal waste 2016". In:
- Gharfalkar, M., C. Campbell, Z. Ali, G. Hillier, et al. (2015). "Analysis of waste hierarchy in the European waste directive 2008/98/EC". In: *Waste management* 39, pp. 305–313.
- Golicic, S. L. and D. F. Davis (2012). "Implementing mixed methods research in supply chain management". In: *International Journal of Physical Distribution & Logistics Management* 42.8/9, pp. 726–741.
- Jahre, M. (1995). "Household waste collection as a reverse channel: A theoretical perspective". In: *International Journal of Physical Distribution & Logistics Management* 25.2, pp. 39–55.
- Johnson, R. B., A. J. Onwuegbuzie, and L. A. Turner (2007). "Toward a definition of mixed methods research". In: *Journal of mixed methods research* 1.2, pp. 112–133.
- Norris, L. (2015). "The limits of ethicality in international markets: Imported second-hand clothing in India". In: *Geoforum* 67, pp. 183–193.
- Pulkkinen, S. and S. Sinisalo (2012). "Quality and quantity of household mixed solid waste in the Helsinki metropolitan area 2012". In: *Helsinki Region Environmental Services Authority, Finland*.

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## REFERENCES

- Will M. Bertrand, J. and J. C. Fransoo (2002). "Operations management research methodologies using quantitative modeling". In: *International Journal of Operations & Production Management* 22.2, pp. 241–264.
- Woolridge, A. C., G. D. Ward, P. S. Phillips, M. Collins, and S. Gandy (2006). "Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective". In: *Resources, conservation and recycling* 46.1, pp. 94–103.
- Yin, R. K. (2013). *Case study research and applications: Design and methods*. Sage publications.



# Electric Vehicles at Public Organisations in Hamburg

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*According to the Hamburger Klimaplan, 50% of all vehicles in public fleets in the city of Hamburg are to run on electricity by the year 2020. For state owned enterprises, a reduced percentage of 35% is expected (Bürgerschaft der Freien und Hansestadt Hamburg, Drucksache 21/2521, 8.12.15). The purpose of this study, which was conducted from November 2015 to June 2017, was to gather the current state and forecast the percentage of electric vehicles in the respective public fleets and to identify conditions and enablers, that would support reaching the targets of the Hamburger Klimaplan. The study covers both the public administration and the public companies in Hamburg, as well as in the metropolitan region. Relevant data was acquired with an extensive pre-processing and analysis of existing motor vehicle registration data, followed by an online questionnaire and a management tool to monitor and plan fleet electrification on single vehicle level. Finally, expert interviews were conducted with the respective units. The study covers more than 70% of all city-owned vehicles. Based on the results of the study, the authors present scenarios for the future development of the percentage of e-vehicles in the respective fleets, including the expected progress towards the given targets. Further findings confirm the feasibility of the targets set under certain preconditions, like availability of specific types of vehicles. Best practices of successful units are summarized and include e.g. active management involvement with regular reporting of the composition of the vehicle fleet*

**Keywords:** Electric Mobility; Electric Vehicle; Scenario; Hamburg

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## 1 Introduction

### 1.1 Background

The majority of climate changing gases are released in cities, in which more than half of the world's population resides. Because of this fact, Hamburg's Senate has decided to take a stand. As a result of the 2015 United Nations Climate Change Conference (UNCCC) in Paris, France the Free and Hanseatic City of Hamburg (FHH) has taken initiative on greenhouse gas reduction and developed a climate plan. Using the climate plan, the FHH targets 50% electric vehicles (e-vehicles) within public administrations' and 35% within public companies' fleet by 2020 (Hamburg, 2015).

Analyses in the context of electric mobility (e-mobility) usually cope with vehicles of private citizen or commercial enterprises and how to achieve a higher pervasion of e-vehicles (Ajanovic & Haas, 2016; IEA & OECD, 2012; Hall, et al., 2017; Spath, 2012; EAFO, 2017a; Taefi et al., 2016). As of today, no specific publication focusing on the use of e-vehicles within state-owned organisations has been published. However, public fleets can play a major role for increasing e-vehicles share.

This paper is based on a study, conducted in Hamburg between November 2015 and June 2017, covering knowledge and application of regulations for e-vehicles, as well as the usage and forecast for e-vehicles in public administrations' and public companies' fleets. The study consists of an online questionnaire and 24 expert interviews. It deals with the research question of the current status of e-mobility in the FHH and metropolitan region of Hamburg (MRH). It will be analysed whether the goals of the climate plan will be achieved by public organisations in the FHH and the MRH, and how to increase the percentage of e-vehicles in public organisations' fleets.<sup>1</sup>

### 1.2 Electric mobility

Significant changes in the Earth's climate have been expected for decades, but the pace has never been as quick as it is today, which is why the UNCCC draws

<sup>1</sup>In this paper the term "state-owned" is understood as synonymous to "public" and the term "enterprises" is understood as synonymous to "organisations". The terms "organisations" and "enterprises" are understood to describe the total of administrations and companies.

great attention to the fact (United Nations, 2016). Road transportation as one of many examples accounts for a large share of greenhouse gas (GHG) emissions worldwide. From 1990 to 2015 GHG emissions from road transportation within the European Union and Iceland increased by 142 million tonnes CO<sub>2</sub>, whereupon road transportation is responsible for about 20% of all Europe's GHG emissions (approx. 10% globally). Simultaneously, the overall European GHG emission level decreased by 1,336 million tonnes CO<sub>2</sub> (equivalent to 23.6%) (EEA, 2017). The numbers stated above underline that there is a severe need for vehicles with alternative drive trains, so called "green mobility" (Bekiaris, et al., 2017; Leal Filho & Kotter, 2015). A goal of the UNCCC is to ensure that actions must be taken now, as a way to further prevent the increase in global temperature in the years to come (United Nations, 2016). As conventional vehicles can no longer satisfy all future mobility, the number of e-vehicles has increased to nearly 1.3 million units worldwide by the beginning of 2016 (around 947 million passenger cars and 335 million commercial vehicles were in operation worldwide at this point in time) (Fornahl & Hülsmann, 2016; Organisation Internationale des Constructeurs d'Automobiles, 2018). From 2015 to 2016, the number almost doubled and surpassed the 2 million-vehicle threshold at the end of 2016 (IEA & OECD, 2017). Heavy subsidies account for a share in this increase (Statista, 2017).

### 1.3 Governmental responsibility

E-mobility is not only a field of scientific interest but is strongly promoted by policy makers. In the United States e.g. automakers must meet the carbon dioxide standards introduced by governmental agencies like the Environmental Protection Agency (EPA) or else they are penalized. Since 2018, the Chinese government has placed demands on the auto industry to have the production of e-vehicles make up for 8% of their total manufacturing (Bundesregierung, 2011; Statista, 2017). Several political decision-makers expressed the ambition to become leading in the area of e-mobility. London, (Greater London Authority, 2015), Amsterdam (Netherlands Enterprise Agency, 2017; Tietge, et al., 2016), Oslo (Transportøkonomisk Institutt, 2013; EAFO, 2017b; Eltis, 2014), Copenhagen (EnergiWatch, 2016; City of Copenhagen, 2012; Hall, et al., 2017) and Barcelona (EAFO, 2017a; City Protocol, 2017; ABM, 2016) are some examples.

Hamburg has been engaged in the development of e-mobility for years, which has resulted in a higher level of development compared to other regions in Germany.

The Hamburg Senate passed a masterplan of publicly accessible e-vehicle charging stations for users throughout Hamburg in 2013. This resolution stipulated that there would be 900 electric driven vehicles for the state-owned sector as well as 592 charging stations by mid-2016 (Hamburg, 2013). Through the development and compliance with the climate plan, with the gradual electrification of state-owned vehicle fleets, Hamburg's government is aiming to be recognized as a role model for e-vehicle usage. (Hamburg, 2015)

#### 1.4 Hamburg´s climate plan

Basis of the climate plan is a guideline on procurement of vehicles with low CO<sub>2</sub>- and pollutant emissions, which was defined and implemented in 2011. In 2015 this guideline was included in the general vehicle regulations of the FHH, so that for the procurement of vehicles for public administrations those with an alternative drive train are to be preferred. The regulation has to be fulfilled, if the average daily distance is less than 80 km, charging stations exist or can be established at frequented destinations and e-vehicles or fuel cell vehicles are available in the required size and configuration (Hamburg, 2014).

In the following the term "e-vehicle" is understood to identify motor vehicles with a permissible total weight of less than 2,600 kg and with the following types of drive: Purely battery driven; Hybrid, externally chargeable with petrol engine; Hybrid, externally chargeable with diesel engine; or Fuel-cell drive. Other hybrid vehicles, e.g. non-externally chargeable are not to be considered as e-vehicles.

The goal of the climate plan is to achieve a 50% share of e-vehicles in public administrations' fleets and 35% share of e-vehicles in public companies' fleets by 2020. Public administrations are e.g. specialised authorities, district administrations and state offices, public companies are legally independent entities with at least 50% shares of the FHH. The targeted percentages apply for passenger and commercial vehicles. Police, fire services and protection of the constitution are excluded from the climate plan. A divergent procurement of conventional vehicles is permitted for exceptions and with justification only, which leads to a reversion of the "exceptional-law-principle".

After this introduction (chapter 1), the research design of the study and the methodology of the study will be presented (chapter 2) and subsequent its results will be illustrated (chapter 3). The conclusion (chapter 4) will highlight main findings and critics, and finally the outlook (chapter 5) will present future prospects.

## 2 Research design

In this chapter the research design and methodology of the study will be explained – starting off with the timeline, followed by the structure of the study, ending with the methodology of the questionnaire and the interviews.

The goals of the study conducted are the following: a) To reveal findings about the development progress of e-mobility at public administrations and public companies. b) To help increase their percentage of e-vehicles of the overall fleet, according to specific forecasts by systematic and comprehensive data evaluation. And c) to assist funding bodies to identify and evaluate opportunities to increase e-mobility in public areas.

This study covers the analysis of the registration figures of the FHH. By systematically analysing questionnaires, it examines factors influencing the percentage of e-vehicles within the public organisations' fleets. Expert interviews were analysed, summarized and compared to identify best practices. Finally, a prognosis was created for the development of the percentage of e-vehicles within the public organisations' fleets, including different future scenarios.

Figure 1 illustrates the overall timeline of the study. Processing of the study took place from November 2015 to June 2017, with the data preparation starting July 2016 and the actual execution between February and May 2017.

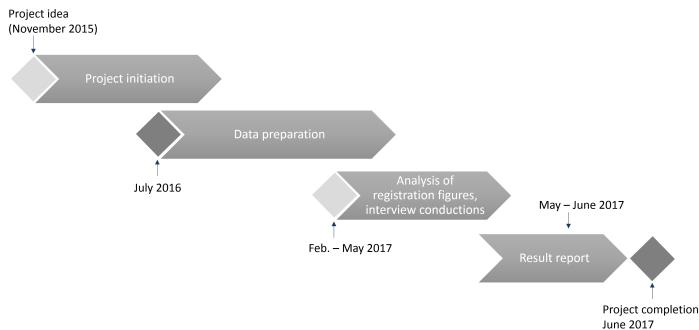


Figure 1: Timeline of the study

## 2.1 Analysis of the e-mobility share based on registration figures

Before the development of the study, registration figures have been analysed. It has proved to be difficult to ascertain involved cars, as neither the local, nor the central German vehicle registration index are designed for a systematic data analysis to screen out certain holder groups. The registration of the holder is a manual process and e.g. changes in organisations names can lead to different registration names for the same legal entity.

The total number of cars registered in the name of the city of Hamburg has been reduced to vehicles owned by public organisations. From all vehicles registered in the name of the city within one year, 8,400 relevant vehicles and the organisations owning these could be extracted. This was realised by firstly filtering the data by owner, secondly the application of further algorithms, and thirdly manual corrections.

Before the conduction of the interviews, the portfolios of e-vehicles of the total of public administrations and companies were analysed. The following Figure 3 and Figure 3 show the development of the number and share of e-vehicles for public administrations and public companies in the FHH respectively.

As the study had its closing date on June 30, 2017 this date has been selected as reporting date for the figures of the past three years.

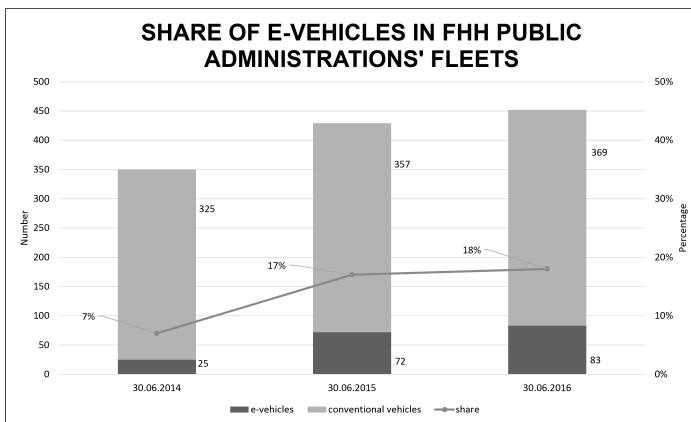


Figure 2: Number and share of e-vehicles within public administrations' fleets of the FHH

Figure 3 shows the development of the overall number of vehicles for public administrations within the FHH between 2014 and 2016. The overall number of vehicles and the percentage of e-vehicles rose. An increase from 7% e-vehicle share in 2014 to 18% in 2016 was achieved, with the largest development of 10% growth in 2015.

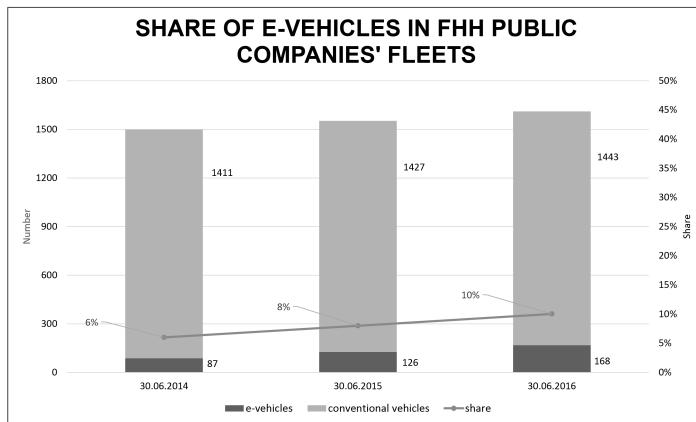


Figure 3: Number and share of e-vehicles within public companies' fleets of the FHH

Figure 3 demonstrates the development of the overall number of vehicles for public companies within the FHH between 2014 and 2016. Similar to the development of the public administrations' fleets, the number and percentage of e-vehicles of public companies rose: An increase from 6% e-vehicle share in 2014 to 10% in 2016 was achieved, with a continuous development of approx. 2% growth each year.

These figures reveal a difference between public administrations and public companies in the FHH. Apparently, the majority of public administrations was able to adapt to the higher e-vehicle percentages quicker than the public companies. The major increase for both groups took place in 2015, one year after the introduction of the procurement regulation. By June 2016, an overall share of 15,4% (2014: 6,5%, 2015: 12,5%) e-vehicles in public administrations' and public companies' fleets together has been achieved (including 79 e-vehicles operated without road registration).

Of all public organisations within the FHH and the MRH, those with a preferably large vehicle fleet were invited to participate in the next step of the study. On one hand participants with a high percentage of e-vehicles were invited in order to

study their motives and insights, on the other hand participants with an extremely low percentage were invited to share their insights on obstacles regarding the realisation of a higher e-mobility rate. Organisations with an average rate were not specifically addressed.

After the analysis of the vehicle portfolios of the surveyed organisations, opportunities for the increase of the percentage of e-vehicles for these organisations were assessed. These findings were integrated in the online questionnaire and the personal interviews. The approach of the interviews was designed with the following two steps: First, the top management of each examined organisation was addressed with the enquiry to take part in the study. Second, the interviews were conducted. Participation of the top management of the surveyed organisation was requested.

## 2.2 The questionnaire

The questions as indicated in Table 1 have been included in both the web-based questionnaire and the personal interview.

Hence, in total 24 public organisations, nine public administrations, and nine public companies in the FHH, and three public administrations, and three public companies in the MRH were analysed. Figure 4 illustrates the timeline of the events of the study.

Table 1: Overview of the questionnaire

Area addressed	Heading Three
Composition of the vehicle fleet	What is the number of e-vehicles in public organisations' car pools and the development of those? Are the registration numbers complete and accurate?
Special factors for vehicle acquisition	Which influencing factors exist and are they significant for former and future vehicle acquisitions?
Use cases / use profiles	How are e-vehicles used? Which usage profiles exist that facilitate or prevent the service of e-vehicles?
Future scenarios	Which scenarios could be created based on the above-mentioned issues?

Around two weeks prior to the interview date, a link for the web-based questionnaire has been send to each surveyed organisation via email. This questionnaire contained the number and models of vehicles registered on the name of the individual study participant.

A first evaluation of the questionnaire was carried out one day before the respective date of the interview. The summarised answers of the individual organisation were part of a presentation during the interview. In the course of the interview replies the questionnaire could be complemented. Replies could be amended by the interviewees for about a week after the interview date.

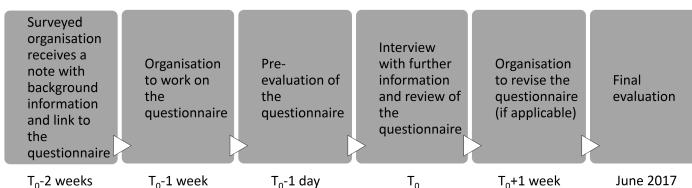


Figure 4: Timeline of the study

### 2.3 Content and methodology of the questionnaire & planning tool

The questionnaire has been divided in six sections, equipped with qualitative and quantitative parts, using closed and open questions, facilitating evaluation and comparisons. The first section dealt with the organisation, the second with the experiences with e-mobility and the third with guidelines and regulations. The fourth section has been divided in three subsections and asked the interviewee about the numbers of vehicles, actual ones from 2014 to 2016 and predicted ones for 2017 to 2020 in the first subsection. Causes for existing deviations have been treated in the second and the management process for the target attainment in the third subsection. Section five handled the vehicle usage and infrastructure. The sixth and last section has been split in two subsections. The first subsection asked about the perception of the effectiveness of potential measures. The second subsection of the questionnaire enquired about feedback. Processing the questionnaire could be paused at any time, following Dillmans (2014) guideline for mixing mode surveys giving the opportunity to back up in and continue the questionnaire at a later time.

With mixing mode survey design, as applied for this study, weaknesses of one mode can be overcome taking advantage of another modes' strength, thus minimising total survey error (Dillman, et al., 2014; De Leeuw, et al., 2008). Using a sequential approach for the mode change during the response phase improves coverage and responses while keeping costs down (Dillman, et al., 2014; De Leeuw, et al., 2008; Callegaro, et al., 2015). Within this study Dillmans (2014) "Type 4" of mixed-mode surveys, using two different modes to obtain responses from the same persons at different time points, was performed. As proposed by Callegaro (2015) the survey started with the less expensive mode, a web questionnaire building the ground, then proceeding with the more intrusive and expensive mode of face-to-face interviews enhancing a common understanding. The selected mixed-mode design provides the researchers with characteristic advantages such as lower costs and improved timeliness (Dillman, et al., 2014). As the answering of the questionnaire prepared the interviewees with an insight about the focus within the interview, effective face-to-face meetings were enabled. Specific mode effects which may be introduced by different modes within mixed mode surveys shall be minimised by dealing with the same content in both modes (online and face-to-face). Short intervals between the two applied modes, two weeks in this study, shall alleviate possible issues with data integrity within mixing-mode surveys. (De Leeuw, et al., 2008; Callegaro, et al., 2015) By having the web questionnaire as mandatory task before the interview an improved response rate was

enabled. With the interview subsequent to the questionnaire difficulties of understanding could be clarified. Afterwards room for amendments to reduce errors and inconsistencies was provided. (Dillman, et al., 2014; De Leeuw, et al., 2008)

### 3 Research results

Below an evaluation of the questionnaires and interviews, findings and best practices identified within a responder analysis are provided. This chapter concludes with a prognosis and the development of scenarios.

#### 3.1 Evaluation of the questionnaires

The 18 interviewed public organisations of the FHH operate 72% of the vehicles of all public organisations within the city. This circumstance makes the survey significant for the analysis of the current state and furthermore permits the derivation of forecasts with high confidence and measures with great effectiveness. Only considering the number of e-vehicles, the surveyed organisations operate 81% of all e-vehicles in the FHH. A similar analysis for the MRH was not possible as the number of vehicles could not be determined with sufficient precision.

In the following text, the results of each section of the questionnaire will be explained:

##### Part 1 – Organisation

Central role for the procurement of vehicles and implementation of guidelines is the involvement of the management of an organisation. In almost half of the surveyed organisation (48%) within the FHH top management controls the purchase of vehicles. In about a quarter (26%) the second management level is in charge. The remainder delegate this task to other management levels such as fleet managers. The organisations in the MRH show a comparable allocation.

Part 2 - Experiences and acceptance of e-vehicles

Lower pollutant emissions, followed by strategic rules have been selected as most significant reasons for the use of e-vehicles. Less driving noise and staff requests were assessed with less importance. This ranking is the same for public enterprises of the FHH and the MRH.

The user acceptance of e-vehicles for public enterprises of the FHH is overall high (74%). 11% of the public enterprises declared a very high user acceptance of e-vehicles and another 11% a medium acceptance. Only 5% declared a low acceptance of e-vehicles. Public enterprises of the MRH show a comparable high acceptance of e-vehicles.

As possibilities for increasing the user acceptance of e-vehicles, an improvement in range and a reduction in charging times for the vehicles were frequently selected. Both possibilities are in the focus of the current technical developments for e-vehicles. A raise in the number of charging stations and information sessions for interested individuals were evaluated as less effective. This ranking is the same for public enterprises of the FHH and the MRH.

For the rating of arguments against the use of e-vehicles high acquisition costs and missing charging infrastructure were ranked high. Organisations from the FHH ranked vehicle range on average between medium and high. Organisations of the MRH designated the same major reasons but with range considered as most important, followed by charging infrastructure and acquisition costs. Please note that merely six organisations from three districts within the MRH could be interviewed.

The answers revealed an awareness of the importance of a strategic regulation for e-mobility and the desire to fulfil those. At the same time a conflict of goals due to potentially higher costs of procurement was disclosed. This demonstrates the significance of project funding to compensate cost disadvantages of e-vehicles.

Part 3 - Guidelines and regulations

Knowledge about guidelines is mandatory for their implementation. Not all organisations of the FHH know the climate plan and the vehicle procurement regulations in detail. The plan is known well in 79% of public enterprises of the FHH, in 5% it is known very well. 42% of public enterprises of the FHH stated that

they know the procurement regulations well, and another 42% that they know them very well. As there exist no comparable guidelines and regulations within the MRH, so no equivalent analysis was possible.

#### Part 4 – Figures and forecasts

Two of the surveyed organisations operate e-vehicles without registration on a large scale. For one, those account for 15%, for the other for 13% of their overall fleet. Please note that these vehicles are not included in the subsequent study forecast.

The information gained within this section has been used for the development of the prognosis and scenarios.

#### Part 5 – Usage and infrastructure

Three (two public administrations, one public company) out of 14 organisations in the FHH that operate e-vehicles are not provided with sufficient availability of charging stations for their e-vehicles. All surveyed organisations in the MRH that operate e-vehicles have adequate charging stations at hand.

### 3.2 Findings of the survey

There were four major findings from organisations with a high e-mobility percentage:

1. There are specific goals for the transition from conventional to climate-neutral vehicles
2. The top management is familiar with the topic of e-vehicles, communicated the objectives and regulation and aligned the profitability assessment accordingly. The status of the goal achievement is presented regularly
3. The fleet manager is well informed about e-mobility and puts his knowledge sustainably and consistently into practice. Impediments are critically questioned

4. Experience with e-mobility establishes confidence. Organisations that are using e-vehicles assess obstacles as lower than those without own experience

The following needs have evolved for many participants in both groups: a) A market offer for e-vehicles for transportation of up to seven passengers. b) A market offer for smaller, industrially used e-vehicles with a higher cargo load, in the following called “e-workshop van”.

Information sessions and briefings for the use of e-vehicles were reported as counteracting for concerns about e-mobility. The expert interviews on the issue of e-mobility were received positively by all study participants. The desire to continue an exchange on e-mobility was expressed consistently.

#### Best practices and potential identification

In both groups best practices were performed after early actions by top management and with sound understanding of the climate plan and the vehicle procurement regulations. For public administrations for instance acceleration of an early changeover to e-vehicles was crucial. For public companies for example a premature determination of individual goals for e-mobility was decisive.

One positive example within the public administrations almost already achieved the target of the climate plan (50% share of e-vehicles) in 2016. They exploited structural conditions to ensure sufficient infrastructure for their e-vehicle fleet and analysed the logbooks of their vehicles. The analysis revealed the opportunity of a cost-neutral extension of their e-vehicle fleet to fulfil their mobility needs. Two positive examples within the public companies almost already achieved or exceeded the goal of the climate plan (35% share of e-vehicles) by the end of 2017. They consistently used financial funding and systematic trial drives of new models. They made the strategic decision for using company-owned e-vehicles for official trips only and made continuous analysis of mobility needs. Before an employee's first use of an e-vehicle an individual briefing was performed each time.

Within public organisations with lower percentage of e-vehicles than the majority, the climate plan and its goals were known fairly and acceleration of an early changeover to e-vehicles by top management was lacking. Within those public administrations for instance the majority of mobility needs were fulfilled

with private cars and employees had concerns about e-vehicles. Some of those public companies for example acquired gas-vehicles a few years ago, which are not considered as e-vehicles as defined in the climate plan Hamburg. For other companies, higher overall costs spoke against the procurement of e-vehicles due to their performance targets and no strategic budget for the transition towards e-mobility was allocated. These characteristics revealed potentials for an increase in percentage of e-vehicles.

### 3.3 Prognosis

Based on the estimations of future fleet planning of the interviewed organisations, a forecast for the development of the percentage of e-vehicles was designed. According to this forecast, the surveyed public companies within the FHH will possess overall 1,340 vehicles and will reach a share of 26% e-vehicles until 2020. The surveyed public companies within the MRH will possess overall 173 vehicles and will achieve a percentage of e-vehicles of 28% until 2020. Neither the public companies within the FHH, nor the ones within the MRH will achieve the target percentage of e-vehicles of the climate plan (35%) without additional measures.

According to the forecast, the surveyed public administrations within the FHH will possess overall 296 vehicles and will reach a share of 36% e-vehicles until 2020. Taking into account all trips, where private cars have been used, another 13% can be obtained. For this it was assumed that for all these trips company-owned e-vehicles would be purchased and used from 2018 on. The number of e-vehicles needed has been calculated assuming that each e-vehicle accounts for 8,000 km per year. The total distance performed in private cars for public administrations within the FHH in 2015 was used and it was assumed that the percentage of distances in private cars will be stable over time. 70 additional e-vehicles would need to be purchased to fulfil the distances driven in private cars. 100% additional expenditure compared to conventional vehicles has been applied. In this way the public administrations within the FHH could achieve a percentage of 49% e-vehicles, of overall 366 vehicles, until 2020.

The surveyed public companies within the MRH will possess overall 115 vehicles and will achieve a percentage of 22% e-vehicles until 2020. Neither the public administrations within the FHH, nor the ones within the MRH will achieve the target percentage of e-vehicles of the climate plan (50%) without additional measures.

### 3.4 Constructing scenarios

In the following text, only organisations from the FHH are taken into account as the figures for the total of organisations from the MRH are not considered to be sufficient accurate.

To construct scenarios, firstly scope and objectives were defined, which for this study is the development of percentage of e-vehicles within public organisations' fleets in Hamburg (Schoemaker, 1995; Axson, 2011; Ogilvy, 2015). Guidelines and regulations have been identified as key factors. The implementation of the climate plan in 2015 arose to have had a major impact on the development of the percentage of e-vehicles within the public administrations' fleets. This becomes apparent comparing the figures from 2014 and 2015. 2014 the surveyed public administrations together had a 7% share and 2015 a 17% share of e-vehicles within their overall fleets. The vehicle engineering of car producers was identified as major external force. The critical uncertainty is seen within the speed of the engineering processes of the car producers and the implementation rate and enforcement of new regulations (Schoemaker, 1995; Axson, 2011; Ogilvy, 2015). The following three measures were revealed as most important from the conducted study and are basis for the development of scenarios:

1. E-vehicles with seven passenger seats.
2. E-vehicles for the use as workshop vans.
3. *Public administrations only:* Ban of the usage of private cars for business trips and simultaneous procurement of e-vehicles for car pools. Public companies only: Increase of e-vehicles as company cars with private use; i.e. changed/ improved tax treatment of electric company cars.

#### Public administrations within FHH

In scenario one for the public administrations of the FHH it is assumed that the above stated measures one, two and three are fully effective. Figure 5, left side shows that in this scenario the public administrations within the FHH would be able to achieve a 76% share of e-vehicles. The ban of the usage of private vehicles for business trips is responsible for the major effect (19% e-vehicles share) (measure three), e-vehicles with seven passenger seats (measure one) for 18% and e-workshop vans (measure two) for another 10% e-vehicle share of the

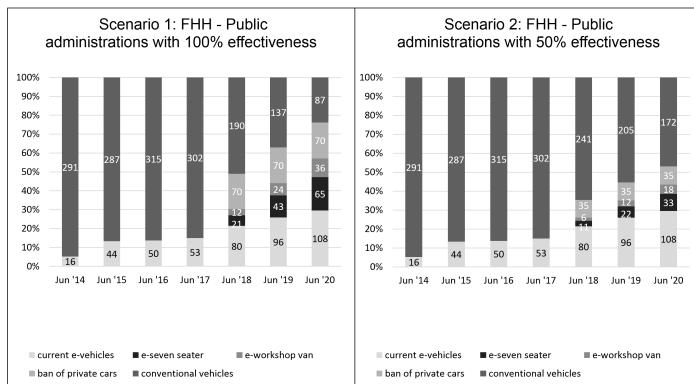


Figure 5: Scenarios for the share of e-vehicles within Hamburg's public administrations' fleets

overall fleets. In this scenario the share of e-vehicles would surpass the 50% target of the climate plan.

Scenario two assumes a 50% effectiveness of all measures. Figure 5, right side, shows, that in this scenario the public administrations would be able achieve a share of e-vehicles of 53% by 2020, which would surpass the 50% goal of the climate plan Hamburg. The ban of the usage of private cars for business trips, accounting for the major effect (10% e-vehicles share) (measure three), e-vehicles with seven passenger seats (measure one) for 9% and e-workshop vans (measure two) for another 5% e-vehicle share of the overall fleets.

#### Public companies within FHH

For scenario one for the public companies of the FHH it is assumed that all above stated measures are fully effective. In this scenario the share of e-vehicles within public companies within the FHH could be increased to 77% in 2020, as shown in Figure 6, left side. The use of e-vehicles as workshop vans (measure two) has the major impact (29%), e-company cars with private usage (measure three) accounts for 18% and e-passenger carriers (measure one) accounts for another 4% e-vehicle

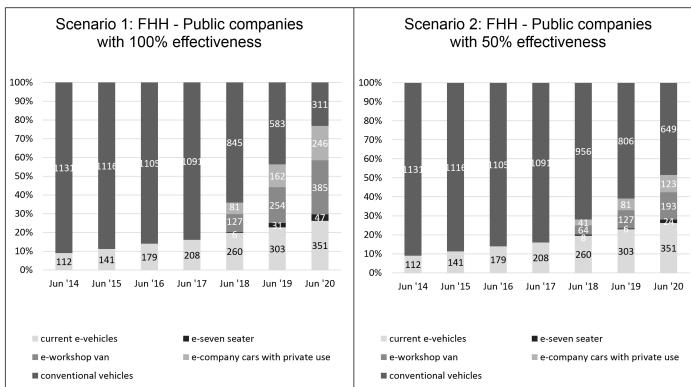


Figure 6: Scenarios for the share of e-vehicles within Hamburg's public companies' fleets.

share of the overall fleets. In this scenario the goal of the climate plan Hamburg (35% e-vehicles share) would be exceeded.

The second scenario has been constructed with the identified measures to be less effective. Scenario two assumes a 50% effectiveness of all measures. In this scenario the public companies would be able to achieve a share of e-vehicles of 52% as shown in Figure 6. This would surpass the 35% goal of the climate plan Hamburg. The use of e-vehicles as workshop vans (measure two) has the major impact (14%), e-company cars with private usage (measure three) accounts for 9% and e-passenger carrier (measure one) accounts for another 2% e-vehicle share of the overall fleets.

Without further amendments, neither the public administrations as a whole, nor the public companies in their entirety would be able to achieve the goal of the climate plan outright. Above identified measures will be needed to make use of existing potentials. The two constructed scenarios (100% and 50% effectiveness of measures) reveal the impact of the potentials for the surveyed groups.

## 4 Conclusion

The study conducted illustrates, that an increase of e-mobility percentages within public fleets is feasible. In order to identify the current percentages of e-vehicles within a certain public organisations' fleet, a consistent database and registration process for the central vehicles registration would be helpful.

To increase the e-mobility percentage in Hamburg systematically, the following actions have been taken by Hamburg Senate in 2017: A modified procurement approach so that e.g. public organisations need to provide more firm reasons for the purchase of a conventional vehicle instead of an e-vehicle.

It has become evident that organisations achieved the goals of the climate plan Hamburg, if they hold the following characteristics: They possess a certain “electric vehicle affinity” and the top management is personally involved. The development of mobility is regularly reported and economic disadvantages are compensated.

Further potentials have been revealed including fleet cars without registrations in the study. Adopting best practices from other cities, like Amsterdam could also help achieving the defined goals.

## 5 Outlook

The following actions were identified to exert a positive influence on the percentage of e-vehicles at public administrations and companies in Hamburg: The further (technical) development of e-vehicles with attention to specific models and range is a must. Electric company cars with private use should see a reduction in the “1% taxation” to make them as attractive as their gasoline- or Diesel-based counterparts. Available e-vans should be extensively introduced and used. Vehicles owners and fleet operators should be personally addressed by a professional contact to enable the exchange of experiences. An explicit and repetitive reporting system for policy-makers directing to quicker and secured attainment has to be introduced, which could include a structured database containing information on driven distances and consumptions of (e-)vehicles. This would allow a rapid and sustainable examination of proposed (non-)usability of different drive-trains.

With the above stated actions, the e-mobility percentage of public organisations in Hamburg could be increased by about 50%-points within about two years' time. These actions might also have a positive impact on the percentage of e-vehicles in public organisations in other German cities.

The larger number of vehicles in Hamburg's public fleets is operated by public companies, which make up for three and a half times the number of vehicles in public administrations. Further effects for e-vehicles in public companies could influence the number of e-vehicles at non-public companies in Hamburg and Germany and therefore the overall vehicle stock in Germany (23% of all registered vehicles in Hamburg are registered to a corporate entity). The reduction of the 1% taxation for privately used company cars and the extensive usage of industrially usable electric vans could have an effect on the number of e-vehicles in non-public companies. More research and further development for e-vehicles, as well as the reduction of 1% taxation is expected to encourage a further increase of the overall e-mobility percentage in Germany and to affect the entire German car fleet.

A consistent database and registration process for the central vehicles registration would be helpful for other studies of this kind. With such database a full-featured listing of vehicles of public administrations and public companies could be created, which would ensure more accurate data and an easier collection for comparative studies.

A study with a probability sampling of all public administrations and public companies e.g. at European level would produce other interesting research results. With the opportunity to analyse the total of public organisations, e.g. with obliged attendance of all organisations, such sampling could be realised. This might lead to more adequate comparable and representative research results.

Further goals of the climate plan Hamburg are by 2030 for the public administration to act CO<sub>2</sub> neutral and to reduce CO<sub>2</sub> emissions in Hamburg by 50% compared to 1990. By 2050 Hamburg wants to achieve a reduction in CO<sub>2</sub> emissions by 80% compared to 1990. (Hamburg, 2015) Whether these goals will be achieved is dependent on the actual increase of e-mobility in Hamburg within the next years.

## References

Agency, N. E. (2017). *Electric transport in the Netherlands 2016 highlights*.

- Agency), E. (E. (2017). *Annual European Union greenhouse gas inventory 1990–2015 and inventory report 2017*. en.
- Ajanovic, A. and R. Haas (Nov. 2016). “Dissemination of electric vehicles in urban areas: Major factors for success”. In: *Energy. Towards low carbon energy systems: engineering and economic perspectives* 115, pp. 1451–1458.
- Authority, G. L. (2015). *Mayor unveils London's Ultra Low Emission future*. en.
- Axon, D. (Mar. 2011). “Scenario Planning: Navigating Through Today's Uncertain World”. In: *Journal of Accountancy* 211,3, pp. 22–27.
- Barcelona), A. (M. de (2016). *Metropolitan commitment to clean mobility*.
- Bekiaris, E., M. Tsamis, and M. Panou (Jan. 2017). “A “Greening Mobility” framework towards sustainability”. In: *Transportation Research Procedia*. 3rd Conference on Sustainable Urban Mobility, 3rd CSUM 2016, 26 – 27 May 2016, Volos, Greece 24, pp. 131–136.
- Bundesregierung (2011). *Jahresbericht der Bundesregierung 2011/2012*.
- Callegaro, M., K. L. Manfreda, and V. Vehovar (May 2015). *Web Survey Methodology*. en. London: SAGE (Publications Ltd.)
- Copenhagen, C. of (2012). *CPH 2025 climate plan*.
- De Leeuw, E. D. d., J. Hox, and D. Dillman (2008). *International Handbook of Survey Methodology*. en. EAM series (European Association of Methodology Series). New York, NY, USA: Taylor & Francis Group.
- Dillman, D. A., J. D. Smyth, and L. M. Christian (Aug. 2014). *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. en. 4th ed. New Jersey: John Wiley & Sons.
- Economic Cooperation and Development), I. (E. A. Ö. (for (2012). *EV City Casebook - a look at the global electric vehicle movement*.
- Economic Cooperation and Development), I. (E. A. Ö. (for (2017). *Global EV Outlook 2017 – two million and counting*.
- Eltis (2014). *Oslo: electric vehicle capital of the world*. en.
- EnergiWatch (2016). *København vil satse på elbusser*. dk.
- Fink, A. (2017). *How to Conduct Surveys: A Step-by-Step Guide*. en. Thousand Oaks, California: SAGE Publications.
- Fornahl, D. and M. Hülsmann (2016). *Markets and Policy Measures in the Evolution of Electric Mobility*. en. Springer.
- Hall, D., M. Moultsak, and N. Lutsey (2017). *Electric capitals of the world*. en.
- Hamburg (2013). *Masterplan Ladeinfrastruktur*. de.
- Hamburg (2014). *Leitlinie zur Beschaffung von Fahrzeugen mit geringen CO2- und Schadstoffemissionen*. de.
- Hamburg (2015). *Klimaschutz und Klimawandel: Senat beschließt Hamburger Klimaplan*. de.
- Institutt, T. (2013). *Norwegian transport towards the two-degree target*.
- Leal Filho, W. and R. Kotter (Apr. 2015). *E-Mobility in Europe: Trends and Good Practice*. en. Springer.
- Nations, U. (Sept. 2016). *The Paris Agreement: FAQs on its affect on climate change*. en-US.
- Observatory), E. (A. F. (2017a). *Cities*.
- Observatory), E. (A. F. (2017b). *Norway*.
- Ogilvy, J. (2015). *Scenario Planning and Strategic Forecasting*. en.
- Protocol, C. (2017). *Logistics for the Implementation of the Electric Vehicle (LIVE)*.
- Schoemaker, P. J. H. (1995). “Scenario Planning: A Tool for Strategic Thinking”. English. In: *Sloan Management Review*; Cambridge, Mass. 36,2, pp. 25–40.

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## REFERENCES

- Spath, D. (2012). *Strategien von Städten zur Elektromobilität. Städte als Katalysatoren auf dem Weg zur Mobilität der Zukunft.*
- Statista (2017). *eMobility 2017.*
- Taeff, T. T., J. Kreutzfeldt, T. Held, and A. Fink (Sept. 2016). "Supporting the adoption of electric vehicles in urban road freight transport – A multi-criteria analysis of policy measures in Germany". In: *Transportation Research Part A: Policy and Practice* 91, pp. 61–79.
- Tietge, U., P. Mock, N. Lutsey, and A. Campestrini (2016). *Comparison of Leading Electric Vehicle Policy and Deployment in Europe.*



# Logistics Sprawl in São Paulo Metro Area

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*The location of logistics facilities close to consumers and well-planned transport infrastructure is important for the flow of goods and sustainability in the region. The main purpose of this research is to verify the logistics sprawl in São Paulo Metropolitan Area and to discuss its reasons. To verify the existence of the phenomenon, a sample of logistics companies' addresses has been selected and the geographic centers of this sample were calculated, using the barycentre of a set of points and then calculating the average distance of these points to the center. The analysis reveals the intensity of the phenomenon between the year 2000 and the beginning of 2017 and explores the attraction factors for logistic companies, including geographic, economic and tax aspects. The results reveal a small sprawl in the studied period for companies with a capital stock equal to or greater than 250 thousand reais, of 1.8 km in the northwest direction of São Paulo Metro Area.*

**Keywords:** Logistics Sprawl; Urban Sprawl; Relocation of logistics facilities; Geography of freight

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## 1 Introduction

During the last decades of the 20th century and at the beginning of this century, large cities have grown intensely, sprawling their structures and population beyond their usual boundaries. This phenomenon is known by the name of Urban Sprawl and always occurs in the suburban regions, around the access roads to the main city, being a development in hills and in low density (Burchell and Mukherji, 2003). The reasons for such sprawl were several. Burchfield et al. (2006) pointed to the following causes for urban sprawl in various regions of the USA: dispersion of employment, automobile dependence over public transportation, rapid population growth, real estate speculation on undeveloped land, ease of drilling a well for water supply, temperate climate, rugged terrain and no high mountains, amount of land available in areas not subject to municipal planning rules, low impact of public service financing by local taxpayers (Burchfield et al., 2006). In Peking, the causes for the urban sprawl were different. With land reform, the tax values charged differed, and many factories and warehouses left the central region in search of lower taxes. Another reason is the permission of public-private partnerships that have made incorporators invest in more central regions, besides the Government encourage the population to migrate to the suburbs. Local governments also made investments in the suburbs to improve the quality of life of the population (Wang and Yixing, 1999).

Although most studies on urban sprawl and expansion are more concentrated in countries of Europe or North America, it is possible to empirically confirm that the phenomenon exists in some Brazilian cities. São Paulo also suffers urban sprawl, with loss of population in central areas of the city due to the increase in investment by developers, increasing the population in peripheral areas (Torres, Alves and de Oliveira, 2007). Just as there is an urban sprawl phenomenon as in the case of São Paulo, is related to the price increase of central properties, there is a specific case of warehouses and logistics operators sprawl outside the boundaries of the metropolis (Cidell, 2010), known as logistics sprawl (Dablanc and Rakotonarivo, 2010).

Therefore, in order to propose public policies to make a better use of urban space, reduce the environmental and social impact, and increase the productivity of these companies, it is necessary to study the causes that push away these logistical structures from urban centers. Given the importance of this theme to megacities, this work aims to study the movement in space and time of ware-

houses and logistics operators within São Paulo Metro Area (SPMA), verifying if there were systematic changes in these dimensions.

The probable moves of these logistic companies may be to peripheral regions or municipalities and their appearance may be sparse or concentrated in a given microregion. In this research, the reasons why this movement occurs over time and its determinant factors to cause this phenomenon will also be discussed later. The second contribution of this work is to understand the dynamics of sprawl in developing countries cities such as Brazil, since most of the work on this subject refers to more developed economies.

This paper is divided into four sections. Section 2 refers to the literature review on "logistics sprawl". Section 3 is a brief presentation of the SPMA. Section 4 refers to data gathering of the companies used, as well as the cut made to get a sample of companies for the analysis. Section 5 presents and discusses the results. The conclusion presents a closure of the research and provides some recommendations for future research.

## 2 Literature Review

The subject of logistics sprawl is relatively recent in the academic literature. One of the first works was published by Dablanç and Rakotonarivo (2010), where the problem is defined. On the other hand, it is observed in the literature that this phenomenon appears indirectly in previous studies (Cidell, 2010; McKinnon, 2009; Bowen, 2008; Woudsma et al., 2008; Hesse, 2004b). This section approaches this phenomenon and tries to summarize the main factors that define the researches presented at the moment.

### 2.1 Definitions of Logistics Sprawl

Logistics sprawl is the dispersion of warehouses and distribution centers in the metropolitan region of a city (Dablanç and Rakotonarivo, 2010). Although there are other similar expressions to define the same problem, the term "logistics sprawl" has become better known in the literature (Aljohani and Thompson, 2016).

Table 1: Works about Logistics Sprawl

Author	Region/Sprawl Extension	Period
Dablanc and Rakotonarivo, (2010)	Paris Île de France: 10km	1974 – 2008
Dablanc, Ross, (2012)	Atlanta (Piedmont Atlantic Megaregion): 4,5km	1998 – 2008
Dablanc, Ogilvie, Goodchild, (2014)	Los Angeles Metro Area: 9.7 km; and Seattle Metro Area: -1.3 km	1998 – 2009
Sakai, Kawamura, Hyodo, (2015)	Tokyo Metro Area: 2,4km	1980 -2003
Woudsma, Jakubicek, Dablanc, (2016)	Greater Toronto Area:1,3km and Greater Golden Horseshoe: 9,5km	2002 – 2012
Heitz, Dablanc, Tavasszy, (2017)	Paris Île de France: 5km and Randstad Metropolitan Areas (Netherlands): Noord Holland: -2km; Zuid Holland: -1km; Flevoland: 3.3km; Utrecht:0.5km)	Paris (2004 – 2012); Randstad (2007 – 2013)
Oliveira, Santos, Nobrega et al., (2017)	Belo Horizonte Metro Area: 1,2km	1995 – 2015

Some studies have been carried out in recent years aiming to understand the extent of the phenomenon in the metropolitan areas. Table 1 is a summary of the main published works about the subject.

According to Table 1, although the subject is fairly recent, the periods surveyed vary widely, from 34 years (Paris Île-de-France) to only 6 years (Randstad). A second aspect is the scope of research, most of them focused on the metropolitan region of cities, following the hypothesis that this phenomenon is characteristic of large metropolises that serve as nodes of a large region, as well as being the center

of a consumer market (Dablanic, Ogilvie and Goodchild, 2014). The exceptions were the researches of Woudsma et al. (2016) which covered an area beyond the immediate metro area (Greater Golden Horseshoe), and Heitz et al. (2017) regarding Randstad (Netherlands), which was about a polycentric sprawl, in other words, with different metropoles of attraction in a single continuous region.

Most of the researches have proved the logistics sprawl of the cities, but there were two exceptions: Seattle had land available near the airport and the port, and this area is served by highways, causing companies to continue to settle in the region (Dablanic, Ogilvie and Goodchild, 2014) and Randstad, where the logistics companies were concentrated in the urban regions, probably due to a local planning policy and greater control of land use (Heitz, Dablanic and Tavasszy, 2017). Although most of the researches have been carried out for metro areas of developed countries, there are new researches in different regions, with two recent surveys, one carried out in Brazil, on the Belo Horizonte region (Oliveira et al., 2017) and a specific research about timber industry in New Delhi (Gupta and Garima, 2017).

The centrographic method was used in the majority of the researches and consists of calculating the barycentre of a set of points and then dispersing the points around this center. The choice of the barycentre is due to the fact that it is more sensitive to address changes over time (Dablanic and Rakotonarivo, 2010). The exception is the research of Sakai, Kawamura, Hyodo (2015) that was carried out using as a parameter the average distance between the logistics company and its points of origin (inbound) and destination (outbound). This calculation was carried out for all the companies, using the average of the Euclidean distance (Sakai, Kawamura and Hyodo, 2015).

## 2.2 Motivational Factors of Logistics Sprawl

There are many factors that contribute to logistics companies migrating from a central region to a more peripheral one. In 2005, it was found that storage in the United States was still concentrated in urban areas, but on the other hand, its growth was higher in suburban and exo-urban areas. In this case, the main reasons for this phenomenon were related to the access to different means of transportation, being the highway and the access to the airport the most relevant and with the greatest correlation with the growth of the number of warehouses, corroborating with the factor "speed of delivery" (Bowen, 2008). It is important to

notice that nowadays the speed of delivery is one of the most important factors for logistics companies (Lasserre, 2004) and that the truck and air transportation have more advantages compared to natural competitors - truck versus train in domestic transportation and air versus sea in international transportation (Bowen, 2008).

Distribution centers tend to move to more inland regions of the country and carriers to the suburban regions of major cities. The explanation for this change to the interior of the country is due to the increase of the volume transported and that the companies become more globalized. In this way, the warehouses near the ports became overloaded, forcing the companies to go inland. Moreover, the need to increase the profitability of enterprises leads them to occupy larger spaces, forcing them to move from urban centers to suburban regions, which are cheaper (Cidell, 2010).

Moreover, retailers and factories are delegating their logistics activities to specialized companies in this type of activity that, due to the gain in scale, seek more space to increase operations and stored stock, and in parallel, peripheral cities use tax subsidies to attract these companies (Hesse, 2004a). Another factor to be considered is the growth of e-commerce, which has led to an increase in demand for warehousing, order consolidation and shipment facilities, which implies five types of logistics structures: mega e-fulfillment centers, parcel sorting centers, local parcel delivery centers, local urban logistics depots and return processing centers (Morganti et al., 2014).

The increase in consumption of goods and merchandise also pressure logistics operators for more physical space and wider roads, allowing a growing flow of trucks to deliver goods. In this way, many activities related to the distribution of goods, moving from their traditional location in central areas, close to ports and railways, have changed to peripheral areas where road and airport connections are more predominant (Rodrigue, 2004; Woudsma et al., 2008).

Finally, we must also consider the increase in global trade, imposing on companies the need for more physical space (Cidell, 2011; Rodrigue, 2006). Lower costs are also a factor of attraction, where companies seek cheaper land costs in the suburbs (Dablanc and Rakotonarivo, 2010).

The price of central regions was also seen as a determining factor for the logistics sprawl, as well as the regulatory policies of the prefectures neighboring Tokyo (Sakai, Kawamura and Hyodo, 2016). A similar survey was conducted for Los Angeles and the main factors of sprawl were the lower price of land outside the city,

the policy of some municipalities in attracting warehouses, logistics infrastructure such as ports and roads already located far from the center (Dablanc, Ogilvie and Goodchild, 2014).

A survey about Toronto Metro area, despite some difficulties with the definitions of data, logistics companies are not distancing themselves significantly from the Toronto center as expected when considering only the Greater Toronto Area, because it was expected that there would be no land for this. On the other hand, when the study considers the Greater Golden Horseshoe region, which encompasses Greater Toronto, there is a strong evidence of logistical sprawling and, specifically, of warehouses. (Woudsma, Jakubicek and Dablanc, 2016).

### 2.3 Impacts of Logistics Sprawl

The impacts resulting from logistics sprawl have not yet been fully studied (Aljohani and Thompson, 2016). However, it can be assumed that all regions that have proven the increase of the logistics sprawl has the increase of distance traveled by the trucks in their deliveries as a consequence (Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012; Dablanc, Ogilvie and Goodchild, 2014; Sakai, Kawamura and Hyodo, 2015; Woudsma, Jakubicek and Dablanc, 2016; Oliveira et al., 2017). As a result of this increased distance, there is an increase of CO<sub>2</sub> emissions from vehicles, increasing the environmental impact, as demonstrated in the study for the Paris region, over 34 years of sprawl. On the other hand, as a suggestion to minimize logistics sprawl, the creation of a regional authority to examine permits for logistical developments and more consideration for new architectural solutions integrating logistics buildings within the urban center would be good solutions (Dablanc and Rakotonarivo, 2010).

In addition to the increased distance, the fact that there are warehouses and transshipment places in the peripheral region of cities attracts more heavy vehicles to this region (Allen, Browne and Cherrett, 2012). Gupta & Garima (2017) studied a specific economic sector - timber industry in New Delhi (India). The authors concluded a huge logistical expansion, being the expansion rate twice the increase of tonne transported, impacting directly on the distances and emissions traveled. The study concluded that a planned decentralization of timber logistics facilities could help reduce emissions by 59% and save 25% on energy.

### 3 São Paulo Metro Area

The studied region is São Paulo Metro Area (SPMA), located in the State of São Paulo, with more than 21 million inhabitants (Brazilian Institute of Geography and Statistics - IBGE, 2017). The 39 municipalities belonging to SPMA are: Arujá, Barueri, Biritiba-Mirim, Caieiras, Cajamar, Carapicuíba, Cotia, Diadema, Embu das Artes, Embu-Guaçu, Ferraz de Vasconcellos, Francisco Morato, Franco da Rocha, Guararema, Guarulhos, Itapeveri da Serra, Itapevi, Itaquaquecetuba, Jandira, Jiquitiba, Mairiporã, Mauá, Mogi das Cruzes, Osasco, Pirapora do Bom Jesus, Poá, Ribeirão Pires, Rio Grande da Serra, Salesópolis, Santa Isabel, Santana de Parnaíba, Santo André, São Bernardo do Campo, São Caetano do Sul, São Lourenço da Serra, São Paulo, Suzano, Taboão da Serra, and Vargem Grande Paulista.

The logistics structure of the region has ten highways that connect the city of São Paulo to all regions of the state, as well as a ring road linking most of them. The SPMA is surrounded by three airports. Airport of Guarulhos is the international airport of the region and there are two more airports located in the city of São Paulo itself, being an exclusive for executive aviation (Campo de Marte) and a civil aviation with domestic flights to the main Brazilian capitals (Congonhas Airport). The main connections of this network are the Port of Santos, the ports of the State of Rio de Janeiro, Minas Gerais and the central and southern regions of the country. The connection with the port of Santos, located 80km from São Paulo, is made through two highways.

### 4 Data and Sampling

The research is divided into two parts: the data collection of companies; sampling and georeferencing of the addresses where the companies are located.

#### 4.1 Data Gathering and Sampling

The companies' data of the 39 SPMA municipalities were collected on the Internet, from the website of State of São Paulo Commercial Board (JUCESP, 2017), which provides files in pdf format. Active and inactive companies were considered at the time of extraction. The following economic activity codes registered in

JUCESP (2017) and related to logistics and storage considered in this research are: 5250-8/05 Multimodal Transportation Operator; 5211-7/01 General Warehouses - Warrant Issue; 5211-7/99 Goods Warehouse for Third Parties, Except General Warehouses and Furniture Storage.

The data collection of these three economic activities was realized by the description of the activity and municipality, which consist of 4638 companies, occurred between January and February 2017. Eleven companies were cut out because they had the wrong city in the registry, and 66 companies due to inconsistencies in the activity description, leaving 4561 in total. Each business address was checked according to their current location in Google Maps®. However, this comparison revealed a real challenge, because as there was an incompatibility between some addresses reported by JUCESP and Google Maps. It was not possible to find the address for 495 companies, for the most part of them, the number was not found, even using the Street View® functionality (Google Maps). In addition, 1881 companies were not identified visually as logistics installation, that is, they were located in residences, shops, apartments or commercial rooms. One of the biggest challenges was identifying the right places, some of which are difficult to identify, and Google Street View® photos were taken at different times (e.g. the company was created in 2016 and the picture of the address was taken in 2011).

For this research, only companies with stock capital above US\$ 71,700.00 (R\$250,00.00) were considered in the analysis. Larger companies usually have a greater impact on traffic and the environment than smaller companies, and certainly must work with a larger volume of supplies and deliveries than smaller companies. Inside the set of 519 companies in the sample, some of them did not exist on these cut dates (2000 and 2017), that is, they started their operations after the analysis cut-off date and were closed before the next date, not appearing in the calculations. This phenomenon occurred with 59 companies and one company was discarded due to lack of reliable information in the register, remaining 459 companies in the final sample.

## 4.2 Geocoding

The company address' geocoding was performed using QGIS® software through the Google Maps API. However, although most of the geographic coordinates were found automatically, some were not found by the API and were manually referenced directly on the Google Maps® site. In addition, it was noted the addresses

on small roads or highways were geocoded far from the correct location. In this case, these types of addresses have been checked and corrected manually. The shape of the municipalities of SPMA was gotten from the Center of Studies of the Metropolis (CEM/Cepid, 2018).

#### 4.3 Data Limitations

Although the data source is abundant, there are limitations of three natures relating to the data source. The first one is the database itself, because the addresses are only of the corporate headquarter, although there is a description of the subsidiaries inside the complete documents. It is noted that some companies had branches in SPMA, which may be part of a more comprehensive research in the future. The fact is only companies based on SPMA were considered in this research. There may be companies based in cities outside SPMA or even in other states, but with branches in the SPMA. These subsidiaries are also out of this research. The post offices warehouses were left out because they are not registered on JUCESP's database.. Finally, it was used key excerpts from each description of economic activity were used to find the companies in the Jucesp database. Due to this and limitations of the site some companies may have been left out of the sample. The second limitation is due to the anachronism of the data. It was considered that the active and inactive companies collected, whose last economic activity of them had one of the CNAEs previously described, had the same activity codes in the past. In addition, companies that were warehouses in the past, but nowadays have other activities remained out of this research. This limitation is due to JUCESP website, which does not allow to search for the past activities of companies. Furthermore, it was not investigated whether the companies' past addresses were also located in warehouses. The third limitation refers to the compatibility of the reported addresses and their real location on Google Maps. Despite the fact that the verification work was exhausting, there is a risk that some of these addresses have not been mapped correctly.

#### 4.4 Analysis Tools and Method

For the calculation of logistics sprawl, the barycentre of all addresses in each year of analysis was calculated, and then the euclidian average distance of all points to this barycentre (Dablanç and Rakotonarivo, 2010). The calculation of

the barycentre and the elaboration of the distance matrix between each company and the barycentre were performed by QGIS v2.18. Population and economic data were analyzed as aspects that cause logistics sprawl. Population growth was calculated using data between the 2000 census and an IBGE estimate of 2017. GDP per municipality varies from 2000 to 2015. Both data are from IBGE. The 2000 GDP data were updated by the officia inflation index (IPCA), also provided by IBGE (2017). The roads and municipalities shapes were collected from Centro de Estudos da Metrópole (CEM, 2018).

## 5 Preliminary Results

### 5.1 Sample and Analysis Representation

Initially, two specific points in time were used to analyze the companies' sprawl: the year 2000 in which the Brazilian demographic census was conducted, and 2017 that was the date of collection. Figure 1a and 1b show the geographic location of companies per year and highlight how close companies are to major access routes.

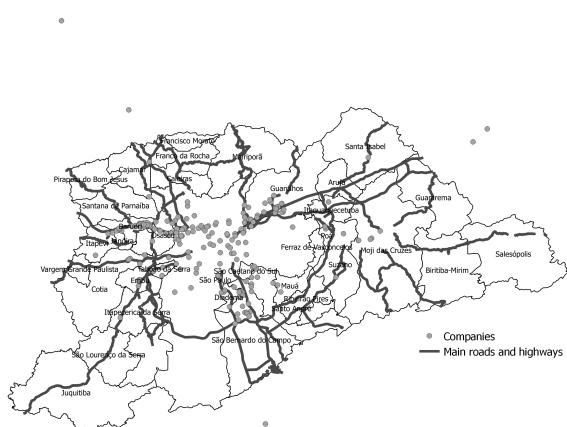


Figure 1: Sample of Companies in 2000

\*Source: NREL (2018)

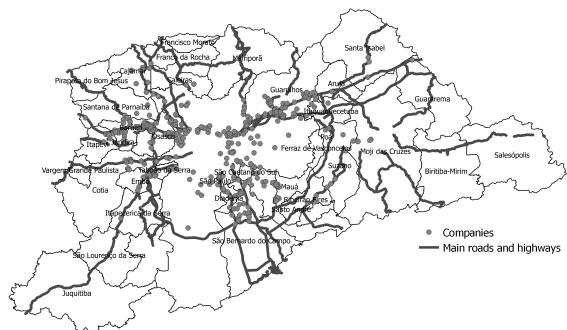


Figure 2: Sample of Companies in 2017

\*Sources: Shapes from Centro de Estudos da Metrópole (2018) and addresses from Jucesp (2017)

Table 2: Shows the growth of companies' number per city, based on the most representative cities in 2017.

City	2000		2017		Growth(%)
	Number	Percent-age	Number	Percent-age	
São Paulo	75	36	132	32	76
Guarulhos	28	13	62	15	121
Barueri	23	11	49	12	113
São Bernardo do Campo	18	9	25	6	39
Osasco	10	5	18	4	80
Embu das Artes	5	2	16	4	220
Mauá	3	1	14	3	367
Others	47	22	101	24	115
TOTAL	209	100	417	100	100

Table 2 highlights the seven main municipalities, whose sum of companies is very close to 80% (column representativeness (%)) 2017) of the total. It is possible to notice the representativeness of the municipalities had little change over the years, but it can be observed that São Paulo had a slight decrease from 36% of the companies in 2000 to 32% in 2017. On the other hand, the growth of companies stands out in municipalities such as Guarulhos, Barueri, Embu das Artes and Mauá, far superior to the growth of São Paulo, confirming the sprawl.

Regarding the barycentre, when considering its spatial variation, from 2000 to 2017, the displacement is 1.8km to the northwest direction. Moreover, the average distance of the companies to the barycentre has also increased over years. In 2000, the average distance was 17.7km, with a standard deviation of 11.9km. In 2017, the number jumped to 19.3km, with a standard deviation of 15.6km. There was a 1.6km increase in the average distance between the companies and the barycentres, resulting in an 8.8% increase. Although this increase is not expressive, it is possible to demonstrate the occurrence of logistics sprawl phenomenon. Some results presented in the literature had similar values (Oliveira et al., 2017; Sakai, Kawamura and Hyodo, 2015; Woudsma, Jakubicek and Dablanck, 2016). The

standard deviation had an increase of 30%, showing the addresses have become more widespread.

Among the cities in Table 2, there was a proportional increase in the number of companies, superior to São Paulo in five cities: Guarulhos, Barueri, Osasco, Embu das Artes and Mauá. All of them concentrate a good logistics infrastructure, being served by highways. In the specific case of Barueri and Osasco, both have the Castello Branco Highway, which connects São Paulo to the west of the state, and the Rodoanel passing through its territories, besides being connected directly to the expressways Marginal do Rio Tietê and Marginal of the Rio Pinheiros. Guarulhos is served by three major highways: the Presidente Dutra Highway and Ayrton Senna Highway, which link São Paulo to the Parába Valley and Rio de Janeiro and Fernão Dias Highway, linking São Paulo to Belo Horizonte, in Minas Gerais State. It is important to mention that Guarulhos is served by Guarulhos International Airport, which is an important air cargo terminal. Embu das Artes is very close to São Paulo and is cut by Regis Bittencourt Highway, which is the main cargo route to southern Brazil. Mauá has a strong industrial park, close to the Rodoanel and close to the access to the highways of the coast, mainly Anchieta Highway, which leads to the port of Santos.

However, an aspect to be highlighted is the taxation of municipalities on services provided by storage companies. The main tax levied on companies is the Service Tax (ISS) and can influence warehouse and storage companies to migrate from one municipality to another, seeking more attractive tax rates. Although an exhaustive study on the evolution of tax values over the years has not been realized, table 3 shows the ISS rates for warehousing and storage activities by municipality in 2017 and it is possible to notice a correlation between the growth of the number of companies in some locations and lower service taxes related to warehousing and storage activities. The only exception to this list is the municipality of São Bernardo do Campo, which has a lower tax rate but has had a small growth in the number of companies. It should be emphasized that a historical study of the evolution of taxes was not carried out, which would be fundamental to certify and quantify the influence in logistics sprawl.

Table 3: Comparison between number of companies' growth to services tax rates, population and GDP

City	Company growth(%)	Service tax rate(%)	Pop. growth (%)	GDP growth(%)
São Paulo	76	5	16	-3
Guarulhos	121	4	26	136
Barueri	113	2	28	333
São Bernardo do Campo	39	3	18	112
Osasco	80	5	7	563
Embu das Artes	220	2%	29	415
Mauá	367	3 to 4	27	109

\*Sources: Prefeitura de São Paulo, 2018; Prefeitura de Barueri, 2018; Prefeitura de Osasco, 2018; Prefeitura de São Bernardo do Campo, 2018; Prefeitura de Guarulhos, 2018, Leis Municipais, 2018.

When comparing population and economic data with the logistics sprawl, it is possible to notice that there is a data correlation between the municipalities that had a bigger growth of logistics companies and population and economic growth.

Figure 2 and 3 show the companies in 2017, in the municipalities with the highest population growth and GDP respectively. It is possible to notice that the biggest economic and demographic growths are also, in the majority, in the cities of the western zone of the SPMA.

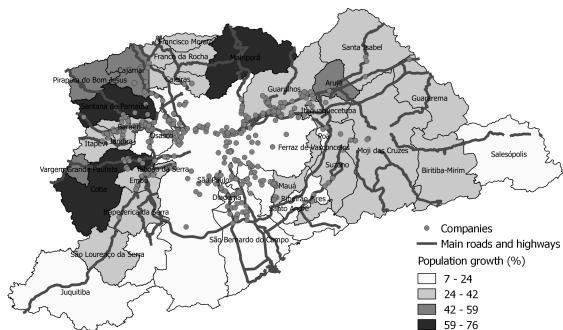


Figure 3: Population Growth per Municipality.

\*Sources: Shapes from Centro de Estudos da Metrópole (2018), addresses from Jucesp (2017) and data from IBGE (2018).

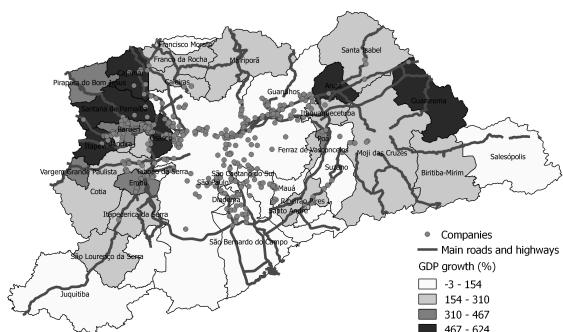


Figure 4: GDP Growth per Municipality

\*Sources: Shapes from Centro de Estudos da Metrópole (2018), addresses from Jucesp (2017) and data from IBGE (2018).

## 6 Conclusion

The conclusion is that SPMA has suffered the phenomenon known as logistic sprawl during the last years. The distance between the barycentre and the companies, on average, was not so expressive, only 1.6km. There was an increase in the concentration of companies in cities neighboring the city of São Paulo, such as Osasco, Barueri, and Guarulhos.

Certainly, some of the reasons for this phenomenon still need to be better investigated, but all the factors presented have some correlation with logistic sprawl: good transportation infrastructure, lower service tax rates, economic growth and demography. It is possible to notice that the biggest economic and demographic growths are also, in the majority, in the cities of the western zone of the SPMA.

Although the sample offered interesting results, the issue of SPMA logistic sprawl is still open and cannot be considered exhausted, since the preliminary results contemplated only a small number of storage and logistics companies to realize the analyzes. As a suggestion for future researches, deepening of the tax question and the more detailed study of the socioeconomic correlations may provide more information about the dynamics of the SPMA.

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## References

- Aljohani, K. and R. G. Thompson (2016). "Impacts of logistics sprawl on the urban environment and logistics: Taxonomy and review of literature". In: *J. Transp. Geogr.* 57, pp. 255–263.
- Allen, J., M. Browne, and T. Cherrett (2012). "Investigating relationships between road freight transport, facility location, logistics management and urban form". In: *J. Transp. Geogr.* 24, pp. 45–57.
- Bowen, J. T. (2008). "Moving places: the geography of warehousing in the US". In: *J. Transp. Geogr.* 16.6, pp. 379–387.
- Burchell, R. W. and S. Mukherji (2003). "Conventional Development Versus Managed Growth: The Costs of Sprawl". In: *Am. J. Public Health* 93.9, pp. 1534–1540.

- Burchfield, M., H. G. Overman, D. Puga, and M. A. Turner (2006). "Causes of Sprawl: A Portrait from Space". In: *Q. J. Econ.* 121.2, pp. 587–633.
- Cidell, J. (2010). "Concentration and decentralization: The new geography of freight distribution in US metropolitan areas". In: *J. Transp. Geogr.* 18.3, pp. 363–371.
- Cidell, J. (2011). "Distribution Centers among the Rooftops: The Global Logistics Network Meets the Suburban Spatial Imaginary". In: *Int. J. Urban Reg. Res.* 35.4, pp. 832–851.
- Dablanc, L., S. Ogilvie, and A. Goodchild (2014). "Logistics Sprawl". In: *Transp. Res. Rec. J. Transp. Res. Board* 2410.1, pp. 105–112.
- Dablanc, L. and D. Rakotonarivo (2010). "The impacts of logistics sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it?" In: *Procedia - Soc. Behav. Sci.* 2.3, pp. 6087–6096.
- Dablanc, L. and C. Ross (2012). "Atlanta: A mega logistics center in the Piedmont Atlantic Megaregion (PAM)". In: *J. Transp. Geogr.* 24, pp. 432–442.
- Gupta, S. and Garima (2017). "Logistics Sprawl in Timber Markets and its Impact on Freight Distribution Patterns in Metropolitan City of Delhi, India". In: *Transp. Res. Procedia* 25, pp. 965–977.
- Heitz, A., L. Dablanc, and L. A. Tavasszy (2017). "Logistics sprawl in monocentric and polycentric metropolitan areas: the cases of Paris, France, and the Randstad, the Netherlands". In: *Region* 4.1, p. 93.
- Hesse, M. (2004a). "Introduction: the Nature and the Location of Freight Distribution". In: *Tijdschr. voor Econ. en Soc. Geogr.* 95.2, pp. 162–173.
- Hesse, M. (Mar. 2004b). "LAND FOR LOGISTICS: LOCATIONAL DYNAMICS, REAL ESTATE MARKETS AND POLITICAL REGULATION OF REGIONAL DISTRIBUTION COMPLEXES". In: *Tijdschr. voor Econ. en Soc. Geogr.* 95.2, pp. 162–173.
- Lasserre, F. (2004). "Logistics and the Internet: Transportation and location issues are crucial in the logistics chain". In: *J. Transp. Geogr.* 12.1, pp. 73–84.
- McKinnon, A. (2009). "The present and future land requirements of logistical activities". In: *Land use policy* 26.SUPPL. 1, pp. 293–301.
- Morganti, E., S. Seidel, C. Blanquart, L. Dablanc, and B. Lenz (2014). "The Impact of E-commerce on Final Deliveries: Alternative Parcel Delivery Services in France and Germany". In: *Transp. Res. Procedia* 4.0, pp. 178–190.
- Oliveira, L. K. de, O. R. dos Santos, R. A. d. A. Nóbrega, L. Dablanc, and R. L. M. de Oliveira (2017). "Análise do espiamento logístico: um estudo para a região metropolitana de Belo Horizonte". In: *Transportes* 25.4, p. 42.
- Rodrigue, J.-p. (2004). "Regions : the Logistical Integration of". In: *Tijdschr. voor Econ. en Soc. Geogr.* 95.2, pp. 147–161.
- Rodrigue, J.-p. (2006). "Transportation and the Geographical and". In: *Growth Change* 37.4, pp. 510–525.
- Sakai, T., K. Kawamura, and T. Hyodo (2015). "Locational dynamics of logistics facilities: Evidence from Tokyo". In: *J. Transp. Geogr.* 46, pp. 10–19.
- Sakai, T., K. Kawamura, and T. Hyodo (2016). "Logistics Facility Distribution in Tokyo Metropolitan Area: Experiences and Policy Lessons". In: *Transp. Res. Procedia* 12, pp. 263–277.
- Torres, H., H. Alves, and M. A. de Oliveira (2007). "São Paulo peri-urban dynamics: Some social causes and environmental consequences". In: *Environ. Urban.* 19.1, pp. 207–223.
- Wang, F. and Z. Yixing (1999). "Modelling Urban Population Densities in Beijing 1982 ± 90 : Suburbanisation and its Causes". In: 36.2, pp. 271–287.

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REFERENCES

- Woudsma, C., P. Jakubicek, and L. Dablanç (2016). "Logistics Sprawl in North America: Methodological Issues and a Case Study in Toronto". In: *Transp. Res. Procedia* 12, pp. 474–488.
- Woudsma, C., J. F. Jensen, P. Kanaroglou, and H. Maoh (2008). "Logistics land use and the city: A spatial-temporal modeling approach". In: *Transp. Res. Part E Logist. Transp. Rev.* 44.2, pp. 277–297.



# Part III

# Sustainability



# Supporting the Selection of Sustainable Logistics Locations

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*Selecting a logistics location is vital for logistics providers, food retailing and other trading companies since the selection poses an essential factor for economic success. Decisions on logistics locations currently mainly take into account economic factors. Environmental aspects play only a subordinate role, which impedes transparent and sustainable decisions. The result is an impeded dialog between the involved stake-holders within the location decision process, which leads to a dismissive position of municipalities and landowners. Besides logistics location may negatively affect eco systems in terms of sealing the surface, wrecking of biodiversity, or CO2 and noise emissions generated by traffic. The increasing importance of sustainability demands for informed decisions when selecting a future logistics location. Sustainability considers environmental aspects, which should be equally integrated in the process of logistics location search. This paper presents an innovative approach for supporting logistics companies when selecting new logistics locations. Basis for the innovative approach are the Analytic Hierarchy Process (AHP) and the Strategic Environmental Assessment tool (SEA). The presented approach extends the AHP method with content and methods out of the SEA tool for considering more environmental aspects in the logistics location selection process. The paper presents the essential steps for developing the innovative approach considering more environmental aspects which leads to more transparent and objective location decisions.*

**Keywords:** logistics location; location selection; environmental criteria; sustainability

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## 1 Introduction

Selecting a logistics location is one of the most crucial decision problems for logistics managers and vital for companies out of the logistics business (Pajones, 2017; Chen-Tung Chen, 2001). In this paper, a logistics location is defined as a business or industrial site, where logistic activities take place. Various types of logistics locations exist, like distribution centers, dry ports, city logistics centers and others (Wagner, 2010; Nehm, 2013). Searching for new logistics locations is a complex process, in which a number of factors and criteria need to be considered (Ming-Shin Kuo, 2011). Various research methods are applied which are often part of a multi criteria decision method (Anjali Awasthi; S.S. Chauhan; S.K. Goyal, 2011; Jacek Źak; Szymon Węgliński, 2014; Ming-Shin Kuo, 2011). Multi criteria decision methods are effective in combining qualitative criteria from the decision makers (location criteria) with mathematical modeling methods to determine the best location for logistics usage (Jacek Źak; Szymon Węgliński, 2014). Decisions are the result of a comprehensive choice process with the objective to minimize costs (*inter alia*, logistics costs or transportation costs.) and maximizing profit (Bloech, 1970; Ashayeri, Jalal; Rongen, Joost M.J. 1997). Besides, subjective decisions by logistics managers also have a significant impact on the selection of logistics locations (Ping-Yu Chang, 2015). Decisions on logistics locations currently mainly take into account economic factors. Ecological and social aspects play only a subordinate role, which impedes transparent and sustainable decisions (Pajones, 2017; K.Sahoo, 2016; Verhetsel, 2015; Kou-Huang, 2014; Hilmola, 2013; Ashayeri, 1997). Logistics locations have significant effects on the environment. Positive effects include revenues for municipalities, jobs or positive effects for the regional economy. Negative effects include sealing of the surface, wrecking biodiversity or CO<sub>2</sub> and noise emissions generated by traffic (Nehm, 2013). In addition to these effects, many more impacts exist. When developing new logistics locations, the different interests of the logistics company, the municipality and the inhabitants have to be considered (Nehm, 2013), which is a challenging task. The objective of the paper is to present the essential steps for developing an innovative approach that supports logistics managers in the selection of sustainable logistics locations. It will be demonstrated how sustainable aspects (ecological and social ones) can be integrated into the decision process which leads to more transparent and objective location decisions.

## 2 Research Design

The innovative approach presented in this paper will demonstrate the essential steps for integrating environmental aspects into the process of logistics location selection.

Literature and secondary data in the fields of logistics location selection and environmental assessment suggests the so called Analytic Hierarchy Process (AHP) and the Strategic Environmental Assessment (SEA) as suitable methods for the economic and environmental assessment of logistics locations. Both methods require a high level of expertise in the fields of economy and ecology. However, logistics managers typically have a higher level of expertise in economics than in environmental issues. A deeper analysis will be conducted to extract the essential steps of the AHP and SEA methods and to acquire knowledge how to apply these methods for supporting the selection process of logistics locations under aspects of sustainability.

The RQ's are defined as follows:

- RQ1: How to integrate environmental aspects into the selection process of logistics locations?
- RQ2: What are the essential steps of the SEA that should be integrated into the AHP to develop an innovative approach for the selection of sustainable logistics locations?

The remainder of the paper is structured as follows: Chapter 3 outlines the fundamentals of the AHP method and the SEA tool. Chapter 4 describes the essential steps of the innovative new approach that has been developed based on AHP and SEA. Chapter 5 finally concludes the paper.

Table 1: Saaty-scale Source: Stojanov, 2013

Scale value	Definition	Interpretation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrate in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When comprise is needed

### 3 Fundamentals

#### 3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is a method for multi criteria decision making and was developed from Saaty at the beginnings of the 1980's. The AHP method enables a pairwise comparison of defined criteria and their alternatives based on the so called "Saaty-scale" (Saaty, 1980). This ordinal scale is characterized

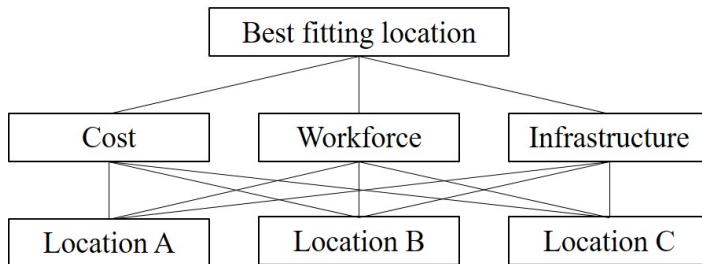


Figure 1: Basic structure of an exemplary hierarchy, own illustration by the author

by nine stages, whereby Saaty recommends the ranks as follows (Table 1), other ranks in between are possible).

The AHP method is based on a hierarchy, where the problem decision is decomposed in top down criteria (Riedl, 2006; Brunelli, 2015; Ping-Yu Chang, 2015). On the lowest level of the hierarchy, the alternatives (Location A, Location B, Location C) are listed. Figure 1 indicates a possible structure of a hierarchy:

The pairwise comparison of the three given criteria has to be conducted as follows:

- 1) Importance of cost compared to workforce for the selection of the best fitting location
- 2) Importance of cost compared to infrastructure for the selection of the best fitting location
- 3) Importance of workforce compared to infrastructure for the selection of the best fitting location

Normally the comparison is done with the help of a matrix, in the given case it would be a 3x3 Matrix. The weightings of each criterion (also called local priorities) are calculated by normalizing the matrix and the sum of the columns and rows. The detailed calculation method is not discussed here, but can be read in the corresponding literature (Riedl, 2006; Brunelli, 2015). The last step is to calculate

the global priorities by comparing the alternatives regarding to the respective criteria.

AHP is a powerful method when the decision problem and the hierarchy are complex and many criteria and alternatives are given. Location selection is one of a broad field of application where AHP is in use (Brunelli, 2015). A typical characteristic of this method is that there is less room of manipulation of the results because of the calculation of the weightings based on the pairwise comparison of the criteria. This is a strength of the method compared with similar methods for decision making such as the benefit analysis (Riedl, 2006).

### 3.2 Strategic Environmental Assessment (SEA)

The Strategic Environmental Assessment (SEA) is a tool to capture and evaluate the possible positive or negative impacts on the environment. Since 2001 the SEA has a legal basis in the European Union and in 2004 the SEA was integrated into Austrian law. In Austria, the SEA tool is used to assess the possible environmental impacts of spatial development plans or land use plans. In this context this tool supports the sustainable development of the country in a strategic way (Austrian Federal Ministry of Sustainability and Tourism, 2018).

Referencing to the SEA guidelines in Austria, SEA is a process which consists on several steps:

- 1) Screening:  
The screening step is an initial step to check if the complete SEA is necessary or not. A checklist enables a structured revision of the respective plan or project. The result of the screening step is a verbal argumentative overall statement of the relevance of the potential environmental impacts caused by the respective plan or project. If significant effects are detected, then the so called scoping is the next step within the SEA process.
- 2) Scoping:  
Scoping is essential because it defines the framework of the subsequent investigations. Similar to the screening step a checklist exists, which supports the scoping process for determining the content of the future Environmental Report. Table 2 exhibits the several steps of the Scoping process:

Table 2: Essential steps of the Scoping process, Source: Austrian Federal Ministry of Sustainability and Tourism, 2018

Scoping steps	What	Why
Alternatives	Identification of alternatives	To find the best alternative in terms of environmental impacts, taking into account the objectives of the project or plan.
Environmental impacts	Defining the types of environmental impacts	To define the types of environmental impacts caused by the project or plan and for focusing the content of the environmental report.
Investigation area	Defining the area of investigation	To identify the area which is possibly affected by the environmental impacts of the plan or project.
Target criteria	Defining the target criteria of the SEA	The criteria are based on the relevant environmental targets of the respective investigation area. Defining a target hierarchy is useful to get a structure into the SEA report and for assessing the respective criteria
Period of time	Determine the time period of investigation	The plan or project affects the investigation area over a certain period of time. The time period usually depending to the project and starts with the implementation of the project.
Level of detail	Defining the level of detail of investigation	This step determines the level and depth of further investigation. The depth depends on the respective criteria.

*Continued on next page*

Scoping steps	<i>Table 2 – continued from previous page</i>	
	What	Why
Methods	Determine the methods for the SEA	The SEA enables the application of diverse methods for measuring, calculating and assessing the potential environmental impacts caused by the project or plan. This step defines the best fitting method regarding to the examined project or plan.
Environmental protection measures	Listing possible measures for environmental protection	This step enables a listing of possible environmental protection measures, if the estimation is possible or useful.
Data and Information	Outline the needed data	To outline the needed data for decision making, assessing the environmental impacts and controlling.
Stakeholders	Define the involved stakeholders	For defining the relevant stakeholders and experts who will be involved in the subsequent SEA process

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3) Environmental Report:

The Environmental Report is the main document output of the SEA process and is based on the results of the scoping process which defines the content framework of the environmental report. The report presents all the assessments, measurements, calculations and analysis carried out in a transparent way.

4) Decision making and public announcement:

The decisions are made with respect to the results of the environmental report. This step also requires a public announcement of the decision-making.

5) Monitoring:

This step enables a controlled monitoring of the environmental impacts of the project or plan in case of implementation. It also allows a proactive intervention in case of undesired developments.

The SEA process includes five steps and the implementation is a huge effort, which takes a lot of time and resources. The determination of relevance of the environmental impacts require expert knowledge in the fields of traffic environment and spatial planning. The SEA tool examines environmental factors like human health, water, air, biology diversity, et. al. as well as the interactions between these factors. Various methods are in use to assess the potential environmental impacts of spatial development plans or land use plans (Austrian Federal Ministry of Sustainability and Tourism, 2018).

In the following, an innovative approach for supporting the selection of sustainable logistics locations with respect to economic and ecological issues will be presented.

## 4 Supporting the selection of sustainable logistics locations

The preceding chapter introduced the SEA tool as a resource intensive process. Because of that, the application of the complete SEA process in terms of location selection is not very satisfactory. For supporting the selection of logistics locations, the AHP method is already in practice. The approach presented in the following section is based on the AHP method and includes suitable and relevant content from the SEA tool.

Table 2 lists the essential steps for supporting the selection of sustainable logistics locations.

Table 2: Essential steps for supporting the selection of sustainable logistics locations

Steps	Experts involved	Steps done in a
Requirements towards the location	High-ranking managers, logistics managers	Meeting
Location search	Real estate developer, location agencies	Meeting
Specification of the logistics building	Engineers, logistics managers	Desktop, meeting
Economic target hierarchy	High-ranking managers, logistics managers, AHP expert	Workshop
Environmental target hierarchy	Spatial planers, environmental engineers, AHP expert	Workshop
Pairwise comparison	Spatial planers, traffic planers, environmental engineers, High-ranking managers, logistics managers, political stakeholders, AHP expert	AHP Workshop
Decision making	High-ranking managers, logistics managers, AHP expert	AHP Workshop

1) Requirements to the location:

In this initial step, high-ranking managers and/or logistics managers come together to define the requirements towards the future location (location criteria). This implies that there is a need for the company to develop a new logistics location. There may be several reasons for this need such as expansion into new markets, optimizations of logistics costs, etc. The review of existing literature suggests traffic connection, land price, labor force potential and security measures as common criteria. Normally the managers also require the position of the location in a macro- (country) or mesoscopic (metropole region) way.

2) Location search:

The defined location criteria are the basis for the location search, where real estate developers or business/location agencies search for appro-

priate locations. The searching process is usually supported by location-databases. The AHP method requires pairwise comparing for more than one location.

3) Specification of the logistics building:

The development of the environmental target hierarchy requires detailed information and specification of the future logistics building such as size of the sealed service, handled trucks per day, number of employees, size of the building(s), operation time, building technology, et al. The detailed plans and specifications are made by engineers and logistics managers. The specifications are basic input for the definition of the types of environmental impacts and the environmental criteria for the target hierarchy.

4) Economic target hierarchy:

Based on the knowledge gained in step 1 and 3, high-ranking managers, logistics managers and an expert in the AHP method start working together to develop the economic target hierarchy. In this step, the defined location criteria, as an output of step 1, are classified in a useful way. This step also allows the addition of further criteria or the deletion of existing ones.

5) Environmental target hierarchy:

Supported by an AHP expert, spatial planers and environmental engineers come together to develop the environmental target hierarchy. Based on the information as output of the steps 2 and 3 the environmental criteria are defined. The specifications and information of the project (future logistics building) support them for objective estimation of the environmental impacts caused by the future logistics building. In addition, the methods and steps in the SEA tool (Table 2) support the spatial planers and environmental engineers for more objective estimations.

6) Pairwise comparison:

One of the most innovative steps in the presented approach is to bring together the various experts outlined in Table 2, for the pairwise comparison is. Comparing the economic criteria as well as the environmental criteria leads to objective results. The method also allows a separate evaluation of the comparison of the economic- and environmental criteria, which leads to better transparency.

7) Decision making:

Based on the objective results as an output of the pairwise comparison, the managers can make their decision. Because the AHP method enables the separate comparison of the locations in an economic and environmental way, the decisions can be made in a more sustainable manner.

## 5 Conclusions and further need for research

The paper presents an innovative approach for supporting the selection of sustainable logistics locations, considering economic and environmental criteria. The application of the Analytic Hierarchy Process - method (AHP) enables the involvement of various experts and other stakeholders in the decision process. Expertise and method knowledge in the field of Strategic Environmental Assessment (SEA) qualifies spatial planners and environmental engineers to estimate the environmental impacts caused by the future logistics location and to develop a meaningful target hierarchy for the AHP process. Bringing together the experts and stakeholders (spatial planers, traffic planers, environmental engineers, high-ranking managers, logistics managers, political stakeholders) in an AHP-workshop for the pairwise comparison of the various criteria and location alternatives leads to more objective results. The final location decision is made by the high ranking logistics managers and based on objective and transparent results from the AHP process.

The implementation of the presented approach is still a resource intensive endeavor and of limited practical use. The increased use in the location selection practice is an open question.

Further research is planned to investigate the knowledge, methods and assessments of environmental experts (spatial planners, environmental engineers).

Objective of these investigations is to generate expertise for qualifying the high-ranking logistics managers to implement the needed developments and assessments (target hierarchy, environmental criteria, pairwise comparison) on their own. This enables an AHP process which takes less resources (less money, shorter time, less experts and stakeholders) in implementation.

## References

- Anjali Awasthi, S.S. Chauhan, and S.K. Goyal (2011). "A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty". In: *Mathematical and Computer Modelling* 53.1-2, pp. 98–109.
- Ashayeri, J. and J. M. Rongen (1997). "Central Distribution in Europe: A Multi-Criteria Approach to Location Selection". In: *Int Jnl Logistics Management* 8.1, pp. 97–109.
- Balakrishnan, N., T. Colton, B. Everitt, W. Piegorsch, F. Ruggeri, and J. L. Teugels (2014). *Wiley StatsRef: Statistics Reference Online*. Chichester, UK: John Wiley & Sons, Ltd.
- Bian Ka (2011). "Application of Fuzzy 5AHP6 and 5ELECTRE6 to China Dry Port Location Selection". In: *The Asian Journal of Shipping and Logistics* 27.2, pp. 331–353.
- Bloech, J. (1970). *Optimale Industriestandorte*. Heidelberg: Physica-Verlag HD.
- Brunelli, M. (2014). *Introduction to the analytic hierarchy process*. New York: Springer.
- Chen-Tung Chen (2001). "A fuzzy approach to select the location of the distribution center". In: *Fuzzy Sets and Systems* 118.1, pp. 65–73.
- Federal Ministry of Sustainability and Tourism, Austria (2018). *Strategic environmental assessment*.
- Fink, K. and C. Ploder, eds. (2006). *Wirtschaftsinformatik als Schlüssel zum Unternehmenserfolg*. Wirtschaftsinformatik. Wiesbaden: Deutscher Universitäts-Verlag / GWV Fachverlage GmbH, Wiesbaden.
- Hilmola, O.-.-P. and H. Lorentz (2013). "Warehousing in Northern Europe: longitudinal survey findings". In: *Industr Mngmnt & Data Systems* 111.3, pp. 320–340.
- Jacek Źak and Szymon Wegliński (2014). "The Selection of the Logistics Center Location Based on MCDM/A Methodology". In: *Transportation Research Procedia* 3, pp. 555–564.
- K. Sahoo, G.L. Hawkins, X.A. Yao, K. Samples, and S. Mani (2016). "GIS-based biomass assessment and supply logistics system for a sustainable biorefinery: A case study with cotton stalks in the Southeastern US". In: *Applied Energy* 182, pp. 260–273.
- Kou-Huang Chen, Chin-Nung Liao, and Li-Chun Wu (2014). "A Selection Model to Logistic Centers Based on TOPSIS and MCGP Methods: The Case of Airline Industry". In: *Journal of Applied Mathematics*, pp. 1–10.
- Ming-Shin Kuo (2011). "Optimal location selection for an international distribution center by using a new hybrid method". In: *Expert Systems with Applications* 38.6, pp. 7208–7221.
- Nehm, A. (2013). *Logistikimmobilien - Markt und Standorte 2013: Deutschland, Österreich, Schweiz, Belgien und Niederlande ; eine Studie*. Stuttgart: Fraunhofer-IRB-Verl.
- Pajones, M., M. Neubauer, and T. Steiner, eds. (2017). *Sustainable Selection of Logistics Location*.
- Ping-Yu Chang and Hsin-Yi Lin (2015). "Manufacturing Plant Location Selection in Logistics Network Using Analytic Hierarchy Process". In: *Journal of Industrial Engineering & Management* 8.5, pp. 1547–1575.

- Riedl, R. (2006). "Analytischer Hierarchiprozess vs. Nutzwertanalyse: Analytic Hierarchyprocess vs. Benefit Analysis". In: *Wirtschaftsinformatik als Schlüssel zum Unternehmenserfolg*. Ed. by K. Fink and C. Ploder. Wirtschaftsinformatik. Wiesbaden: Deutscher Universitäts-Verlag / GWV Fachverlage GmbH, Wiesbaden, pp. 99–120.
- Stojanov, S., S. Besermenji, M. Vujicic, V. Majstorović, and R. Stojasavljević (2013). "Measuring Tourism Potential of Places of Interest and Memorial Objects Using Analytical Hierarchy Process (AHP) - Case Study". In: 59, pp. 2306–2315.
- Verhetsel, A., R. Kessels, P. Goos, T. Zijlstra, N. Blomme, and J. Cant (2015). "Location of logistics companies: a stated preference study to disentangle the impact of accessibility". In: *Journal of Transport Geography* 42, pp. 110–121.

# Meta-Analysis of Sustainable Transport Logistics Trends

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*In general, Austrian manufacturing companies need to catch up in terms of sustainable transport logistics. Awareness-raising on sustainability and a broad debate are necessary that companies rethink in this context. This paper, therefore, develops and applies a meta-analysis in order to analyze the development of transport logistics trends. This research integrates qualitative and quantitative elements of the content analysis. Firstly, existing trend analyses are evaluated and compared in order to subsequently define trend categories. Secondly, the identified trend categories are analyzed by a qualitative content analysis. Finally, a frequency analysis is performed to describe temporal developments. This meta-analysis evaluates how sustainability in terms of transport logistics has developed in comparison with other subject areas based on a prestigious, well-known international journal regarding logistics and traffic issues. Five relevant trends have been identified, their temporal development has been analyzed and a forecast has been created. Current transport logistics trend analyses usually do not challenge the topic of sustainability qualitatively by means of a meta-analysis. The validity of the definition whether a trend is relevant is increased, since the search items are analyzed in the context of previously defined trend categories. The meta-analysis is practically applicable, as in the period from 2014 to 2017 short-term and medium-term effects were tested in 171 editions of a subject-specific, but nonscientific international journal around logistics and traffic issues. This journal is published since 1945 and, therefore, comprehensively reflects the practical discussion about transport logistics.*

**Keywords:** Meta-Analysis; Sustainability; Logistics; Trends

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## 1 Introduction

Issues concerning sustainability are currently polarizing scientific, academic and practical debate. In 2018 the Institute of Industrial Management at FH JOANNEUM is conducting a study to identify the transport logistics status of Austrian manufacturing companies with sustainability as one core part of the survey. The closed survey involves logistics executives from manufacturing companies with more than nine employees and a turnover of more than two million euros. So far, 136 online questionnaires have been completed. This interim result corresponds to a return rate of 4% – the survey will be open until the end of June 2018.

The survey results reveal that sustainability has not yet found the spread that would be necessary regarding the climate targets of the European Union for instance. The following chart shows that companies are required to act.

Only one third of the questioned companies state, that they have set concrete, measurable sustainability goals and that they measure them regularly. Referring to the famous statement “what doesn't get measured, doesn't get done” this percentage shows, that there is a need to catch up for Austrian manufacturing companies. Furthermore, when asked whether the company is pursuing sustainable transport management, 80% respond with “no”. For those who answer “yes”, it is noticeable that the reasons are more in the self-motivation and image building than, for example, in legal requirements, as shown by Figure 2.

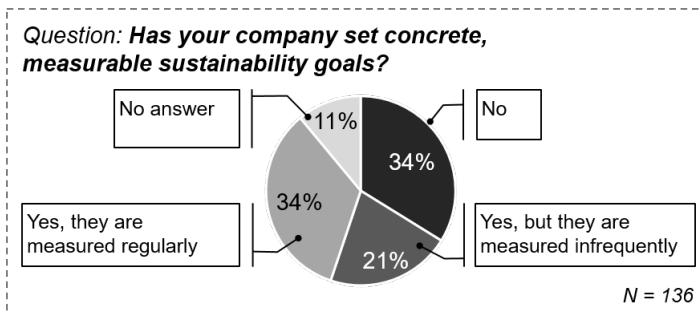


Figure 1: Survey interim result regarding sustainability goals

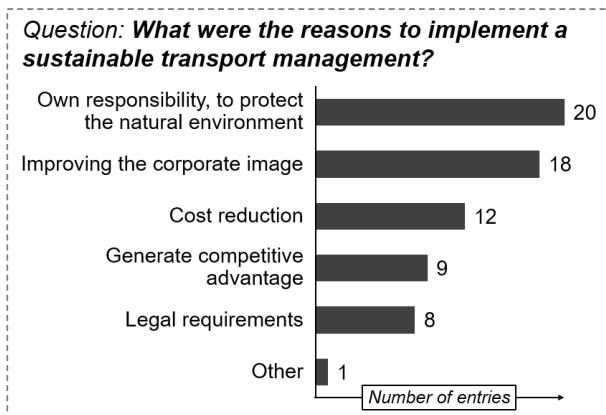


Figure 2: Survey interim result regarding sustainable transport management

The aspect that companies self-initiatively set sustainability measures is to be highlighted positively. However, 70% of the companies do not identify the carbon footprint caused by their transports ( $N=119$ ) and another 65% are not willing to pay more for environmentally friendly logistics services ( $N=105$ ). In general, the interim results of the survey show that there is a need for action.

Awareness-raising on sustainability and a broad debate are necessary that companies rethink in this context. Therefore, this paper analyzes a prestigious, well-known international journal regarding logistics and traffic issues and shows how sustainability aspects in logistics develop according the research question: "Which logistics trends are currently relevant and how have these developed in the medium term?" For this purpose, a meta-analysis was carried out on the international weekly journal "Verkehr". We examined how trends evolved depending on how often they were covered within a text passage over the period from 2014 to 2017. In addition, forecasts have been created for the next three years (2018 to 2020). This is not a meta-analysis in the classical sense. It focuses on the integration of qualitative and quantitative content analysis elements to evaluate logistics trends. However, the journal includes a large number of differ-

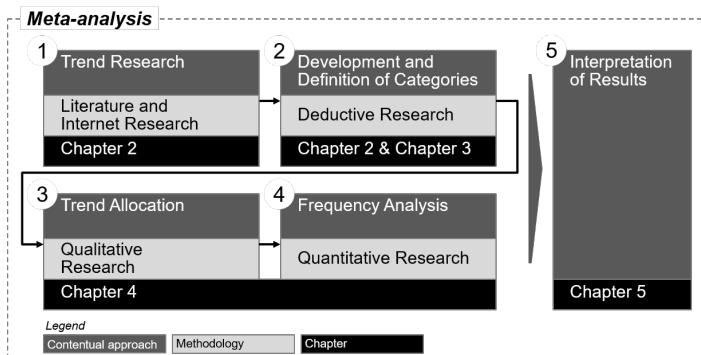


Figure 3: Methodology of this paper

ent interviews, contributions, studies, evaluations etcetera that are evaluated. This equals the “analysis of analyses” as Glass (1976, pp.3-8) has described the meta-analysis. Therefore, this paper summarizes the approach under the term “meta-analysis”. The following chart shows this paper’s methodology.

Firstly, published transport logistics trends are identified and evaluated by a literature and internet research (chapter 2). Secondly, chapter 2 and chapter 3 develop categories regarding trends and define their content in order to carry out a deductive research. Based on the previously defined categories, the text material – 171 editions of the international weekly journal “Verkehr” – is analyzed with the aid of “QCMap” and all search items are allocated to the trend categories due to their context. Then, a frequency analysis is performed in order to analyze the time series the search items have been mentioned. Furthermore, a forecast about future developments is created. Finally, the results are interpreted.

## 2 Development of the Analysis Categories

Due to the fact that relevant and irrelevant pieces of information are mixed up in texts, qualitative evaluation methods have to analyze fuzzy data. For this purpose, standardized approaches are missing (Saunders, Lewis and Thornhill,

2012, p.556). The methods range from the free interpretation of texts to qualitative content analysis, which follows strict rules (Gläser and Laudel, 2006, pp.41-42). Mayring (2010, p.602; 2015, pp.20-22) for instance distinguishes between three variants: data summary, explication and structuring, whereby hybrid forms are commonly applied. Data summary is the process of reducing the text material to one text corpus. Explication stands for scrutinizing problematic passages in the text by examining the surrounding text passage. However, structuring the qualitative data is the key technique in qualitative analysis: characteristics of a text are identified by using a category system (Diekmann, 2004, pp.512-513).

Several approaches exist of how to structure data. Basically, text passages, words, a combination of words, paragraphs or even an entire newspaper page can be used as an analysis criterion (Diekmann, 2004, p.488 and 513). The relevant information is marked with a code, usually a keyword. The target of coding relevant information is to create a well-structured framework that supports analysis. Numerous possibilities exist of how to assign a code. As this paper follows the purpose of analyzing transport logistics trends, the codes are created by using terms of theoretical concepts (Saunders, Lewis and Thornhill, 2012, p. 558).

Furthermore, the codes can either be created prior to conducting the data analysis – deductively – or – inductively – during the data analysis (Gläser and Laudel, 2006, p.43). Due to the fact, that this meta-analysis aims at identifying trends within text passages based on a previously carried out literature and internet research, the deductive approach is applied.

## 2.1 Deductive Category Application

The goal of the deductive category application is to evaluate the text material based on predefined categories. For this purpose, the structuring dimensions – categories – are derived from the research question. These dimensions are then often differentiated or split into characteristics. The defined dimensions and differentiated characteristics are then combined into a category system. Whether and when a text part is assigned to a category is specified through coding rules. The text passages that address a category are marked. Mayring (2015, pp.97-106) refers to these passages as "references". Subsequently, the marked text material is processed and extracted. This processing is based on the goal of structuring. In the context of this paper the objective of the structuring process is to summarize the material on specific topics or contents, meaning logistics trends in this case.

## 2.2 Development of Trend Categories

It has been outlined that categories have to be defined before starting the text analysis. These categories represent the trends that are analyzed qualitatively and quantitatively. An initiating trend research is carried out to examine published developments in transport logistics. Four sources, which publish logistics trend assessments have been identified: Transalex (Transalex Internationale Spedition GmbH, 2018), Chamber of Commerce Austria (Wirtschaftskammer Österreich, 2017), Journal "Verkehr" (Stiftne , 2014, p.9; 2015, p.5; Breinbauer, 2014, p.10; 2015, p.6; 2016, p.7; Klacska, 2015, p.4; Senger-Weiss, 2016, p.6; Müller, 2017, p.8) and Logistik News 24 (Beilhammer, 2017). Table 1 shows the results of the trend research. They are clustered in "Logistics" for all general logistics trends, "Transport Logistics" and "Intralogistics", since only trends in the context of transport logistics are further analyzed. The journal, which was finally analyzed, is in German, therefore also German trend publications were evaluated in advance. In the following, the German search items are described in English in Table 3 and chapter 3.

Table 1: Overview about logistics trends

Source	Trend	Category
Transalex	Green Logistics	Logistics
	RFID Nutzung	
	Intelligente Logistik	
	Grüne Logistik	
	Automation	
	Technologietrends	
	Bündelung von Transporten	Transport
	Flexible Logistikketten	
	Innovative Fahrzeugkonzepte	
	Nutzung von Frachtbörsen	
	Selbstfahrende Fahrzeuge	
Transalex	Schienengüterverkehr	Transport

## *2 Development of the Analysis Categories*

	Osteuropa Transporte Intralogistik Trends in der Lagerhaltung Smart Devices und Datenbrillen	Intralogistics
Chamber of Commerce Austria	Vernetzung von Regionen Internationale Kooperation Ausbau Logistikzentren Universelle Logistik-Service-Anbieter Digitalisierung End-Consumer-Logistik Supply-Chain-Management Autonome, elektrische, vernetzte Nutzfahrzeuge Entkoppelung Gepäcktransport von Personenverkehr Flexible Transporte Umweltfreundliche Transportmittel Gütertransport im urbanen Raum: Elektromobilität, Last-Mile-Problem	Logistics Transport
Journal "Verkehr"	Digitalisierung und Automatisierung Reindustrialisierung Politik im Supply Chain Riskmanagement Regionalisierung der Supply Chain	Logistics
Journal "Verkehr"	Industrie 4.0, Logistik 4.0 Green Logistics Österreich als Logistikstandort Wandelnde Kommunikation (Internet of Things)	Logistics

	Industrie 4.0, Big Data, Internet of Things Arbeitsbedingungen im Wandel Start-Up-Boom Stärkung Wettbewerbsfähigkeit Logistik 4.0 für kleine und mittlere Unternehmen Autonomisierung Drohnen Elektromobilität Möglichkeiten von Flüssigerdgas Smart Urban Logistics Fahrerloser Lkw Autonome Fahrzeuge Innovative Zustellkonzepte Frachtbörsen	Transport
Logistic News 24	Umweltschutz Digitalisierung Big Data Emissionsärmere Zukunft Logistik ohne Emissionen	Logistics Transport
Logistic News 24	Elektromobilität, Hybridantrieb Lieferungen über Nacht (Elektromobilität)	Transport

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The identified trends are reviewed. Trends that do not belong to the external transport of goods, as developments in internal logistics or passenger transport, are not taken into account. Trends which are marked with “Logistics” and, therefore,

Table 2: Defined categories for the trend analysis

#	Category	German Wording
1	Green Logistics	Green Logistics
2	Smart Logistics	Intelligente Logistik
3	Alternative Drive Systems	Alternative Antriebe
4	Innovative Vehicle Concepts	Innovative Fahrzeugkonzepte
5	Freight Exchange	Frachtbörsen
6	Rail Freight	Schienengüterverkehr
7	Transport Bundling	Transportbündelung
8	Flexible Supply Chains	Flexible Logistikketten
9	Smart Urban Logistics	Smart Urban Logistics

apply to transport logistics as well, are evaluated whether they are meaningful for the underlying research question or not. Therefore, “Policies in Supply Chain Risk Management” (“Politik im Supply Chain Riskmanagement”), for example, is not taken into account in category formation.

Equally excluded are trends that cannot be measured, for example due to their regional roots, as this meta-analysis focuses on international transport. These include, *inter alia*, the “Networking of Regions” (“Vernetzung von Regionen”) and “Austria as a logistics location” (“Österreich als Logistikstandort”). Furthermore, ambiguous trend labels are broken down and assigned to the respective trend category. As an example, the “Autonomous, Electric, Networked Commercial Vehicles” (“Autonome, Elektrische, Vernetzte Nutzfahrzeuge”) are suitable. Firstly, they are separated into “Autonomous Vehicles”, “Electric Vehicles” and “Digitalization”. Then redundancies are equalized with other trends. Finally, trends are logically clustered in superordinate categories. For example, the trends “Environmental Protection” (“Umwelt-schutz”), “Low-emission Future” (“Emissions-särmere Zukunft” and “Logistics without Emissions” (“Logistik ohne Emissionen”) are assigned to the category “Green Logistics”. “Autonomous Vehicles” and “Self-Driving Vehicles” (“Selbstfahrende Fahrzeuge”) are assigned to the category “Innovative Vehicle Concepts” (“Innovative Fahrzeugkonzepte”). Table 2 shows the defined trend categories. The wording that is used in German is included, since the meta-analysis has been applied to a journal that is published in German.

### 2.3 Identification of Search Items

In order to examine the categories by meta-analysis, search items are assigned to the defined categories. The reason for this is that in the source material, but also in the trend publications, often several names for the same trend can be found. This can also be observed in the previous category formation. In addition, sub terms for trends are assigned to the categories, which represent a collective term.

Table 3 provides an overview of the search items of all categories and a description why the search item is selected.

Table 3: Search items per category

Category	Search Items	Description
Green Logistics	Grüne Logistik	The category name Green Logistics is translated into German. The term Green Logistics is also used in the trend publication of Transalex.
	Umweltfreundlich*	It is confirmed that environmental friendliness is related to Green Logistics (Niess, 2017). The synonym "environmentally friendly*" ("umweltfreundlich*") is interrupted with a star and should be used as a placeholder for terms such as environmental friendliness or environmentally friendly, to take every conceivable expression of the term into account in the following text analysis. Sustainability represents the English translation of the German term "Nachhaltigkeit". The term "Nachhaltigkeit" itself is not cited in this context as a search item, since it is not considered in the analysis material in the ecological, but rather in the political context.
	Sustainability	
Smart Logistics	Intelligente Logistik Industrie 4.0, Big Data, Internet of Things, Cloud Computing Logistik 4.0 Physical Internet	"Intelligente Logistik" represents the German name of the category. These terms are taken directly from the trend research, before summarizing in this category. In addition, these are digitization trends (Gensrich, 2017). This synonym is taken directly from the trend research. The vision of the "Physical Internet" is a smart concept per se (Montreuil and Louchez, 2015).

Alternative Drive Systems	Alternative Antriebe	"Alternative Antriebe" represents the German name of the category.
	Elektromobilität, E-Mobilität, E-Mobility, elektrisch*, Hybrid, Brennstoffzelle, Erdgas, CNG, Flüssigerdgas, LNG	The terms of the left column are given as Alternative Drive Systems to the conventional internal combustion engine. CNG is a synonym for natural gas and LNG for liquefied natural gas. In electric mobility, due to their versatile spelling, different variants are given. Electric* ("elektrisch*") serves, as well as environmentally friendly* before, as a collective term for further modifications. The same principle applies to the term hybrid (Hilgers, 2016, p.7, 19 and 58).
Innovative Vehicle Concepts	Innovative Fahrzeugkonzepte	"Innovative Fahrzeugkonzepte" represents the German name of the category.
	Fahrerlos, selbstfahrend, autonom	The term autonomous (autonom) is taken from the results of the trend research and supplemented by the synonyms driverless (fahrerlos) and self-propelled (selbstfahrend"). An internet research on the subject of Innovative Vehicle Concepts shows that drones are part of the autonomous delivery logistics. Therefore, they are included in this category (Horizont, 2017). According to the research project EMILIA, Cargo Bikes are among the Innovative Vehicle Concepts of the future (Kotrba, 2017). English and German terms were used for the analysis.
Drohnen		
	Cargo-Bike, Cargo Bike, Lastenrad, Lastenfahrrad	
Freight Exchange	Frachtbörsen	"Frachtbörsen" represents the German name of the category.

	Laderaumbörse, Transportbörsen, Frachtplattform	There are different logistics exchanges, which are considered in this category (Schneider, 2018).
Rail Freight	Schienengüterverkehr	"Schienengüterverkehr" represents the German name of the category. The name of the Rail Freight category is abbreviated to find as many terms as possible in the source material. The term "train" ("Zug") is added as a synonym.
	Schiene, Zug	In literature, the freight yard is considered as part of Rail Freight Transport, which is why it is included as a search item in this category. The asterisk (*) at the end of the word serves as a placeholder. So "Güterbahn*" covers the terms "freight yard" and "freight stations" for example.
	Güterbahn*	
Transport Bundling	Transportbündelung	"Transportbündelung" represents the German name of the category. In the trend research, Transport Bundling is identified as a trend. In the trend description the groupage/collective freight/transport ("Sammelverkehr", "Sammeltransport" and "Sammelguttransport") is a form of transportation bundling.
	Sammelverkehr, Sammeltransport, Sammelguttransport	
	Bündelung von Transport	In this case, the category name has been reworded.
Flexible Supply Chains	Flexible Logistikketten	"Flexible Logistikketten" represents the German name of the category.
	Flexible Lieferkette, flexible Versorgungskette	For this category two synonyms were defined as search items.

Smart Urban Logistics	City-Log*, City Log*, Ballungsraumlog*	The Climate and Energy Fund commissions a new program in its annual programs (2012 and 2014) Smart Urban Logistics. In these annual programs logistics in conurbations and city logistics are emphasized (Vogel, 2018). City-Log*, City Log* and "Ballungsraumlog*" are placeholders for German and English terms in this context.
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Nine categories were determined in the trend research. Based on the further defined search items, the text material will subsequently be searched. In order to assign text passages correctly to the categories, the concepts behind the categories are defined in the following.

### 3 Content Definition of the Analysis Categories

In the following all categories are defined in order to assign text passages accordingly.

#### **Green Logistics**

Green Logistics aims to capture and ultimately reduce emissions and resource consumption resulting from transportation processes. Green Logistics belongs to the field of environmental management, which integrates environmental aspects into business decisions (Wittenbrink, 2015, p.1). As the trend towards Green Logistics is considered a veritable revolution in the logistics industry, there are accordingly many research projects that promote the implementation of Green Logistics. One example is the research project "Green Logistics", which, among other things, has targets such as the reduction of the environmental impact of logistics and the development of new green products for the logistics market (Fraunhofer-Institut für Materialfluss und Logistik IML, 2018). From the objective of Green Logistics to capture and reduce emissions and resource consumption

resulting from transport processes, it can be deduced that this trend is the starting point for other trends as Alternative Drive Systems for instance.

### **Smart Logistics**

Since the search items of Smart Logistics are quite extensive, each of them is addressed in order to create an overall picture.

*Industry 4.0:* The term for the so-called fourth industrial revolution is a conception of the German government in order to maintain the competitive ability of high-wage countries as Germany through measures in the fields of science, economy and society (Wollert, 2017). The Internet of Things (IoT) enables the networking and communication of objects. Technical devices of various types automatically transmit data to one another and assume monitoring, control and regulating functions. The automatic exchange of data between devices is referred to as machine-to-machine (M2M) communication. In transport logistics, this technology can be used, for example, in fleet management or in shipment tracking (Pfohl, 2016, p.16 and 318).

*Internet of Things:* There exist many definitions for the IoT. Therefore, this paper follows the definition of the ISO, because several aspects are covered: “*An infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react.*” (ISO/IEC JTC1, 2015, p.3).

*Physical Internet:* A global supply chain system is outlined by the vision of the Physical Internet (PI). Due to the fact that the manufacturers, transportation providers and retailers operate in a shared logistics network which has an internet-like structure, the name Physical Internet has been assigned. The PI is open and intermodal. Standardized, modular and reusable containers are used, which have real-time identification capabilities. They are routed through commonly operated logistics facilities. The basis technology for the realization of the PI is the IoT. The PI relies on the IoT in terms of communication and also has many features in common (Montreuil and Louchez, 2015).

*Cloud Computing:* Cloud computing is characterized by the provision of IT infrastructure as well as platforms and applications as an electronically available service on the Internet (Baun et al., 2011, pp.1-2).

*Big Data:* Large, fast-moving, complex data volumes, caused by the increasing use of information technology, characterize Big Data. Those characteristics of Big Data can be highlighted by the "Three Vs". Volume – increasing amounts of

data are available. Velocity describes the speed of new data creation. Variety provides information about the heterogeneity of the data content (Dorschel, 2015, pp.6-8)

*Logistics 4.0:* Logistics 4.0 represents a link between the IoT and high-performance sensors and innovative robotics in logistics. According to this, Logistics 4.0 can be described as networking the entire supply chain through IT. This means that there exists a digital twin of all objects affected in the supply chain. The properties of these objects, such as the identification number or the current physical location, can be communicated to the environment – the objects are networked with the environment (Bousonville, 2017, p.5).

### **Alternative Drive Systems**

Alternative Drive Systems are defined as systems, which do not work on the principle of the internal combustion engine. The first truck with a diesel engine dates back to the 1920s and is expected to dominate the commercial vehicle market for the next decade. However, some important arguments, such as the dependency on energy suppliers, characterize the need for alternatives or additions to conventional drives. Concern about global warming remains the most significant criterion for finding alternative energy. The most well-known form of the complementary technology to the diesel fuel is the electrical powered drivetrain in hybrid vehicles. In hybrid drive systems, the primary energy is derived from fossil fuels. However, hybrid drives take a second energy source into account, normally electricity. Although this increases the efficiency of diesel fuel, it does not solve the problem of fossil fuels. In contrast the electric motor completely replaces the conventional combustion engine. A distinction is made between electric drive with fuel cell and electric drive with batteries. Natural gas, also a fossil energy source, decreases CO<sub>2</sub> emissions by about 25 percent in direct comparison with diesel. The name for natural gas in vehicles is “Compressed Natural Gas” (CNG). Natural gas liquefies at -163 degrees Celsius. This creates another alternative fuel – Liquefied Natural Gas (LNG) (Hilgers, 2016, pp.3-4).

### **Innovative Vehicle Concepts**

Autonomous or driverless driving means the targeted movement of a vehicle without any intervention of a person. The vehicle recognizes by visual information sources, which are also available to the driver, which input data to obtain. Autonomous driving serves primarily to relieve the driver by supporting or replacing human perception. The vehicle recognizes potential sources of danger independently and reacts accordingly (Daimler AG, 2018). The drone, an unmanned aerial

vehicle, is either man-controlled with a joystick or autonomous (Ziegler, 2016). Cargo bikes are mainly used in parcel delivery, such as the Postal Operators and are suitable for transporting goods. Since 2012, cargo bikes with electric drive have been tested in Germany's urban areas. The potential savings are around 85 percent of car rides (Bombach, 2016, p.1 and Schradi, 2018).

### **Freight Exchange**

At Freight Exchanges the freight providers meet cargo space providers. It has to be considered by contract that loading date and region as well as and unloading date and region are recorded. Furthermore, the times for loading and unloading are defined. An advantage for the providers of freight services is that agreement and information costs can be reduced, since the provider has to submit his offer only once (Sänger, 2004, pp.73-74).

### **Rail Freight**

Rail Freight Transport describes the transport of goods by train. In 2012 in Austria around 30 percent of the total land freight traffic were handled on the railway. According to the overall traffic plan's goal this value has to be increased by ten percentage points by 2025 (Wirtschaftskammer Österreich, 2017).

### **Transport Bundling**

Transport Bundling is a collective transport that collects goods from several consignors and delivers them to a receiving point. It is generally more cost-effective than the shipment of individual goods. The decisive factor in Transport Bundling is that the cargoes are picked up and delivered in one tour (Sihl, Meizer and Leitner, 2009, p.10).

### **Flexible Supply Chains**

The aim of a flexible supply chain is to anticipate changes and react agile (Dr. Thomas + Partner GmbH & Co. KG, 2015).

### **Smart Urban Logistics**

In Europe, around 80 percent of people live in urban cities – a challenge for logistics and the environment. Reaching people in metropolitan areas, while taking into account the environment, characterizes Smart Urban Logistics and city logistics (Allen, Browne and Holguin-Veras, 2015, p.293 and Erd, 2015, pp.2-3).

The categories and the search items have been identified and defined. Chapter 4 describes how the text material is analyzed within the software "QCAmap".

## 4 Implementation of the Meta-Analysis – Trend Allocation and Frequency Analysis

The text material is available digitally in PDF format. Therefore, it is possible to evaluate the text material using software. The development of software solutions for the qualitative analysis of content has progressed since the 1980s. Developed by Philipp Mayring and Thomas Fenzl together with the company coUnity Software Development, QCAMap represents one of these software applications. The software offers a specific focus on qualitative content analysis (Mayring, 2014).

First of all, the result expectations have to be defined. In this study, a frequency analysis should provide information on the number of mentions and on the temporal distribution of trends. Based on this evaluation, the frequencies are examined to assess the relevance of the trends. The trend analysis is based on the “inductive category generation”, which is available in the software. The reason for this is that it is possible to find previously defined search items, mark them and assign them to the predefined categories. In the “category statistics”, it is then possible to evaluate the categories in their relative and absolute frequency. In addition, it reveals in how many documents the category occurs. The “document statistics” assigns the entries per category to the documents in which they were selected. Based on this method different analyzes can be carried out. Subsequently, it is necessary to define the analysis units.

*Coding unit:* The coding unit is the smallest component of the material that can be coded. For trend analysis, the “klare Bedeutungskomponente” is selected from the drop-down box.

*Context unit:* The context unit defines the background of the coding decision. All text material is entered in this field.

*Recording unit:* The recording unit is the whole text material.

After the input parameters are defined, the user is directed to the coding mode. In order to analyze a category, the search items are identified by a search function. For example, if the category Green Logistics is to be researched, the terms Green Logistics, “Grüne Logistik”, “umweltfreundlich” and “Sustainability” will be searched one after the other. The category Green Logistics achieves more than 500 hits, which have to be analyzed step by step by the user. The user decides now, based on the categories defined in Chapter 3, whether the hit is related to Green Logistics, or whether it is mentioned in a different context. If a hit meets the

criteria, the user marks the affected text (word, phrase, sentence, paragraph) and creates a new category (in this case "Green Logistics"). If a new trend is analyzed, a new category has to be created. Once all the categories have been created and all search items listed in Table 3 have been explored and assigned, the evaluations can be downloaded. The findings and results of this paper are presented and explained in chapter 5.

## 5 Findings and Results

Figure 4 shows an overview about the relevance of the trends according the analyzed editions of the journal "Verkehr". The time course of the trend development is subsequently presented for all trends with more than 100 hits.

In the chart above the context-related mentions of the categories analyzed by the meta-analysis in this paper are shown. Based on a mere counting of the search items in the text material, the search items of the category Alternative Drive Systems have more than 800 hits and the search items of the category Rail Freight even more than 5,000. This makes the benefit of the conducted meta-analysis

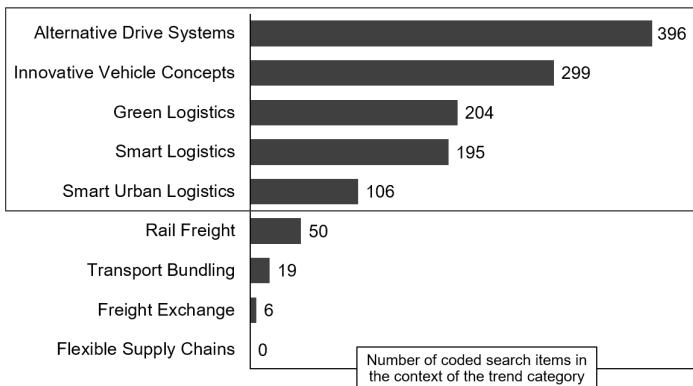


Figure 4: Absolute frequencies of trend categories

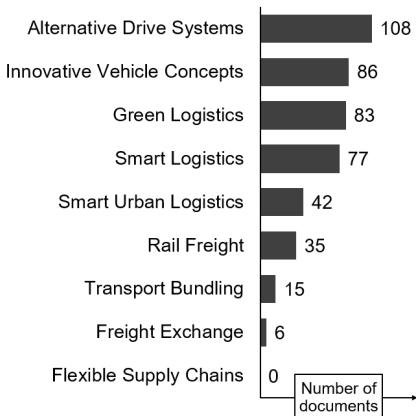


Figure 5: Number of documents the trends were covered

clear: The validity of the definition whether a trend is relevant has been increased, since only text passages that cover the defined trend have been assigned. Figure 5 shows the number of documents in which the trends occurred.

The chart shows that the more journal editions cover a trend, the more often it occurs. Consequently, occasional thematic priorities do not distort the overall ranking in this analysis. The first five trends which have been covered more than 100 times during the period from 2014 to 2017 are presented on a quarterly basis in the following (Figure 6 to Figure 10) and interpreted subsequently. For this purpose, the data available on a weekly basis have been aggregated. The x-axis shows the time course on a quarterly basis. The y-axis shows the frequency in which the search items of the category occur in the context of the category. Based on the maximum value, the y-axis was set for all charts from 0 to 60. The black line shows the development of the trends according the analyzed editions of the journal (historic data). The dashed line shows the forecast until the end of the year 2020. The forecast has been created via the Excel function “PROGNOSIS.ETS”. This function calculates a future value based on existing historic values using the AAA version of the ETS (Exponential Smoothing) algorithm. The forecasted value is a continuation of historic values at the specified target date (Microsoft Office

Support, 2018). This function has been chosen, because Exponential Smoothing is a widely applied standard method for forecasting historic values (Raessler and Mertens, 2017). However, it has to be noted, that the presented forecast is a rough empirical estimation based on the identified historic values. Especially, in connection with the long underlying forecasting horizon, this value has to be understood as an indication.

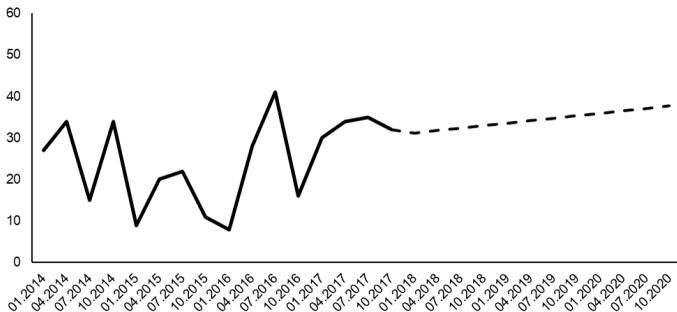


Figure 6: Trend development "Alternative Drive Systems"

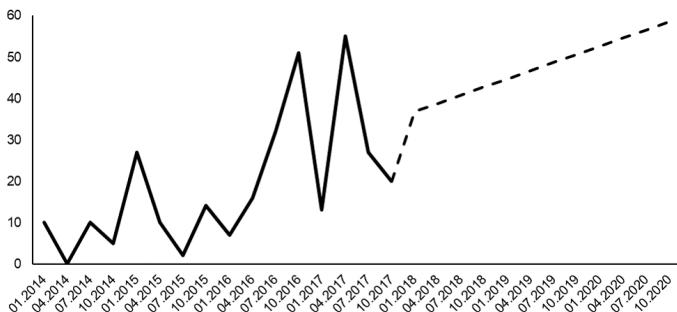


Figure 7: Trend development "Innovative Vehicle Concepts"

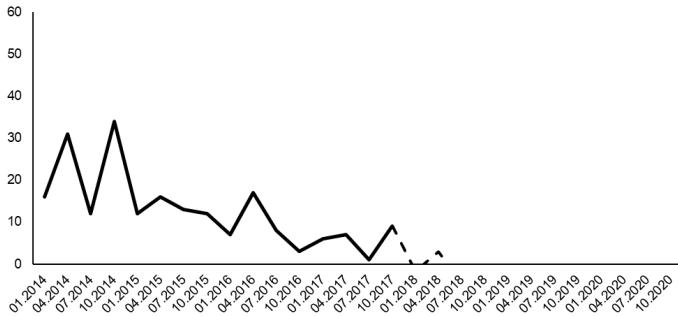


Figure 8: Trend development "Green Logistics"

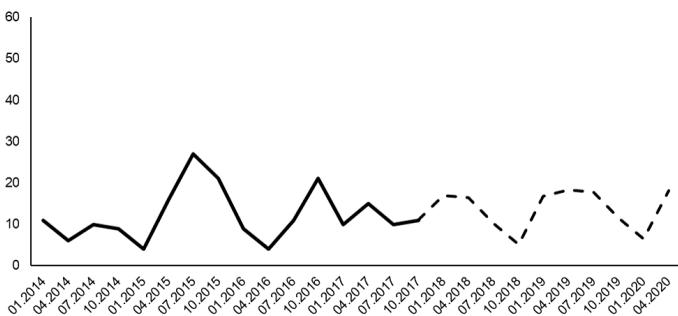


Figure 9: Trend development "Smart Logistics"

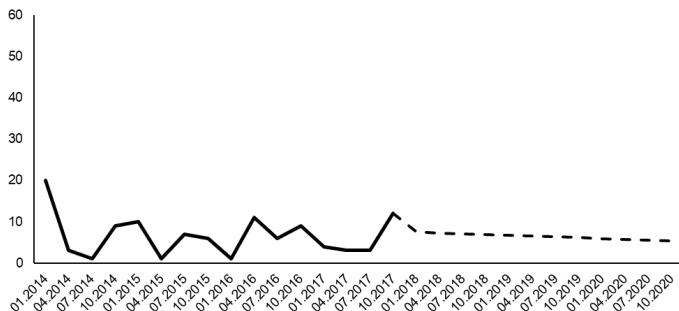


Figure 10: Trend development "Smart Urban Logistics"

**Alternative Drive Systems:** The trend Alternative Drive Systems shows strong fluctuations. Recently, there has been an increase in this trend and, according to the forecast, this topic will increase slightly in the future.

**Innovative Vehicle Concepts:** While little attention has been paid to this trend in the past, there has recently been an increase that is likely to continue in the future.

**Green Logistics:** Green Logistics was a strong trend at the beginning of the analysis period but has recently dropped. It is interesting, if the forecast proves true and whether this topic will be ignored in the future.

**Smart Logistics:** It turns out that this subject fluctuates and obviously has a certain consistent seasonality.

**Smart Urban Logistics:** In general, this trend is less relevant than the other trends. A slight decrease in the future is forecasted.

The meta-analysis reveals that the top trends Alternative Drive Systems and Innovative Vehicle Concepts will continue to be important topics in the logistics debate. Especially, the trend Alternative Drive Systems has a strong relationship to Green Logistics. However, even if the meta-analysis shows that sustainability aspects play an important role in the debate on logistics trends and their development, it is noticeable that Green Logistics itself has become less relevant during the last years. It has also been confirmed in the interim results of the study of the Institute Industrial Management presented at the beginning of this paper that the topic

of sustainable transport logistics in general is not that important to companies. Therefore, sustainability aspects should not only be given more importance in the future in terms of Alternative Drive Systems, but rather generally.

## References

- Allen, J., Browne, M., Holguin-Veras, J., 2015 (2015). *Sustainability strategies for city logistics*, Philadelphia: Kogan Page Limited.
- Baun, C., Kunze, M., NIMIS, J., Tai, S (2011). *Cloud Computing: Web-basierte dynamische IT-Services*. Springer: Berlin Heidelberg.
- Beilhammer, M. (2017). *Logistik Trends (2017): Neue Techniken vorgestellt*.
- Bombach, E. (2016). *Traktionskonzept für ein Lastenfahrrad*. Wiesbaden: Springer.
- Bousonville, T. (2017). *Logistik 4.0: Die digitale Transformation der Wertschöpfungskette*. Wiesbaden: Springer.
- Breinbauer, A. (2014). "Logistik, SCM, Transport und Verkehr 2014/2015". In: *Verkehr* 70(50).
- Breinbauer, A. (2015). "Was die Logistik 2016 bewegt". In: *Verkehr* 71(50-52).
- Breinbauer, A. (2016). "Chancen und Risiken durch das politische Umfeld". In: *Verkehr* 72(50-52).
- Daimler AG (2018). *Definition "Autonomes Fahren"*.
- Diekmann, A. (2004). *Empirische Sozialforschung, Grundlagen, Methoden, Anwendungen*. Hamburg: Rowohlt.
- Dorschel, J. (2015a). *Einführung und Überblick*. Wiesbaden: Springer Fachmedien.
- Dorschel, J., ed. (2015b). *Praxishandbuch Big Data: Wirtschaft – Recht – Technik*. Wiesbaden: Springer Fachmedien.
- Dr. Thomas + Partner GmbH & Co. KG (2015). *Die Logistikkette einer Wertschöpfungskette*.
- Erd, J. (2015). *Stand und Entwicklung von Konzepten zur City-Logistik*. Wiesbaden: Springer Fachmedien.
- Fraunhofer-Institut für Materialfluss und Logistik IML, n.d. (2018). *Ziele von Green Logistics*.
- Gensrich, E. (2017). *Digitalisierungstrend - Diese Begriffe sollten Sie kennen*.
- Gläser, J. and Laudel, G. (2006). *Experteninterviews und qualitative Inhaltsanalyse*. Wiesbaden: Verlag für Sozialwissenschaften.
- Glass, G. (1976). "Primary, Secondary, and Meta-Analysis of Research". In: *Education Researcher* 10, pp. 3–8.
- Hilgers, M. (2016). *Alternative Antriebe und Ergänzungen zum konventionellen Antrieb*. Wiesbaden: Springer Fachmedien.
- Horizont (2017). *Autonome Transportlogistik auf der "letzten Meile"*.
- ISO/IEC (2017). *Study on IoT Reference Architectures and Frameworks*.
- Klacska, A. (2015), "Zuversichtlich ins Jahr 2016." In: 71.50-52, p. 4.
- Kotrba, D. (2017). *E-Bikes, E-Autos und Software machen Güterverkehr sauberer*.
- Mayring, P. (2010). *Qualitative Inhaltsanalyse*. Wiesbaden: Verlag für Sozialwissenschaften.
- Mayring, P. (2014). *Qualitative Content Analysis*.
- Mayring, P. (2015). *Qualitative Inhaltsanalyse: Grundlagen und Techniken*. Weinheim: Beltz.
- McKinnon, A., Browne, M., Piecyk, M. and Whiteing, A., ed. (2015). *Green Logistics: Improving the environmental sustainability of logistics*. Philadelphia: Kogan Page Limited.

## REFERENCES

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- Mey, G., Mruck, K., ed. (2010). *Handbuch Qualitative Forschung in der Psychologie*. Wiesbaden: Verlag für Sozialwissenschaften.
- Microsoft Offi e Support (2018).
- Montreuil B. and Louchez, A. (2015). *The Physical Internet Will Rest On The Internet Of Things*.
- Müller, J. (2017). "Die Drohne bringt das Paket". In: *Verkehr* 73.50-52, p. 8.
- Niess, F. (2017). *Forschen für eine umweltfreundliche Logistik*.
- Pfohl, H.-C., 2016 (2016). *Logistikmanagement: Konzeption und Funktionen*. Wiesbaden: Springer Vieweg.
- Raessler, S. and Mertens, P. 2017 (2017). *Prognoserechnungsverfahren*.
- Sänger, F. (2004). *Elektronische Transportmärkte: Untersuchungen zur Optimierung des Straßengütertransports*. Wiesbaden: Springer Fachmedien.
- Saunders, M., Lewis, P., and Thornhill, A. (2012). *Research Methods for Business Students*. Edinburgh: Pearson.
- Schenk, M., ed. (2009). *Digital Engineering – Herausforderung für die Arbeits- und Betriebsorganisation*. Berlin: GIT.
- Schneider, M. (2018). *Keywords*.
- Schradi, D. (2018). *Das Lastenrad*.
- Senger-Weiss, W. (2016). "Mehr Dynamik für Standortpolitik". In: *Verkehr* 72.50-52, p. 6.
- Sihl, W., Meizer, F. and Leitner, R. (2009). *Unternehmensübergreifende Logistikmodelle zur Erhöhung der Nachhaltigkeit und Energieeffizienz*. Berlin: GIT.
- Stiftne , R. (2014). "Logistikjahr 2014 – Logistikzukunft 2015". In: *Verkehr* 70.50-52, p. 9.
- Stiftne , R. (2015). "Digitalisierung verändert die Logistik". In: *Verkehr* 71.50-52, p. 5.
- Vogel, T. (2018). *Effizienter Güterverkehr in Ballungszentren*.
- Wirtschaftskammer Österreich (2017a). *Logistik: Struktur, Zukunft und Trends der Branche*.
- Wirtschaftskammer Österreich (2017b). *Schienengüterverkehr*.
- Wittenbrink, P. (2015). *Green Logistics: Konzept, aktuelle Entwicklungen und Handlungsfelder zur Emissionsreduktion im Transportbereich*. Wiesbaden: Springer Fachmedien.
- Wollert, J. (2017). *Industrie 4.0 – warten bis die Revolution vorbei ist?*
- Ziegler, M. (2016). *Definition von Drohne*.



# Clean Technologies and Energy Efficiency in SMEs

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1 – UNTREF

*A strategic association has been made between the National University of Tres de Febrero (UNTREF) and the Municipality of Tres de Febrero. These institutions jointly analyzed SMEs (small and medium-sized enterprises) located in the mentioned district, with the aim of designing and analyzing the implementation of clean technologies. Firstly, based on the information provided by the Industry Department, the SME sector was surveyed. Three manufacturing companies from different industries were selected, in order to carry out the proposed study. In this connection, a diagnosis tool was designed for each case, in order to detect possible areas for improvement to optimize the resources required for the process, implement renewable energy sources, minimize waste and improve the working environment, among others. This tool is designed to be used through the whole SME sector, and not exclusively for the analyzed cases. Based on the results achieved, a working team has been constituted with representatives of the associated sectors, in order to design different alternatives to be implemented in each case. Said alternatives aim at minimizing or mitigating the environmental impact caused by the Companies manufacturing processes. The objective is to incorporate technologies and practices following the premise of sustainable development, promoting the environment care, thus improving companies competitiveness.*

**Keywords:** Environment; Clean Technologies; Energy Efficiency

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## 1 Introduction

Through the last years, the society has begun to become aware of the manner human activity cause continuous damage to the environment. Mostly, this degradation is generated by the industrial manufacturing processes. Therefore, it results essential to promote practical knowledge on the way of reducing its impact on the environment, improving energy efficiency and reducing emissions.

Currently, many industries consider sustainability as a key aspect in their processes, considering the rational use of strategic resources, whether fossil fuels, water or soil fuels. At the same time, the aim of this project is to minimize the impacts caused by industrial waste, whether in liquid, solid or gaseous state.

Chen et al. (2013) report that there are significant opportunities for small and medium-sized enterprises (SMEs) in developing countries, which could generate growth and jobs, while providing solutions to the challenges that exist in the climate topic. The droughts, erosion, floods and high levels of pollution in the world have become a real problem that affects economies and societies in all continents of the planet. The climate change issue has led countries to take measures to avoid a future environmental catastrophe, and that is the reason why addressing this problem presents an economic opportunity for developing countries like Argentina.

Encouraging local industries in developing countries to have clean technologies in their production processes can stimulate sustainable economic growth and generate wealth, since they will be able to simultaneously work on the urgent priorities presented by development, such as access to energy, clean and potable water, without affecting the climate.

In recent years, clean technologies have grown as an important global market. Klewitz et al. (2010) estimate that US \$ 6.4 billion will be invested in developing countries in the next few years. For the release of this environmental and economic potential, it is necessary to support the ecological companies. SMEs that dedicate themselves to clean technologies confront enormous challenges, especially when it comes to obtain an initial financing in the growth phase. Countries can help by creating specific policy incentives that could help support SMEs in areas such as innovative financing mechanisms, acceleration of businesses and entrepreneurship, market and technological developments, and legal and regulatory framework.

However, despite the efforts made by some social and government sectors in Argentina, tending to direct industries towards a sustainable profile, the SME sector of the Province of Buenos Aires is still relegated due to the trouble experienced by these companies to keep on developing and standing during economic instability periods. This project seeks to raise awareness and to perform specific cases (cases of study) for the introduction of cleaner processes, developing a tool that may provide a sustainability diagnosis, revealing non-sustainable processes, sub processes and policies, in order to generate one or more solutions to increase sustainability in these companies. This idea has been developed by Quintero et al. (2007).

The objective of this work is to promote the implementation of clean practices and technologies in SMEs through the design of a tool that provides a quick and low-cost sustainability assessment, being able to locate manufacturing sectors that generate waste, as well as the consumption of raw materials and energy. These aspects will be used to detect areas of improvement in terms of optimization of resources, minimization of waste, mitigation of negative impacts caused by the activity, introduction of renewable energy sources, care of the working environment and the environment itself, among others variables.

## 2 Proposal

A strategic association was made between the National University of Tres de Febrero (UNTREF) and the Municipality of Tres de Febrero. Science and Technology Institute, Research and Development Secretariat and Degree Careers in Hygiene and Safety and Environmental Engineering of the UNTREF, including the Municipality represented by the Industry Department. This Association will visit and conduct a diagnosis on the voluntaries SMEs, with the purpose of designing and analyzing the implementation of clean technologies in these companies. Firstly, the SMEs were surveyed pursuant to the information provided by the Department of Industry. Three manufacturing companies from different industries were selected in order to carry out the proposed study. The selected companies were intended to serve as pilot cases and drivers for other companies, in view of promoting clean production process.

For this reason, a diagnosis tool was designed for the selected cases, in order to detect possible areas for improvement to optimize the resources required for the process, implement renewable energy sources, minimize waste, and improve the

working environment, among other aspects. A similar view is held by Owodunni (2016).

This tool was designed to be applied by technicians from the District's Department of Industry. As from the tool's application in the selected cases, some adjustments have been made based on the diagnosis results, applying specific improvements according to the needs of each case. These proposals aimed at mitigating the environmental impact generated in the companies manufacturing processes. The objective was to incorporate technologies and practices following the sustainable development premise, and the environment care, thus improving companies' competitiveness. The alternatives designed were introduced to each company with the aim of making a selection pursuant to the interests and possibilities in each case.

### 3 Methodology

Four instances from the design to the final report, and other intermediate instances were established for the layout of the working tool. These four instances are depicted as follows:

In the first one, a survey form was prepared with the purpose of assessing facilities, consumption of raw material and inputs, generation of waste, machinery used, sustainable policies of the company, future plans, and desire for improvement. The method used should accept any value response setting the context of the respective value, so that during data processing, all the values can be compared with the standard. It requires key questions with short answers that are processed after the interview, in order to obtain the required data.

The survey is divided into seven different sections such as company identification, internal organization, operational processes, energy consumption, sustainable practices, relationship with the community and long-term projections.

For the first release of information and for practical reasons, it was used a printed form with questions about companies administration, number of employees, duration of the working day and the occupied surface. Furthermore, the questions referred to a productive process, its distribution in the production chain and, supplies used for each process. Finally and very important for the project, knowing about waste generated and any kind of sustainable practice they were applying in the production process.

The second step consisted on the evaluation of the tool trough by visiting and surveying three SMEs, contacted and selected by the Municipality. The purpose of this step was to determine the use easiness of the tool and the need to add or remove questions. The survey data was processed and focused on raw material consumption, energy inputs and waste generation. In case that the data was insufficient it was planned a second visit and survey.

In the third step included sustainability report has been conducted, spotting the areas and improvement alternatives, according to the data gathered in the interview.

In the last step, a detailed report of the improvement alternatives was prepared together with a budget and possible financing to carry it out. This final report was delivered, along with the data processing and the survey, including the possible improvement alternatives where each company chose the most appropriate ones to provide a detailed report later on.

## 4 Results

By using the tool, the amount of waste produced by each company was first analyzed. As we can see in Table 1, the largest amount of waste is produced by the company with the largest number of employees and the largest total surface.

However, the percentage of waste surface compared to the total surface of the company is very small. In the three companies analyzed this percentage is less than 1%, therefore this does not represent a problem to consider in the analysis of clean technologies of the companies studied. These results agree with the information obtained through the surveys. None of the three companies studied had waste problems.

With respect to the consumption of electrical energy, the three companies have a normal consumption of energy under the norms of the Argentina industry. The company with the highest energy consumption is SME 3. This company is a craft brewery that consumes 22090 kw/month due to the equipment used during the process.

Table 1: SMEs information

	SME 1	SME 2	SME 3
Number of employees	4	45	10
Total Surface [m <sup>2</sup> ]	337	1400	600
Waste Surface [m <sup>2</sup> ]	3	6	2
Energy Consumption [Kw/month]	5548	18704	22090

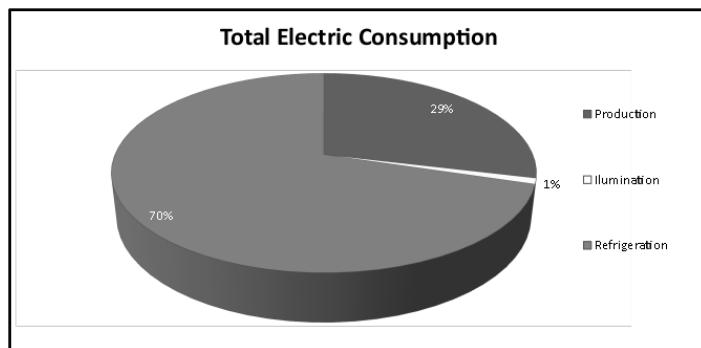


Figure 1: SME 3 – Total Electric Consumption

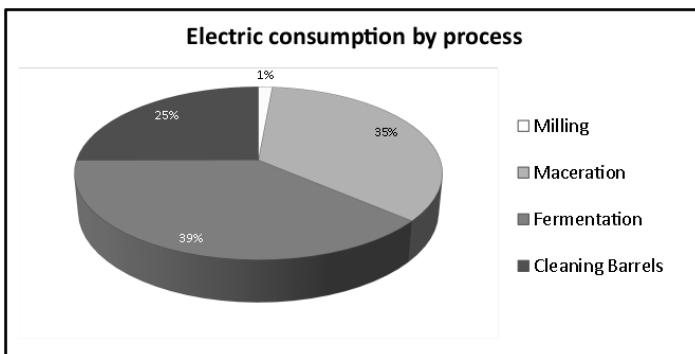


Figure 2: SME 3 – Electric Consumption by process

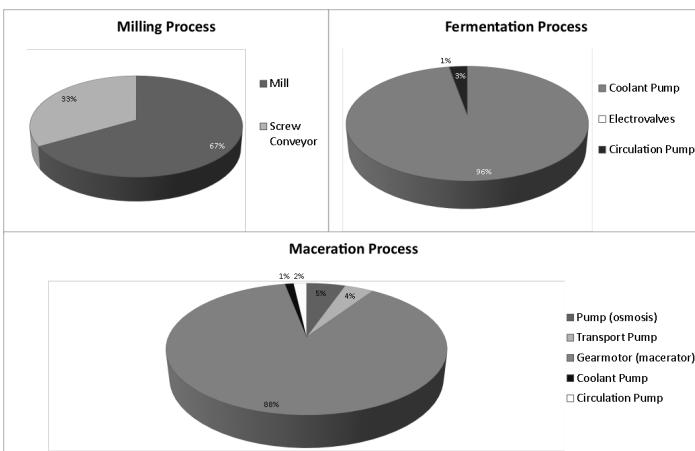


Figure 3: SME 3 – Electric consumption by machine

According to the survey made, the high consumption of energy represents a problem for this company. A detailed study of the electrical consumption of this SME was carried out.

As can be seen in Figure 1, the total electric consumption is classified according to where it comes from. The electrical consumption due to the lighting of the industry represents 1% of the total consumption, while the consumption due to the manufacturing process and to the refrigeration of the products represents 29% and 70%, respectively.

Using the clean technologies tool, the electric consumption of each process of the craft beer company was analyzed. Figure 2 shows the electric consumption by process of the company.

The milling process does not cause a problem in the electrical consumption. The barrels cleaning process represents 25% of the total consumption due to the use of a pressure washer to clean the barrels. The process of maceration represents 35% and the process of fermentation and maturation of beer 39% of the total energy consumption. By the use of the tool, energy consumption was classified according to the power consumed by each machine in each process.

Figure 3 shows the percentages of the energy consumption of each machine for the processes of mixing, maceration and fermentation. As we can see, in the processes of mixing and maceration the high levels of energy consumption are due to the power of the mixer and the motor, respectively. To reduce the consumption of these processes the engine used should be changed.

Fermentation is the process that consumes most electrical energy due to the power of the cooling pump. The beer fermentation process requires a proper cooling system to keep the temperature constant. The energy consumption of the fermentation cooling system could be reduced by using thermal insulators in the equipment. In this way, heat losses in the equipment could be avoided, generating lower energy consumption.

## 5 Conclusions

The results after the implementation of the diagnostic tool were satisfactory and it did not require a second visit or additional request in order to identify the points of generation of pollutants, that use a largest consumption of supplies. For example,

it can be observed just in the processing of electricity consumption data that in the company that produce craft beer its processes and machines are the highest electricity consumption.

Alternative options were analyzed to reduce the relevant consumption of the process, for example, a correct isolation of the refrigeration system would reduce the losses due to heat input, which would reduce the electrical consumption of the refrigeration system that represents 70% of the consumption total electric.

From the results we obtained of the study, it was possible to have in statistical numbers, the little training and knowledge that the owners and employees of the companies have about clean technologies. For this reason, it is planned in the future to offer a course aimed at the different SMEs of the municipality of Tres de Febrero so that the transfer to clean technologies can be carried out.

These courses will be held in theoretical and practices sessions, where a methodology will be presented to determine the aspects of the process of a company that must be addressed first to improve the quality of the product without inferring in the environment. Through the transfer of clean technologies to SMEs they could improve the quality and competitiveness in the production of goods and services.

A diagnosis and analysis tool was developed for the implementation of clean technologies in SMEs, which will be transferred to the Industry Department of the Municipality of Tres de Febrero. In this sense, the technical team of the Municipality will be able to carry out these diagnosis and analysis actions. At the end of this project, the participating SMEs obtained alternatives of ideas and projects to be developed with the purpose of implementing clean practices in their most relevant companies in terms of planning.

## References

- “A holistic and rapid sustainability assessment tool for manufacturing SMEs” (2014). In: *CIRP Annals - Manufacturing Technology* 63, pp. 437–440.
- Bercobich N. & Lopez, A. (2015). “Políticas para mejorar la gestión ambiental en las pymes argentinas y promover su oferta de bienes y servicios ambientales”. In: *CEPAL – SERIE Medio ambiente y desarrollo* 65, pp. 2–65.

- Owodunni O. O. & Pinder, D. (2016). "Sustainability improvement in milling operation through improved tool design and optimized process parameters-an industrial case study". In: *13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use*. Vol. 1, pp. 498–503.
- "Propuesta de ahorro de energía a una empresa de la región sur de Sonora a través de un diagnóstico energético" (2008). PhD thesis. Instituto Tecnológico de Sonora. Des Navojoa, Mexico.
- Quesada Bermúdez, M. (2015). "Propuesta de programa de producción más limpia para la empresa de pinturas blue start". PhD thesis. Instituto Tecnológico de Costa Rica.
- Quintero O. & Salichs, A. (2007). *Gestión Ambiental para una producción más limpia en la región centro de Argentina. Rosario, Argentina*. Tech. rep. Fundación Libertad.
- "The Role of Intermediary Organizations in Eco-Efficiency Improvements in SMEs: A Multi-Case Study in the Metal- und Mechanical Engineering Industries in Germany" (2010). In: *CCSBE 2010 Conference*. Lüneburg: Centre for Sustainability Management.