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Data Science in Maritime and City Logistics

Data-driven Solutions for Logistics and Sustainability

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Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle
(Editors)

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Preface

Data sciences continue to shape the industrial and scientific world opening new opportunities across a wide range of sectors. Artificial intelligence is considered a key driver of data science that has the potential to introduce new sources of growth. The recent advances in machine learning and automation have created a whole new business ecosystem.

This year's edition of the HICL proceedings complements the last year's volume: Digital Transformation in Maritime and City Logistics. All entities along the supply chain are challenged to adapt new business models, techniques and processes to enable a smooth transition into an innovative supply chain.

This book focuses on core topics of data science and innovation in the supply chain. It contains manuscripts by international authors providing comprehensive insights into topics such as Maritime Logistics, Business Analytics, Port Logistics or Sustainability and provide future research opportunities in the field of supply chain management.

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 2020

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

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Sustainability and City Logistic

Development of sustainability performance measurement framework for measuring complex sustainability impacts in the manufacturing industry

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Purpose: This research aims to develop a framework of sustainability performance measurement and to propose sustainability impact criteria that can be used to measure complex sustainability impacts in the manufacturing industry.
Methodology: Fuzzy-Analytical Hierarchy Process (Fuzzy-AHP) and the Delphi method were used to calculate the weights of sustainability impact criteria. Then, the impact pathway of a life cycle assessment was constructed to illustrate the interrelationship between each impact criterion. A proposed framework of sustainability performance measurement is presented along with the suggested sustainability impact criteria.
Findings: Based on the Delphi method and Fuzzy-AHP, the environmental aspect is the area that has received the highest concern (49.4%). The important endpoint impact criteria of the environmental aspect consist of Effect on global climate, Ecosystem quality, Animal biodiversity, and Resource management.
Originality: The biggest challenge of sustainable development that is yet to be answered is how to measure sustainability performance. The environmental aspect is the area that has received the most attention while the economic and social aspects are still under-represented. To fill the gap, this research proposes a framework of sustainability performance measurement that considers all interrelationships between each sustainability aspect.

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1 Introduction

Sustainability has become an important topic in our society especially in the recent time of economic globalization and environmental social movement. It was brought into public focus for the first time in 1987. The United Nations described the definition of sustainability as "a development that meets the needs of the present without compromising the ability of future generations to meet their needs" (United Nations 1987). It became the most often quoted and referred to regarding sustainability. In 1998, John Elkington introduced a sustainable development framework called the Triple Bottom Line (TBL) that not only considers traditional monetary factors but also integrates environmental and social aspects into sustainability (Elkington 1998). The increasing awareness of sustainability has driven many organizations and firms to re-evaluate their supply chain management strategies and business models.

In the past, decision-makers often focused and based their decisions solely on the economic aspect. This trend has changed over the past decade. Nowadays, the focus is projected towards the development of a sustainable supply chain that considers the goals of all three sustainability aspects namely, economic, environment, and social. Thus, Sustainable Supply Chain Management (SSCM) became a crucial element in many organizations' strategies, especially the manufacturing sector. To be sustainable, all players in the supply chain must be committed to the principle of sustainability (Amindoust et al. 2012). For this reason, measuring sustainability performance among players in the supply chain remains one of the biggest challenges in order to create a sustainable supply chain.

Life-Cycle based methods are the most popular tools used for evaluating sustainability. In the late '60s, Life Cycle Costing (LCC) was introduced and became well-known among economists. Unlike the traditional cost accounting tools, LCC considers not only certain specific costs such as investment cost or operating cost, but rather overall costs associated throughout the whole life cycle of a product or service (Gluch and Baumann 2004; Woodward 1997). After that, the concern over environmental pollution and environmental movement during the 70s' motivated the development of another life-cycle based tool called "Life Cycle Assessment (LCA)" (Hauschild et al. 2018). It is used to assess and evaluate the environmental impacts that are caused by the life cycle of a product or service. It is a well-constructed tool that integrates environmental international standards such as ISO 14040 or 14044 in the analysis (Ness et al. 2007).

At this point, the focus of sustainability has been mainly on economic benefits and environmental impacts while the social aspect does not appear to be considered as often as the other two perspectives. Social Life Cycle Assessment (SLCA) was the last life cycle assessment tool that was introduced to assess the positive and negative impacts on the social aspect (O'Brien et al. 1996). Even though the topic of SLCA is still fairly new to the area of life cycle assessment but the topic has gained more attention among researchers and scholars during the past decade (Finkbeiner et al. 2010).

However, most of the life cycle assessment tools are often applied to each sustainability aspect separately (Klöpffer 2003). Due to this reason, many researchers have proposed a hybrid approach that combines two or more approaches together such as a combination between LCC and SLCA, or LCC and LCA. It is also suggested that each aspect of sustainability should be equally evaluated to avoid the complication in the process of result interpretation (Neugebauer et al. 2016; Kloepffer 2008). The combination of the life cycle assessment tools is believed to be a better approach that can represent the overall sustainability in the life cycle.

This research aims to develop sustainability impact criteria and to propose a sustainability performance measurement framework for measuring the complex sustainability impacts in the manufacturing industry.

2 Exploring frameworks of sustainability assessment

To assess sustainability performance, we need to understand the basic characteristic of activities that might affect each sustainability aspect. Figure 1 displays four fundamental flows as inputs and outputs of a corporation (Hutchins and Sutherland 2008). A common goal of every organization is to convert these fundamental flows into a product or service. In general, the focus on financial resource flow is one of the most important aspect in conducting business. However, it is inevitable that emissions or any other negative substances would also be a part of the output. This requires the corporations to balance the focus to all three sustainability aspects equally. As mentioned in the first section, LCA is commonly used to evaluate the environmental effects that are related to all stages of the product life cycle. In 1997, the International Organization for Standardization (ISO) released a set of standards (ISO 14040) to support the principle and framework of LCA. It is separated into 4 phrases which are Goalsand scope definition, Inventory analysis, Impact assessment, and Interpretation (Hauschild et al. 2018). The principle of LCA is to assess the change of physical substances chemically and evaluate the effect of the activities on two impact categories namely midpoint impact criteria, and endpoint impact criteria. For example, Human Health is categorized as one of the endpoint impact criteria. The impact pathway of Human Health is affected by several midpoint impact criteria such as ozone depletion, acidification, or eutrophication. Inventory data such as emissions of carbon dioxide, sulfur dioxide, or methane is required to analyze the impact on both midpoint and endpoint impact criteria. Thus, the input flows can be linked to the assessment as a cause of the impact pathway. To support the interpretation of the result, using both midpoint and endpoint impact criteria when conducting LCA is recommended. It is proved that the endpoint categories are more relevant to decision-makers (Bare et al. 2000). The result from LCA represents mainly the aspect of the environment. Hence, the result of LCA cannot be interpreted as an overall sustainability performance. To achieve that, LCC and SLCA must be performed as well.

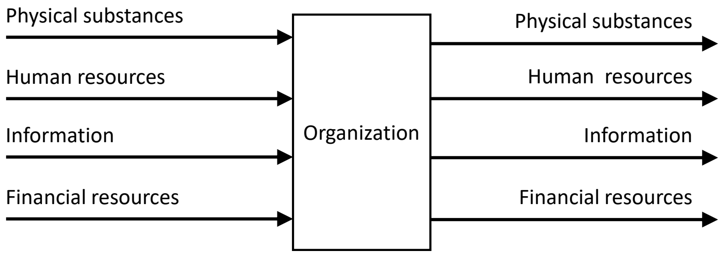

Figure 1: Primary flow of a corporation adopted from (Hutchins and Sutherland, 2008)

Classical LCC is often conducted only for economical gain for the company. In some cases, environmental and social aspects are integrated into the evaluation of LCC (Gluch and Baumann 2004). In 2016, Economic Life Cycle Assessment (EcLCA) was introduced. The framework of EcLCA suggests that midpoint impact categories and endpoint impact categories should be constructed to evaluate economic sustainability. It is believed to be a better reflection of the economic aspect. (Neugebauer et al. 2016).

In the context of sustainability, the social context is still underrepresented. In general, social assessment is performed only to report and evaluate the progress regarding the social context of the organization such as working

hours, or average wages. In 2006, the first methodological framework of social life cycle assessment was proposed. It is suggested that an area of protection such as human well-being should be used in the evaluation. The impact category should consist of stakeholders who are affected by the business such as workers, supply chain players, or society (Dreyer et al. 2006). In 2008, an analysis of existing approaches of SLCA was conducted. It can be concluded that people's perception regarding social impacts is varied, subjective, and can be difficult to measure (Jørgensen et al. 2008). Since most of the social criteria evaluate the degree of human satisfaction and social value, they are not easy to quantify. (Santiteerakul and Sekhari 2011). In 2009, the United Nations Environment Programme (UNEP) published the first international social life cycle assessment guideline called "Guidelines for Social Life Cycle Assessment of Products" (Benoît and Mazijn 2009). The framework of SLCA suggested by UNEP can be combined with LCA since they share a common framework. There are available sets of social indicators that are published by several international organizations such as Global Report Initiative (GRI) or United Nations-indicators of Sustainable Development (UN-CSD) (Joung et al. 2013).
From this literature, the decision makers' perspective on sustainability has not been fully integrated into the framework of life cycle assessment tools. The method of Multiple Criteria Decision Making can be combined with the methodological structure of the life cycle assessment to deal with a complex problem with contradictory goals (Verones et al. 2017). Each decision-maker often has different perceptions and perspectives regarding sustainability. One of the advantages of using MCDM is that the decision-makers

have control over the sustainability aspects in which they are interested in. This approach was first mentioned in 1997, it is suggested that the step of goal definition and scope in LCA is subjective and should be guided by decision-makers. Thus, it is necessary to use the Analytical Hierarchy Process (AHP) to evaluate and select the impact categories (Miettinen and Hämälänien 1997). In recent research, a combination approach between MCDM and LCA was used to evaluate renewable energy technologies. It shows that the hybrid approach, especially the combination of LCA and AHP, is a better option to evaluate comprehensive sustainability (Campos-Guzmán et al. 2019; Santoyo-Castelazo and Azapagic 2014; Ong et al. 2020).

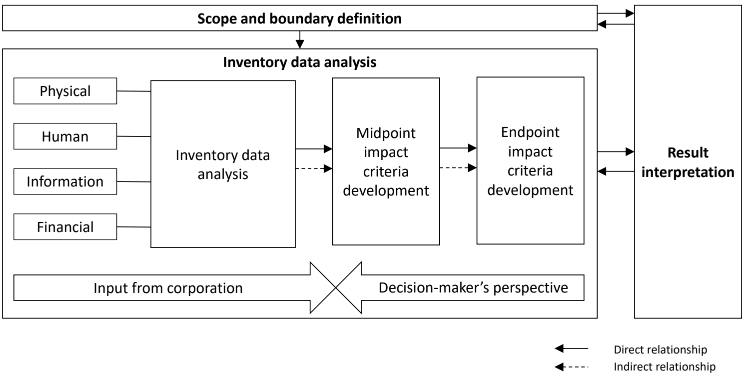

Figure 2: A proposed framework of sustainability performance measurement

Base on this literature, we developed a proposed framework of a sustainability performance measurement (Figure 2). It was constructed base on the integration of LCA, SLCA, and EcLCA. During the stage of inventory analysis and impact assessment, the impact pathway must be constructed to display the relationship between the corporation flows and the concept of life cycle assessment. The diagram is influenced by both sides, the left side of the diagram is affected by the corporation flows. The right side of the diagram consists of midpoint and endpoint impact criteria that are influenced by the decision-maker's perspective regarding sustainability.

3 Development of the endpoint impact criteria using a combination of Fuzzy-AHP and the Delphi method

This section focuses on the development of the endpoint impact criteria by using the combination of the Delphi method and Fuzzy-AHP.

3.1 Delphi method

The Delphi method is one of the most popular tools for evaluating expert opinions. It method can be applied and integrated with many decision-making tools due to the broad coverage of its principle (Vidal et al. 2011). The Delphi method is commonly used to deal with the qualitative data such as opinions or judgments in order to obtain a consensus perspective from a group of experts (Rahimianzarif and Moradi 2018). In this research, we used the Delphi method to qualify results from the experts and reach a consensus of experts' opinions.

3.2 Triangular fuzzy set theory

The fuzzy set theory was introduced to objectify human judgment that is often uncertain and subjective. It helps decision-makers to evaluate the decisions that involve uncertainty in the assessment process (Govindan et al. 2013). Triangular fuzzy numbers are commonly used as a fuzzy extension of the multiplicative pairwise comparison method (Krejčí 2018). Thus, triangular fuzzy numbers were selected to use in this research. According to the triangular fuzzy set theory, a fuzzy set is a class of objects where memberships can vary on a scale of 0 to 1. A membership function can be defined as equation 1.

$$M_W(x) = \begin{cases} 0, & x < a, x > c \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \end{cases} \quad (1)$$

Where a is the lower boundary value, c is the upper boundary value, and b is the middle value of the triangular fuzzy number. Let's consider two triangular fuzzy numbers W_1 and W_2 where $W_1 = (a_1, b_1, c_1)$ and $W_2 = (a_2, b_2, c_2)$. The main operational laws for two triangular fuzzy numbers are as follows:

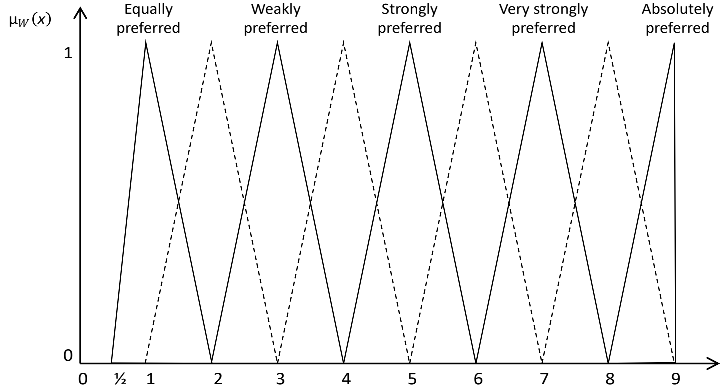

Figure 3: 9-point scale membership functions adapted from (Saaty, 1977)

$$\begin{aligned} &W_1 + W_2 = (a_1+a_2, b_1+b_2, c_1+c_2), \\ &W_1 \otimes W_2 \approx (a_1a_2, b_1b_2, c_1c_2), \\ &\lambda \otimes W_1 = (\lambda a_1, \lambda b_1, \lambda c_1), \lambda > 0, \lambda \in R, \\ &W_1^{-1} \approx (1/c_1, 1/b_1, 1/a_1) \end{aligned} \quad (2)$$

In this research, we used a 9-point fuzzy scale of membership function which was customized from Saaty's scale (Saaty 1977; Krejčí and Talasová 2013). The output of the fuzzy sets in terms of linguistic are "equally preferred", "equally and weakly preferred", "weakly preferred", "weakly and strongly preferred", "strongly preferred", "strongly and vary strongly preferred", "vary strongly preferred", "vary strongly and absolutely preferred", and "absolutely preferred". These linguistic terms represent the fuzzy numbers scale in numerical scores vary between 0.5 to 9 as seen in Figure 3.
For example, if the criteria i is strongly preferred than criteria j, according to the linguistic terms, the fuzzy number of this comparison will be $a_{ij} = (4,5,6)$.

3.3 Multicriteria decision-making approach

As mentioned in the previous section, the combination of Fuzzy-AHP and the Delphi method was used to calculate, rank, and analyzed criteria. There are two main groups of criteria, main criteria, and sub-criteria. Main criteria consist of three sustainability as aspects namely economic, social, and environment while sub-criteria refer to a group of endpoint impact criteria.

Table 1: Main criteria and sub-criteria

Economic	Social	Environment
Cost reduction and saving	Workers well being	Green image
Financial risk	Consumer well being	Resource management
Variety of products and services	Cultural diversity	Animal biodiversity
Market share	Society responsibility	Ecosystem quality
Financial growth	landscape aesthetics	Global climate
Promotion of innovation	Regional economy	Waste management

3.3.1 Expert survey and initial criteria development

Before conducting an interview, the initial main criteria and sub-criteria must be identified. As mentioned above that the main criteria are represented using three main sustainability aspects. On the other hand, a of the endpoint impact criteria were investigated using a literature review and expert interview (Bai and Sarkis 2010; Begić and Afgan 2007; Domingues et al. 2015; Evans et al. 2009; Haddad et al. 2017; Liu 2014; Liu et al. 2013; Hirschberg et al. 2008). There were 6 experts in the areas of sustainability and manufacturing participated in the interview. The experts were asked to review and give their opinions regarding the list of literature criteria. Apart from the literature criteria, two additional criteria were suggested by the experts which are "Variety of products and services", and "Green image". The summary or the main criteria and sub-criteria is presented in table 1.

3.3.2 Pairwise comparison and the Delphi method

Based on the literature criteria, a pairwise comparison was constructed. Questionnaires in the form of pairwise comparisons were sent out to the experts. Using the 9-point fuzzy scale, the experts had to compare and decide for each pairwise comparison a 1 - 9 scale.

After the first round of pairwise comparison, the results were sent to each expert in which they could see other's evaluations anonymously and reconsider their results. The analysis of the second round revealed that only three participants had varied their pairwise comparison answers. The result from the second round was sent to the expert one more time. At this round, the experts did not change their answers in their pairwise comparisons. Thus, the result from the experts had reached global consensus in the second round. The result of the second round was later used for the final evaluation.

3.3.3 Consistency test

Verifying consistency was used to evaluate results from pairwise comparisons whether the preference information provided by the experts is inconsistent. Based on the Saaty's AHP methodology, consistency index is used to evaluate the consistency of the judgment in each comparison matrix

(Saaty 1977). It is suggested that the consistency analysis should be performed based on the typical AHP approach (Liu et al. 2017).

Table 2: The value of RI (Deng 2017)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Thus, comparison matrices must be checked for consistency before fuzzifying. The consistency index (CI) and the consistency ratio (CR) can be calculated using equations as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI} \qquad (3)$$

Where λ_{max} is the largest eigenvalue of the comparison matrix, n is the dimension of the matrix, and RI is a random consistency index. The dimension of the matrix determines the RI value (table 2). According to Saaty, the comparison matrix is acceptable if CR is less than 10% (Saaty 1977).

After the process of pairwise comparison, the results from each expert were checked individually to determine whether they are consistent using the method mentioned above. If the result fails the consistency test, the expert must revise the pairwise comparisons. The result will be further processed in the next step when they are all consistent and reach consensus.

3.3.4 Fuzzy pairwise comparison matrix

After the pairwise comparisons and consistency check, the given scales from each expert were converted into fuzzy numbers. The result is shown in table 3. Using the method mentioned in section 3.3.2, an example of a fuzzy matrix of the pairwise comparison for three main criteria (economic, social, and environment) can be calculated as follows:

Table 3: Pairwise comparison of the main criteria

	Economic (Ec)	Social (S)	Environment (En)
Economic (Ec)	(1, 1, 1)	(4, 5, 6) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (2, 3, 4)	(2, 3, 4) (1, 2, 3) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (1/4, 1/3, 1/2)
Social (S)	(1/6, 1/5, 1/4) (2, 3, 4) (2, 3, 4) (2, 3, 4) (2, 3, 4) (1/4, 1/3, 1/2)	(1, 1, 1)	(1/4, 1/3, 1/2) (1/4, 1/3, 1/2) (1/3, 1/2, 1) (1/2, 1, 2) (1/2, 1, 2) (1/4, 1/3, 1/2)
Environment (En)	(1/4, 1/3, 1/2) (1/3, 1/2, 1) (2, 3, 4) (2, 3, 4) (2, 3, 4) (2, 3, 4)	(2, 3, 4) (2, 3, 4) (1, 2, 3) (1/2, 1, 2) (1/2, 1, 2) (2, 3, 4)	(1, 1, 1)

For example, the fuzzy pairwise comparison between Ec and S can be calculated into fuzzy numbers as follows:

$(4 \times 1/4 \times 1/4 \times 1/4 \times 1/4 \times 2)^{1/6} = 0.561$

$(5 \times 1/3 \times 1/3 \times 1/3 \times 1/3 \times 3)^{1/6} = 0.755$

$(6 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 4)^{1/6} = 1.070$

Therefore, the fuzzy matrix of the main criteria are as follows:

$$Fuzzy\ Matrix = \begin{array}{c} \\ Ec \\ S \\ En \end{array} \begin{array}{c} \begin{array}{ccc} Ec & S & En \end{array} \\ \begin{bmatrix} (1,1,1) & (0.561, 0.755, 1.070) & (0.445, 0.648, 0.953) \\ (0.935, 1.325, 1.782) & (1,1,1) & (0.330, 0.514, 0.891) \\ (1.049, 1.543, 2.245) & (1.122, 1.944, 3.026) & (1,1,1) \end{bmatrix} \end{array}$$

Using the same method, the fuzzy matrixes of all criteria were calculated.

3.3.5 Calculation of weight vectors

To obtain the weight vector, the extent analysis method was applied (Chang 1996). The method can be described as follows:
Assume that X and U are an object set and a goal set respectively where $X = \{x_1, x_2, \ldots, x_3\}$ and $U = \{u_1, u_2, \ldots, u_3\}$. Then we take each object and conduct extent analysis for each goal, respectively. Thus, we can obtain m extent analysis values for each object as follows:

$$W_{g_i}^{1}, W_{g_i}^{2}, \ldots, W_{g_i}^{m} \qquad i = 1,2,\ldots,n$$

Where $W_{g_i}^{j}$ $(j = 1, 2, \ldots, m)$ represent triangular fuzzy numbers. Then we calculate the fuzzy synthetic degree value with respect to ith object as follows:

$$S_i = \sum_{j=1}^{m} W_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} W_{gi}^{j} \right]^{-1} \qquad (4)$$

According to the fuzzy comparison pairwise matrix in section 3.3.4, the fuzzy synthetic degree value of the main criteria (economic) can be calculated using equation 4.

$$\sum_{i=1}^{3}\sum_{j=1}^{3} W_{gi}^{j} = (1, 1, 1)+(0.561, 0.755, 1.070)+\ldots+(1, 1, 1)$$
$$= (7.443, 9{,}729, 12{,}967)$$
$$\sum_{j=1}^{3} W_{gi}^{j} = (1, 1, 1)+(0.561, 0.755, 1.070)+(0.445, 0.648, 0.953)$$
$$= (2.007, 2.403, 3.023)$$

Thus, the fuzzy synthetic degree value of the main criteria (economic) is equal to

$$S_{Ec} = (2.007, 2.403, 3.023) \otimes \left(\frac{1}{12.967}, \frac{1}{9.729}, \frac{1}{7.443}\right)$$
$$= (0.155, 0.247, 0.406)$$

Applying the same calculation, the fuzzy synthetic degree value of the main criteria (social, and environment) can be calculated as follows:

$$S_{S} = (2.265, 2.839, 3.673) \otimes \left(\frac{1}{12.967}, \frac{1}{9.729}, \frac{1}{7.443}\right)$$
$$= (0.175, 0.292, 0.493)$$
$$S_{Ec} = (3.172, 4.487, 6.271) \otimes \left(\frac{1}{12.967}, \frac{1}{9.729}, \frac{1}{7.443}\right)$$
$$= (0.245, 0.461, 0.843)$$

After calculating the fuzzy synthetic degree value of each criterion, the degree of possibility must be calculated by comparing between two triangular fuzzy numbers. The degree of possibility between two triangular fuzzy numbers, $W_1 = (a_1,b_1, c_1) \geq W_2 = (a_2,b_2, c_2)$, can be defined as $V(W_1 \geq W_2) = \sup_{y \geq x}[\min(\mu_{W_1}(x),\mu_{W_1}(y))]$ which is equivalent to $V(W_1 \geq W_2) = hgt(W_1 \cap W_2)$. Then

$$\mu(d) = \begin{cases} 1, & \text{if } b_1 \geq b_2 \\ \frac{a_1 - c_1}{(b_1 - c_1) - (b_2 - a_2)}, & \text{if } a_2 \geq c_1 \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

Where d is the maximum intersection value between W_1 and W_2

Equation 6 defines the degree of possibility for a fuzzy number that is greater than k fuzzy numbers W_i (i = 1, 2, …, k).

$$V(W \geq W_1, W_2, \ldots, W_k) = \min V(W \geq W_i),\ i = 1, 2, \ldots, k \quad (6)$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$, for k = 1, 2, …, n; k ≠ i. We can obtain the weight vector by

$$M' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (7)$$

Where A_i ($i = 1, 2, \ldots, n$) are n elements. After that, the normalized weight vectors must be calculated. Finally, final a non-fuzzy number (M) can be defined by

$$M = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (8)$$

Using the same example from previously, the weight vector of the main criteria can be calculated using equation 5 to 8, as follows:

$$V(S_1 \geq S_2) = \frac{0.175 - 0.406}{(0.247 - 0.406) - (0.292 - 0.175)} = 0.838$$

$$V(S_1 \geq S_3) = \frac{0.245 - 0.406}{(0.247 - 0.406) - (0.461 - 0.245)} = 0.430$$

$$V(S_2 \geq S_1) = 1$$

$$V(S_2 \geq S_3) = \frac{0.245 - 0.493}{(0.292 - 0.493) - (0.461 - 0.245)} = 0.595$$

$$V(S_3 \geq S_1) = 1$$

$$V(S_3 \geq S_2) = 1$$

Finally, the weight vector of the main criteria before normalization is

$$d'(A_1) = \min V(S_1 \geq S_2, S_3) = \min \{0.838, 0.430\} = 0.430$$

$$d'(A_2) = \min V(S_2 \geq S_1, S_3) = \min \{1, 0.595\} = 0.595$$

$$d'(A_3) = \min V(S_3 \geq S_1, S_2) = \min\{1, 1\} = 1$$

$$M' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T = (0.430, 0.595, 1)$$

Thus, the non-fuzzy weight vectors of the three main criteria after normalizing are as shown below.

$$M = (0.212, 0.294, 0.494)$$

Using the same calculation, the non-fuzzy weight vectors of all sub-criteria were calculated. Overall, the environmental aspect is the most important main criterion (0.494), followed by the social (0.294) and economic (0.212) aspects respectively. The result shows that the criteria 'Effect on global climate" is the most concerned criterion (0.215) in the environmental category. For the social aspect, "Worker well-being" receives the highest weight (0.161), while the most important midpoint criterion in economic aspects is "Promotion of innovation" (0.058). The null weight problem occurred to two criteria from each category. Therefore, the final selected endpoint impact criteria are highlighted in Figure 4.

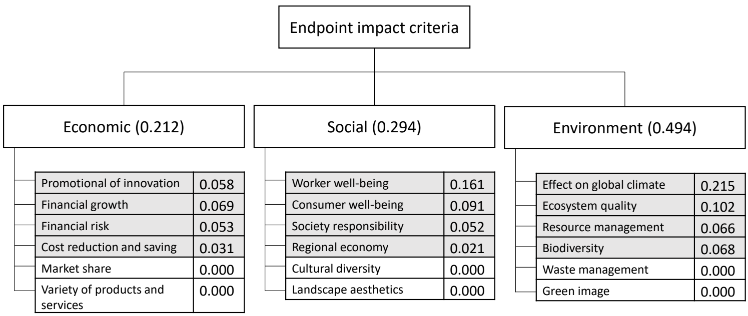

Figure 4: Final weights of main criteria and sub-criteria

4 Impact pathway development

Based on the finding of the endpoint impact criteria from section 3, the impact pathway of sustainability assessment was developed. As we were able to identify the endpoint impact criteria using an integration of the Delphi method and Fuzzy AHP, the next step is to address the midpoint impact criteria. Literature review and international guidelines such as GRI or UNEP were used to identify related midpoint impact criteria and their relationships to the endpoint impact criteria. Relationships between midpoint and endpoint impact criteria are displayed using arrows. Direct and common relationships are illustrated with solid lines, while indirect relationships are shown in dash lines. Figure 5 illustrates the impact pathway of the midpoint and endpoint impact criteria and a summary of the proposed framework of sustainability performance measurement for the manufacturing industry.

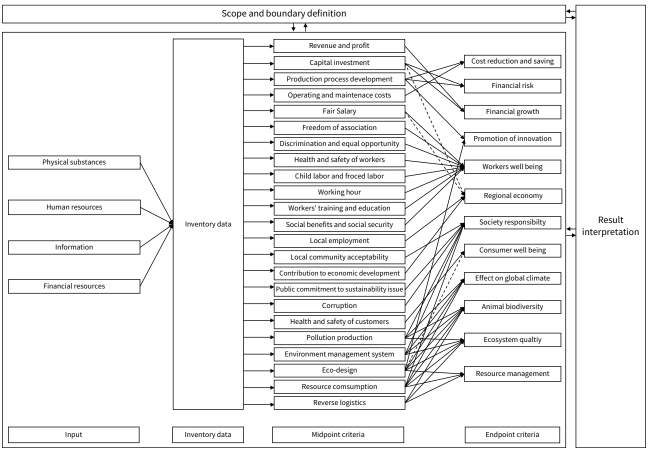

Figure 5: Impact pathway of midpoint and endpoint impact criteria

5 Summary and conclusion

This research has presented a proposed framework of a sustainability performance measurement which aims to measure the complex sustainability impacts in the manufacturing industry. We integrated the principle of LCA and MCDM to cover both of the sustainability thinking and the perspectives of decision-makers. In this research, Fuzzy AHP and the Delphi method were used to identify the endpoint impact criteria. During this phase, six experts from the area of sustainability and manufacturing were participating. The result shows that the most concerning aspect of sustainability is the environment. By applying the principle of Pareto, 4 endpoint impact criteria from each sustainability aspect were selected. An impact pathway was developed base on the selected endpoint impact criteria to illustrate the interrelationship between endpoint impact criteria, midpoint impact criteria, inventory data, and corporate flows.

This framework adds to the topic that is widely discussed on how to incorporate the opinions of decision-makers into the life cycle assessment approach. By constructing an impact pathway, we can clearly see the complex relationships of midpoint and endpoint criteria. The framework is still under development, even though the development of midpoint and endpoint criteria was implemented in this research, several issues must be further discussed. Firstly, the step of scope and boundary definition was not considered in this research because there were several experts that came from different manufacturing fields. Secondly, the analysis of inventory data and how it affects midpoint and endpoint impact criteria has not yet been accomplished. As for the environmental and economic aspects, the existed methods might be suitable to map out the effects of inventory data on certain midpoint and endpoint impact criteria. However, for the social aspect, it is still challenging to analyze the inventory data and its impacts because it consists of both quantitative and qualitative midpoint and endpoint impact criteria which could be a subject for future research.

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Commercial Electric Vehicle Routing in Urban Logistics: A Systematic Literature Review

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Purpose: Global supply chains increasingly demand sustainable setups, from the first to the last mile in transportation. Particularly in urban settings, the use of commercial electric vehicles for transport tasks might be a suitable measure to increase overall sustainability.

Methodology: For an initial structuring step of this growing research field, this paper conducts a systematic literature review based on Denyer and Tranfield (2010). The aim is to provide an overview regarding existing routing approaches for commercial electric vehicles, their characteristics and their suitability for typical application contexts in urban logistics (e.g. retail, parcel delivery, gastronomy).

Findings: The results point out topical gaps regarding the specific characteristics considered in the routing models and the focus of their optimization objectives. Among others, research gaps where identified regarding specific urban logistics requirements like energy management considerations for cooling/heating, mixed fleet modelling and (partial) recharging.

Originality: While the ecologic and economic impacts of electric vehicles have already been researched extensively, the OR-perspective on their commercial use still is an emerging topic. This review contributes to the structuring of this research field, which can play a key role in the practical application of electric vehicles in urban contexts.

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1 Introduction

In recent years, greenhouse gas (GHG) emissions became a central point of concern and attention in the logistics and transportation sector. The topic is becoming even more relevant as road freight transport emissions in the EU increased strongly since 1990 (Faberi, et al., 2015; European Environment Agency, 2018). In 2017, the share of transport sector GHG emissions in the EU-28 was 24.6%. More than 70% of these emissions were caused by road transportation (European Environment Agency, 2020). As continuous strong growth in freight transport is expected between 2010 and 2050, there is an urgent need for sustainability improvements in logistics worldwide (Klumpp, 2016; Barcellos de Paula and Marins, 2018; Klumpp, 2018; Okraszewska, et al., 2019).

In this context, electric vehicles are one of the most discussed options as multiple studies show their GHG-emissions-reduction-potential. (Hawkins, et al., 2013; Giordano, Fischbeck and Matthews, 2018). In recent years, the number of commercial electric vehicles used in logistics has been growing. Increasing ranges further enlarge their application fields (Cagliano, et al., 2017; Figenbaum, 2018; International Energy Agency, 2018)). Hertz, UPS, Coca-Cola or Deutsche Post DHL Group are only a few of the companies that already use electric vehicles in their transportation processes (The Coca-Cola Company, 2011; Pelletier, Jabali and Laport, 2014; Cosimato and Troisi, 2015; Quak, Nesterova and van Rooijen, 2016; Kampker, Gerdes and Schuh, 2017).

With more use of electric vehicles in logistics, the corresponding research field is growing as well: An increasing number of papers and scientific publications focuses on operational approaches and subfields of green SCM

(Sheu, Chou and Hu, 2005; Srivastava, 2007; Seuring and Müller, 2008; Min and Kim, 2012). The literature review conducted herein focuses on an OR perspective, namely vehicle routing problems for electric vehicles. This perspective is particularly important, as new approaches are needed to consider characteristics and operational challenges that distinguish electric vehicles from vehicles with combustion engines (range, charging times, etc.). Those properties need to be taken into account by companies to enable a successful practical use of electric vehicles (Altintas, et al., 2012; Klumpp, Witte and Zelewski, 2014).

This paper focuses on urban logistics, which is often seen as a promising application context for electric vehicles. According to the UN, urban areas provide huge potential for sustainability improvements as they account for more than 60% of total GHG emissions (United Nations, 2020). With ever-growing shares of the population living in cities, urban logistics are vital as cities rely on frequent deliveries of food and retail goods, deliveries to businesses and homes etc. Urban logistic systems are characterized by a high degree of complexity and diversity. Different cities of different sizes and in different locations are home to different economic sectors and supply chains. While the different urban areas are very diverse (and therefore in need of specific OR approaches), some typical segments and characteristics of urban logistics can be found in almost every urban setting. Out of the typical segments of urban logistics as classified by Behrends (2016) this paper will focus on the main segments retail, parcel delivery and gastronomy. The review analyses and synthesizes the state of the art regarding vehicle routing problems for electric vehicles in urban logistics based on these three segments.

Retail is a widely represented sector in all urban areas. Its logistics are characterized by tight schedules, time restriction (e.g. delivery times), high volumes (and weights) as well as demanding product requirements (e.g. cooling for food or pharmaceuticals) (Brewer, Button and Hensher, 2008; Behrends, 2016; Fernie and Sparks, 2019).

Parcel delivery is a strongly growing segment of city logistics – mainly due to a switch from conventional to online retail channels. The processes are often characterized by pick-up and delivery tours in large vans or small to medium-sized trucks with small time windows and multiple stops during tours (Behrends, 2016).

The gastronomy segment incorporates two major processes. The first is the transport of goods to businesses (e.g. food and beverages delivery to a restaurant), which is characterized by demanding product requirements (e.g. cooling for food), high weights of goods (e.g. beverage delivery) and limited time windows for delivery processes. The second major process is the delivery of meals from the business to the final customer, which is often performed on a just-in-time basis with changing demands, high time pressure and strong requirements regarding the product temperature (Behrends, 2016).

The purpose of this paper is to provide a comprehensive structured overview regarding the state of the art of vehicle routing models for commercial electric vehicles in urban logistics (based on retail, parcel delivery and gastronomy), to identify its research gaps and to derive a possible future research agenda.

To achieve this goal, this paper is organized as follows: In the first section, the concept of a systematic literature review and the reasons for its use are described. The methodological literature basis for this review and its guidelines are made explicit and the steps conducted in the systematic review are listed. This section is followed by the first steps of the systematic review itself – the question formulation (section 2.1) and the locating of studies (2.2). The third step of the literature review as described in Denyer and Tranfield (2010) – the study selection and evaluation – is conducted in section 2.3 of this paper. For the resulting literature basis, a systematic descriptive and thematic analysis and synthesis of the selected literature is performed (sections 2.4 and 2.5). For the purpose of this paper, the "reporting and using the results" – the last step of the structure of a systematic literature review based on Denyer and Tranfield (2010) – is incorporated into the discussion and limitations (section 3). Finally, a conclusion completes this research (section 4).

2 Systematic Literature Review: Vehicle Routing for Electric Vehicles in Urban Logistics

A systematic literature review is conducted in order to provide a comprehensive and structured overview over the state of the art of routing models for electric vehicles in urban logistics. Rousseau, Manning and Denyer (2008) define the word systematic in this context as "… comprehensive accumulation, transparent analysis, and reflective interpretation of all empirical studies pertinent to a specific question". To make sure that all relevant publications are included and to avoid bias (which often occurs in traditional narrative reviews) systematic literature reviews follow clearly defined steps (Tranfield, Denyer and Smart, 2003; Kitchenham and Charters, 2007; Denyer and Tranfield, 2010).

First standardized approaches to systematic literature reviews were developed in the medical sciences (The Cochrane Collaboration, 2008). While those are often cited, Fiori and Marzano (2018) and Denyer and Tranfield (2010) argue that the uncritical adoption of the medical model of a systematic literature review in other fields of research is not recommendable. They provide revised and specific guidelines for the conduction of systematic literature reviews in the fields of management and organization studies. The literature review in this paper is based on these steps as described in Denyer and Tranfield (2010) and Tranfield, Denyer and Smart (2003). The used method ensures transparency, reliability and completeness of the literature review (Kitchenham and Charters, 2007). In the following segments, the central steps of the review are described.

2.1 Question Formulation

A clearly defined research question is crucial for a systematic literature review. It helps to define inclusion and exclusion criteria and improves the utilization of findings (Denyer and Tranfield, 2010). The goal is to define a suitable unbiased, precise, encompassing and meaningful research question – including an explicit consideration of the OR aspect with focus on the vehicle routing problem (VRP). The resulting research questions were: i) What is the state of the art of vehicle routing problems for electric vehicles in urban logistics? ii) Which research gaps can be identified and which recommendations for a future research agenda can be derived?

2.2 Locating Studies

Based on the research questions and an initial literature scoping, keywords and search strings were identified and selected to find the relevant literature. In early 2020 the electronic databases EBSCOhost, ECONBIZ and Google Scholar were searched for papers and publications using the keywords: “electric”, “electric vehicle”, “vehicle routing”, “logistics”, “electric truck”, “urban”, “VRP” and “EVRP” These keywords were combined in different variations to create additional search strings using Boolean connectors (OR, AND, NOT) and - when necessary other operators like truncation characters (e.g. ‘*’). This procedure follows the recommendations by Denyer and Tranfield (2010). The abstracts of the publications found (by using the keywords/search strings) were scanned to ensure a fit with the research questions. In this first stage of the review, publications were only included in the review if their headings, keywords and/or abstracts clearly indicated that the publication did deal with the topic of the research questions. The hereby-achieved outcome of papers was rather low when publications were only included if they focused specifically on urban logistics. Hence publications were also included if they considered a VRP for electric vehicles but were not specifically developed for urban logistics. This process resulted in 99 potentially relevant publications. Afterwards the principle of snowballing was employed to make sure that the review is comprehensive. Through this principle, another 21 potentially relevant publications were identified. At the end of the process the same publications continued to appear, which was seen as a signal that a point of saturation was reached. Duplicates were eliminated. In total, 118 potentially relevant publications remained at the end of the locating of studies – chosen only based on the publication's headings, abstracts and keywords. All the literature considered was published between 2011 and the end of 2019. In this first step of the review all kinds of different relevant literature was collected (academic papers, books, non-peer-reviewed paper, scientific websites, conference and discussion papers and grey literature). This procedure follows the guidelines by Denyer and Tranfield (2010), who emphasize the importance of the inclusion of all relevant literature in the first step in order to ensure an all-encompassing overview. Nevertheless, the quality of the identified publications does not remain unchecked throughout the literature review. In the following section "study selection and evaluation" (2.3), a quality evaluation of the identified publications is conducted.

2.3 Study Selection and Evaluation

During the first step, 118 potentially relevant publications were collected. This section of the systematic literature review concentrates on the selection and evaluation of the found publications. To ensure a complete and unbiased structured literature review, the selection of publications based on their content follows predefined inclusion- and exclusion-criteria. Those were defined based on small pilot literature searches conducted before the locating of studies (Denyer and Tranfield, 2010). For this literature review, the following criteria for inclusion or exclusion of publications were determined:

Inclusion criteria: Publications are only included if they address vehicle routing approaches (e.g. VRPs, TSPs, etc.). Furthermore, only publications are included that mainly refer to (battery) electric vehicles (BEV) and road logistics. Because of their high practical relevance for companies worldwide, publications on mixed fleet routing problems (with electric vehicles) as well as mixed OR-problems like the routing-location-problem and similar approaches are included in this publication. To ensure timeliness and high quality of the systematic literature review only peer-reviewed journal articles and conference proceedings/contributions published between 2010 and December 2019 are considered.

Exclusion criteria: Publications are excluded if they do not mainly address vehicle routing (e.g. charging station location/charging problems) or address non-battery electric vehicles. This includes vehicles with conventional engines as well as alternatively fueled and hybrid electric vehicles. The latter are excluded, because the focus of this paper lies on the special characteristics of electric vehicles and the implications for their use in urban logistics. Additionally, the search strings - as set in section 2.2) - did not specifically target publications on hybrid vehicles, which is why the found publications would show an incomplete picture of the research on hybrid electric vehicles and therefore have to be excluded. Furthermore, all publications that do not deal with road vehicles (e.g. electric trains, ships, drones) or do not deal with logistics (e.g. public transport, taxis, etc.) are excluded. Finally, all non-English publications remain unconsidered.

While in the first step of the literature review, only the headings, abstracts and keywords were checked to collect potentially relevant literature, in this second step the full texts of the publications were used to ensure that a publication fits the inclusion- and exclusion criteria. Of the 118 potentially relevant publications found in the locating of studies (section 2.2) 77 were published in scientific journals – another 23 were conference proceedings or contributions. The excluded publications from other sources were publications in collected volumes (3), dissertations or thesis papers (8) and reports or grey literature (7). Of the 100 remaining publications, 6 had to be left out because they only (or mainly) referred to hybrid vehicles. Another 5 publications were dealing with green routing in general but did not specifically address electric vehicles. Of the remaining publications, 9 had to be left out because they did not mainly address vehicle routing approaches (for electric vehicles) but energy consumption simulations, charging and scheduling approaches or other OR approaches related to green logistics. Another 23 publications had to be excluded as they did not refer to road logistics – either because they referred to non-road vehicles or because they dealt with public transport, taxis or private vehicles. The concluding part of the study selection and evaluation is the quality evaluation of the remaining studies. To ensure high quality of the literature analyzed in the following steps of the systematic review, the sources of the remaining journal articles were checked for their quality using the online Master Journal List by Clarivate Analytics (http://mjl.clarivate.com). Based on this quality evaluation, twelve more unsuitable publications had to be excluded, resulting in a final sample of 35 journal articles and 10 conference proceedings at the end of the study selection and evaluation. These 45 publications met all the predefined inclusion and exclusion criteria and built the basis for the literature analysis and synthesis in the following section of this paper.

2.4 Descriptive Analysis and Synthesis

All preceding steps were conducted to find a final sample of literature. In this section, this sample is used for a structured analysis and syntheses of the selected literature to answer the research questions defined in section 2.1. As Denyer and Tranfield (2010) describe, analysis and synthesis in systematic literature reviews are two different, but strongly connected processes. While the analysis aims to break the publications in their constituent parts and to describe how they are related, the synthesis' goal is to "…make associations between the parts identified in individual studies" (Denyer and Tranfield, 2010).

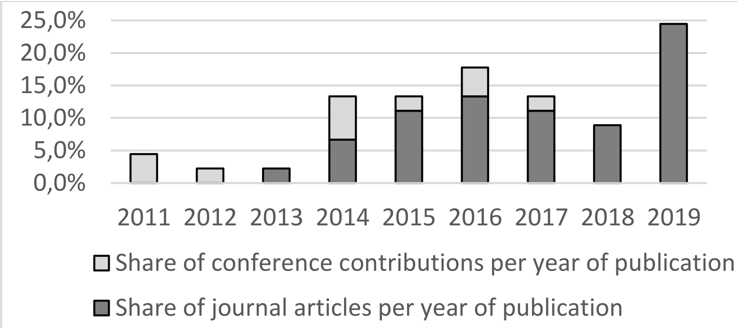

Figure 1: Yearly distribution of final sample journal articles and conference contributions (n = 45)

For the purpose of this paper, analysis and synthesis are split into a descriptive and a thematic part. The descriptive part aims at giving a general overview of different quantitative aspects of the 45 selected publications. As a first part of the descriptive analysis and synthesis, the yearly distribution of the final sample of publications was identified. All selected publications of the final sample were published between 2011 and December 2019 (see Figure 1). The timeliness of the topic is shown by the fact that more than 90% of the analyzed publications were published in 2014 or later.

Table 1: Sources of final sample journal articles

Journal	No. of articles
European Journal of Operational Research	6
Computers & Operations Research	5
Transportation Research Part B: Methodological	3
Transportation Research Part E: Logistics and Transportation Review	3
Other Journals (single publications): Algorithms, Applied soft computing, Energies, EURO Journal on Transportation and Logistics, European Transport - Trasporti Europei, IEEE Transactions on Smart Grid, IET Intelligent Transport Systems, International Journal of Production Economics, Journal of Advanced Transportation, Journal of Cleaner Production, Mathematical Problems in Engineering, Omega - International Journal of Management Science, Operations Research, OR Spectrum, SAE International Journal of Alternative Powertrains, Transportation Research Part C: Emerging Technologies, Transportation Research Part D: Transport and Environment, Transportation Science	18

When looking specifically at the 35 articles published in journals Table 1 shows that the majority of the articles were published in journals with focus on operations research (37%) or transportation research (33%). The remaining publications were published in journals on management, computing, energy, engineering, logistics and production.

2.5 Thematic Analysis and Synthesis

After having finished the descriptive analysis and synthesis, this section provides a thematic analysis and synthesis of the 45 publications. Table 2 shows all the components and characteristics that were extracted from the final sample of 35 journal articles and 10 conference proceedings.

Those components mostly refer to the newly formulated or adjusted/variated old routing problems proposed in the respective publications. In addition to the proposed routing approaches, the table shows the objective of the optimizations and a wide choice of their constraints and characteristics. Furthermore, Table 2 also shows if a publication includes algorithms/heuristics to solve the proposed routing problem.

Out of the analyzed 45 publications, seven stand out, as they do not propose - or sufficiently describe - a new or adjusted routing problem. The publications Abousleiman, Rawashdeh and Boimer (2017), Abousleiman and Rawashdeh (2014a) and Abousleiman and Rawashdeh (2014b) only refer to heuristics and algorithms for energy-efficient routing approaches for electric vehicles but do not propose own routing problems. The conference contribution by Liakos, Angelidis and Delis (2016) does propose an own routing model (EV-DPDPTW) but misses the description of the model's specifics. Similarly, the publication by Vonolfen, et al. (2011) – even though it does propose a specific routing problem for glass-waste collection with electric trucks – it does not describe the model specifics with regard to adjustments made for electric vehicles. Last but not least, publications by Juan, et al. (2016) and Erdelić and Carić (2019) stand out as they are literature reviews on routing models and environmental, strategic and operational issues associated with battery and hydrogen-based electric vehicles in logistics. Although their findings are of high interest, they do not specifically target urban logistics.

Table 2: Features of final sample journal articles (marked white) and conference contributions (marked grey)

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Abousleiman and Rawashdeh, 2014a)		No own model	•	-	-	-	-	-	-	-
(Abousleiman and Rawashdeh, 2014b)		No own model	•	-	-	-	-	-	-	-
(Abousleiman, Rawashdeh and Boimer, 2017)		No own model	•	-	-	-	-	-	-	-
(Anderluh, et al., 2019)	Two-echelon approach	2eVRPSyn	•	Costs/ Emissions/ Social Factors	•	/	/	•	-	-
(Basso, et al., 2019)	Two-stage-approach	2sEVRP	/	Energy Consumption	•	/	•	CM	L	(•)
(Breunig, et al., 2019)	Two-echelon approach	E2EVRP	•	Costs	•	•	/	•	L	/
(Desaulniers, et al., 2016)		EVRPTW (4 variants)	•	Costs	•	/	•	•	L	(•)
(Erdelić and Carić, 2019)	Review	-	-	-	-	-	-	-	-	-
(Felipe, et al., 2014)		GVRP-MTPR (variant)	•	Recharging Costs	•	/	/	•	L	•
(Figliozzi, 2011)		RVRP	(•)	Vehicles/Routes/ Costs	•	/	•	•	L	(•)
(Froger, et al., 2019)		E-VRP-NL (variant)	•	Time	•	/	/	•	NL	•
(Ghandriz, et al., 2016)	Fleet-Composition-Routing-Problem	HVRPMF-PUP	(•)	Costs	•	MF	•	CM	L	/
(Goeke and Schneider, 2015)		E-VRPTWMF	•	Time/Costs	•	MF	•	CM	L	/
(Hiermann, et al., 2016)		E-FSMFTW	•	Costs	•	MF	•	•	L	/

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Hiermann, et al., 2019)		H2E-FTW	•	Costs	•	MF	•	•	L	•
(Jie, et al., 2019)	Two-echelon approach	2E-EVRP-BSS	•	Costs	•	•	/	•	BS	/
(Juan, et al., 2016)	Review	-	-	-	-	-	-	-	-	-
(Juan, Goentzel and Bektaş, 2014)		VRPMDR	•	Costs	•	MF	/	•	L	/
(Keskin and Çatay, 2016)		EVRPTW-PR	•	Distance	•	/	•	•	L	•
(Keskin and Çatay, 2018)		EVRPTW-PR (variant)	•	Vehicles/Costs	•	/	•	•	L	•
(Khadraoui, et al., 2015)	Modular vehicles	MeVRP	•	Costs	•	•	•	•	L	/
(Liakos, Angelidis and Delis, 2016)		EV-DPDPTW (no model description)	•	-	-	-	-	-	-	-
(Liao, Lu and Shen, 2016)		OEVTP	•	Time	/	/	/	•	BS	•
(Macrina, et al., 2019)		GMFVRP-PRTW	•	Costs	•	MF	•	•	L	•
(Montoya, et al., 2017)		E-VRP-NL	•	Time	•	/	/	•	NL	/
(Murakami, 2017)		EDVRP	•	Costs	•	MF	/	CM	/	/
(Pelletier, Jabali and Laporte, 2019)	Considers uncertainty	EVRP-ECU		Costs	•	/		CM	-	-
(Preis, 2014)		Energy-optimizing-VRP	•	Energy Consumption	•	/	•	CM	L	/
(Rezgui, Aggoune-Mtalaa and Bouziri, 2015)	Modular vehicles	eM-FSMVRPTW	•	Costs/Distance	•	•	•	•	L	/
(Roberti and Wen, 2016)		E-TSPTW	•	Distance	/	/	•	•	L	(•)
(Schiffer and Walther, 2017)	Location-routing problem	ELRP-TWPR		Distance/Vehicles/ Charging Stations	•	/	•	•	L	•
(Schiffer and Walther, 2018)	Location-routing problem	RELRPTWPR	•	Costs	•	/	•	•	L	•

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Schneider, Stenger and Goeke, 2014)		E-VRPTW	•	Distance	•	/	•	•	L	/
(Schneider, Stenger and Hof, 2015)		EVRPRF	•	Costs	•	/	/	•	L	/
(Shao, et al., 2017)		EVRP-CTVTT	•	Costs	•	/	•	•	L	/
(van Duin, Tavasszy and Quak, 2013)		FSMVRPTW (variant)		Costs	•	•	•	•	L	/
(Verma, 2018)		EVRPTWBSS	•	Costs	•	/	•	•	L	/
(Vonolfen, et al., 2011)	Specific waste-collection problem for e-trucks	SIRP variant (adjustment for electric vehicles not described)	•	-	-	-	-	-	-	-
(Worley, Klabjan and Sweda, 2012)	Location-routing problem	Charging station location and routing problem	/	Costs	•	/	/	•	L	/
(Yang and Sun, 2015)	Location-routing problem	BSS–EV–LRP	•	Costs	•	/	/	•	BS	/
(Yang, et al., 2015)		EV Route Opt. with TOU Electricity Price	•	Costs	/	/	/	•	L	/
(Zhang, et al., 2018)		EVRP	•	Energy Consumption	•	/	/	CM	L	/
(Zhao and Lu, 2019)	real-world EVRP by logistics company	EVRP (by Chinese parcel company)	•	Costs	•	•	•	•	L	/
(Zhenfeng, et al., 2017)		E-VRPTW (variant)	•	Costs	•	/	•	•	L	/
(Zuo, et al., 2019)		EVRPTW-CNCF	•	Costs	•	/	•	•	NL	•

All other 38 publications propose some kind of routing approach for electric vehicles in the logistics context. For 23 of the 38 proposed routing approaches the objective of the optimization is a cost minimization. The cost incorporated into this optimization differ significantly between the proposed models. In three models total time is minimized, another three objective functions aim at minimizing the total distance travelled. Three models optimize the energy consumption and the remaining six approaches have multipart objective functions.

As table 2 shows, only three of the 38 models are not multi-vehicle models. The majority of electric vehicle fleets in the routing models are homogeneous vehicle fleets. Seven out of the 13 publications in which heterogeneous fleets are modeled deal with mixed fleets of electric vehicles and vehicles with other forms of propulsion (e.g. combustion-engines and hybrid vehicles). Time windows in which customers can be served are implemented in around 61% of the models.

In 82% of the proposed routing models, vehicle energy consumption is assumed linear to the distance driven. Only in the remaining seven publications, the models incorporate an individual energy consumption model. Energy consumption models are designed to account for different factors affecting the energy consumption of the vehicles (e.g. vehicle speed, terrain, weather conditions, recuperation, cooling of products in the cargo area, auxiliaries, etc.).

With regard to vehicle charging, the models differ significantly in various characteristics. The vast majority of proposed models includes the simplifying assumption that vehicle charging is a linear process. Only the routing approaches by Montoya, et al. (2017), Zuo, et al. (2019) and Froger, et al.

(2019) include more realistic nonlinear charging functions. Three models do not model charging processes at all, and another three models implement battery-swapping stations instead of recharging stations (Yang and Sun, 2015; Liao, Lu and Shen, 2016; Jie, et al., 2019). In a swapping station, batteries are changed for fully loaded ones (Margaritis, et al., 2016). Only the model by Verma (2018), allows both recharging and battery swapping. Partial recharging is modeled in (certain variants of) 12 of the models. While most of the reviewed publications propose specified models for routing, the approaches by Worley, Klabjan and Sweda (2012), Yang and Sun (2015), Schiffer and Walther (2017) and Schiffer and Walther (2018) simultaneously optimize vehicle routes and recharging locations.
Additionally, the approaches by Breunig, et al. (2019), Jie, et al. (2019) and Anderluh, et al. (2019) need special mentioning as they belong to the class of two-echelon approaches. In these routing models, the logistics process is split into two echelons with different characteristics (e.g. first echelon: Delivery to two distribution center, second echelon: Transport to business in the city center). In the three two-echelon-models the electric vehicles are either modeled in one or in both echelons. Lastly the approach described by Zhao and Lu (2019) is of high interest as it is the only approach raised by a company. It covers a routing model for electric vehicles in Wuhan (China).

3 Discussion and Limitations

Regarding the two research questions, following results have been identified: First of all, an increasing interest in the topic can be stated, focusing on research affiliated with European, Asian and North American institutions. Journal-wise there is an interesting duality: On the one hand, there are three major outlets for publications on the topical field proposed (European Journal of Operational Research, Computers and Operational Research, Transportation Research). On the other hand, there are a large number of 13 smaller outlets also sporting publications regarding the analyzed topic, showing the broad interest and rooting of the innovative question of electric vehicle routing in logistics contexts. In the comparison between conference contributions and journal papers, it became obvious that conference contributions often address minor or specific problems – without e.g. presenting a new OR model but based on existing models or data. This can be understood as academic division of labor between these different publication categories in a perfect manner.

As regards content, most papers are – in a typical OR perspective – optimizing transport costs in the specified routing problems. The scarcity of models considering sustainability related objectives might constitute an important research gap, as one of the major objectives of the commercial use of electric vehicles is increased sustainability. The value-technology link integrating cost and energy perspectives – crucial for electric vehicles and sustainability approaches – is present in a very low number of papers and should be explored further.

As described in section 1, the three main segments of urban logistic systems that are focused in this paper (retail, parcel delivery, gastronomy) have in common that they are all characterized by tight schedules and different kinds of relevant time windows (e.g. retail delivery time windows or guaranteed time windows for parcel or food delivery). Time is a major competitive factor in all these contexts. While an explicit consideration of time in the objective function is an exemption (e.g. Liao, Lu and Shen, 2016; Montoya, et al., 2017; Froger, et al., 2019) and therefore forms a research gap, time windows are accounted for in more than 60% of the proposed routing models in the final sample of publications.

Another aspect of urban logistics (as described in section 1), which poses challenges for routing models is the cooling or heating of goods during transport. In retail, guaranteeing a constant temperature for pharmaceuticals or cooling food on the transport to supermarkets are typical examples. In gastronomy, similar challenges can be found in the delivery of fresh ingredients for restaurants or the heating of food delivered to customers (e.g. pizza delivery). Here, a major research gap can be found as more than 80% of the examined routing models make the simplifying assumption that vehicle energy consumption is linear to the distance driven. Only seven of the analyzed routing models propose a more realistic energy consumption model. These models, which are implemented into the proposed routing approaches, account for different factors that can affect the energy consumption on a tour. The energy consumption of auxiliaries (e.g. cooling system), which – for example is included in the model by Basso, et al. (2019) – is only one of many aspects that can be included in such models. Other important aspects are topography, speed, acceleration, weight of load, outdoor temperature, rain (wipers), media consumption, road conditions, etc. With respect to urban logistics especially speed, acceleration and weight of the load are of high interest. As described in section 1, parcel delivery as well as food delivery processes (in gastronomy) are characterized by multiple stops and accelerations during tours. Beverage deliveries in retail and gastronomy (e.g. delivery to a restaurant) are high-weight transports. These examples show that – in order to route electric vehicles efficiently in urban contexts – energy consumption models (considering all relevant aspects e.g. auxiliaries, speed, load) need to be included in more approaches and should be an essential part of the future research agenda.

Another result of interest is the fact, that most of the examined routing approaches model homogeneous vehicle fleets. In this context, another research gap can be identified. Especially in the transition period towards electric vehicle logistics, there will be need for heterogenous and especially mixed fleet vehicle routing models. Such vehicle fleets comprising combustion engines and electric vehicles are and will be relevant due to investment and transition costs. One of many practical examples is the parcel delivery company DHL (Kampker, Gerdes and Schuh, 2017). This need for mixed-fleet-models is not reflected sufficiently in the analyzed sample of publications, as only 13 publications model heterogeneous fleets and only seven of them deal with mixed fleets of electric vehicles and vehicles with other forms of propulsion.

The literature review also showed that only about one third of the examined routing models incorporate partial recharging. Most other approaches only model full charging of vehicles. These findings might constitute an additional research gap as for example, for gastronomy and especially food delivery, partial recharging could be of high interest as it could be realized

in the limited time windows between customer's orders in which full battery-charging cannot be completed. Therefore, partial recharging should ideally be modeled in routing problems for urban logistics. Additionally, most models lack more realistic nonlinear charging functions. Less than 10% of models account for nonlinearity in vehicle charging processes. As energy demand and supply are crucial factors for the use of electric vehicles (e.g. range problematic), a greater number of models implementing nonlinear charging processes would be beneficial.
The literature review showed that, while there are quite a few approaches tackling the requirements of urban logistics routing for electric vehicles (e.g. Basso, et al. (2019), who model an extensive energy consumption model), to the best of our knowledge, a routing model combining all major relevant aspects for the urban context (e.g. energy consumption model, mixed fleet modelling, partial recharging modelling, etc.) is still missing.

Limitations of this literature review are as follows: Strict inclusion and exclusion criteria were applied to ensure a clear research focus and high scientific standard of the examined publication. For example, only peer-reviewed journals and conference proceedings were included – therefore, other publications are not analyzed. Moreover, – as with all structured literature reviews – only the applied search words were connected to the titles, keywords and abstracts of the identified papers; therefore, some publications might be missed with different but content-related titles, keywords and abstracts. Additionally, this paper focused on three main segments of urban logistics (retail, parcel delivery, gastronomy). This focus was chosen to reduce the complexity of the very diverse and complex field of urban logistics. However, other important segments of urban logistics (e.g. waste logistics, construction, etc.) might require different features in routing models and should therefore be targeted specifically in future research in order to draw a broader picture (Behrends, 2016). As regards the analysis, this paper is somewhat limited due to its objective which is to provide a general overview over the approaches. In consequence, in-detail analysis of the examined routing approaches is not the focus of this paper. While (for example) the objective functions of the models were distinguished by their overall goal (e.g. cost minimization), an in-detail analysis of the considered cost components is not covered by this paper.

4 Conclusion

The aim of this paper was to provide an overview of existing routing approaches for commercial electric vehicles, their characteristics and their suitability for typical application contexts in urban logistics (in particular: retail, parcel delivery, gastronomy). On this basis, it was the second goal of this paper to identify specific research gaps and to derive recommendations for a future research agenda. The literature review showed a growing interest in the field of routing approaches for electric vehicles in urban contexts, with growing numbers of relevant publications in the very recent years. Journal-wise, an interesting duality of major (e.g. EJOR) and smaller outlets was observed.

As regards content, most routing models are – in a typical OR perspective – optimizing transport costs. The scarcity of routing approaches considering the value-technology link integrating cost and energy perspectives, as well as sustainability and time related objectives forms a first part of the research agenda that can be derived based on this paper. This is especially true, as sustainability aspects are a major reason for the use of electric vehicles and as time is a crucial factor in many segments of urban logistics (e.g. retail, parcel and food delivery). However, it was found that, while very few models included time in their objective functions, time windows (as they occur in many urban contexts, e.g. parcel delivery) were integrated in more man 60% of the analyzed approaches.

One of the major aspects that could be derived from the literature review for the future research agenda was the need for more models including precise context-adjusted energy consumption models. Here a major research gap was identified between the requirements of urban logistics (e.g. food cooling/heating on transports, weight of the load, multiple stops during tours, etc.) and the fact that more than 80% of the examined routing models simply assume energy consumption linear to the distance driven, without considering any of these effects.

Only very few routing models include energy consumption models that meet (parts of) the requirements that typical urban logistics contexts pose (Basso, et al., 2019). The literature reviewed also revealed that the existing examined routing approaches merely model homogeneous fleets only. Especially for the transition period towards electric mobility, the future research agenda should include more heterogenous and especially mixed fleet vehicle routing approaches fitting the typical real-world fleet compositions. Similar findings consider the recharging process in general and partial recharging and nonlinearity of recharging in particular, which are accounted for in a minority of approaches and should form part of the future research agenda in this field. In general, the result of the literature review showed that, a vehicle routing model combining all major relevant aspects for urban logistics (e.g. energy consumption model, mixed fleets, partial recharging, etc.) forms an additional important research gap.

As this paper focused on three major segments of the diverse field of urban logistics system (retail, parcel delivery, gastronomy), interesting further aspects of a future research agenda would be an analysis of other important segments of urban logistics (e.g. waste logistics, construction, etc.), which might require different routing model features. Altogether, research has an important task to analyze and provide further information regarding the use of electric commercial vehicles as these will be the backbone for most urban delivery fleets in the coming decades.

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Environmental sustainability in B2C e-commerce: the impact of multiitem shopping

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Purpose: B2C e-commerce is growing worldwide, and a major concern regards its environmental sustainability. Some studies compared the environmental impact of the online and offline purchasing processes, considering the shopping made at one store at a time (e.g. a book bought in a physical store or on internet). This work aims instead to investigate the environmental impact of multi-item shopping.

Methodology: The environmental impact of the purchasing processes is evaluated in terms of CO2e emissions. The model, based on an activity-based approach, allows to assess the environmental impact of the online and offline shopping in the main industries (fashion, consumer electronics, books, grocery) considering (i) one purchase at a time and (ii) multiple purchases in different stores, either online or offline.

Findings: If comparing the same purchase made in the online and offline channels, for a specific industry, the e-commerce case generates lower emissions – even if the results depends on many variables, e.g. customer density, mean of transport. Results overturn when, in the same offline shopping trip, the customer buys in more than one store.

Originality: The main contribution is the multi-item approach while evaluating the environmental sustainability of the purchasing processes, which is not tackled by literature in this regard. This allows to make significant considerations on sustainability from a logistics perspective.

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1 Introduction

B2C e-commerce is growing worldwide, and an increasing concern regards its environmental sustainability. Several studies compare the online and offline purchasing processes from an environmental perspective. They usually consider the environmental impact of one purchased product or order, being equal the number of items bought online and offline.

Anyway, reality may display very different situations. On the one hand, the order composition may be different between the traditional and the e-commerce purchasing processes (Carrillo et al., 2014). As an example, the value of the online grocery shopping is on average higher than the traditional grocery shopping in store (B2C e-commerce Obsevatory, Politecnico di Milano, 2019). On the other hand, a customer buying in the offline channel may purchase, in the same shopping tour, more items related to different product categories. This is, as an example, the case of a customer driving to a mall and buying some fashion clothes from a shop and the groceries from the supermarket. If the same customer ordered the same products online (i.e. all the groceries and the fashion clothes), there will presumably two different shipments (i.e. from the grocery store and from the retailer of fashion products). In this regard, the comparison of the emissions related to the two purchasing processes - online vs offline - must consider, on the one hand, only one customer tour and, on the other hand, two deliveries.

Being this the premise, the present work aims to evaluate the environmental sustainability of B2C e-commerce by considering multi-item shopping. In particular, the environmental impact of online and offline purchasing processes is assessed in the main industries (i.e. fashion, consumer electronics, books, grocery) considering (i) one purchase at a time and (ii) multiple purchases in different stores. More precisely, environmental impact is measured in terms of CO2e (i.e. CO2 equivalent) emissions. An assessment model following an activity-based approach is presented. Since precise data are necessary to feed the algorithms of the model and thus data from companies need to be collected, the Italian context is considered by the present study.

The reminder of the paper is organized as follows. The next section provides the literature review, with a focus on environmental impact of B2C e-commerce from a logistics perspective. Then, the objective and the methodology adopted within the study are described. The next section reports the environmental assessment model. Results are shown and, in the final section, conclusions are drawn, and research limitations are identified.

2 Literature review

The environmental assessment in the field of B2C e-commerce purchasing process is typically carried out for reaching two purposes. On the one hand, provide companies and logistics service providers with information useful to take the sustainability perspective in their decisions, in particular identifying the main areas to act on in order to reduce emissions (e.g. Van Loon et al., 2015; Mangiaracina et al., 2016). On the other hand, give governments insights about how to improve urban areas through measures which could affect city logistics (e.g. privileged access to delivery vans, free city tax for green vehicles) or about developing policies and regulations for the long-term development of the industry (e.g. Yi et al., 2017). Moreover, the studies almost always make a comparison of the environmental impact of the online and offline purchasing processes, in all their different variants, and the identification of the variables most affecting them. Transportation activities are the ones, in general, most affecting the results (e.g. Brown and Guiffrida, 2014; McLeod et al., 2006; Wiese et al., 2012). Anyway, results depend on many other context factors, above all the type of industry considered. In this regard, when dealing with FMCG, warehousing related emissions get significant as well. Literature displays different methodologies attempting to assess the environmental impact of online and offline purchasing processes. In particular, studies propose environmental assessments considering different functional units (see 2.1) and system boundaries (see 2.2), for general or specific industries (see 2.3)

2.1 Functional unit

The functional unit is intended as the object for which the environmental impact is assessed (Van Loon et al., 2014). Literature displays two main approaches. First, the single item is considered (e.g. Williams and Tagami, 2002; Sivaraman et al., 2007). Second, the whole order is accounted (Weber et al., 2010; Mangiaracina et al., 2016).

Van Loon et al. (2015) investigate the environmental impact (quantified in terms of CO2e) of one item - belonging to a larger shopping basket - fulfilled through different channels. A particular allocation of emissions regards the last mile delivery, where emissions are usually allocated based on the number of deliveries (Edwards et al., 2010), regardless of the type of item shipped. The constrain in the last mile delivery tour is indeed typically the time, and not the weight of the products (Siikavirta et al., 2002). Similarly, Weber et al. (2010) defined the functional unit as a unit of one album of music and Williams and Tagami (2002) use the single item, the book. Sivaraman et al. (2007) set a quite particular functional unit, i.e. renting three DVDs at one time (going to the DVD rental shop or ordering online). In this precise case, the choice of the authors is because at the manufacturing facility, DVDs are packed in three. The order as functional unit was also considered by Mangiaracina et al. (2016), whose study assessed the impact of an order made of, on average, 1.3 fashion products.

2.2 System boundaries

Williams and Tagami (2002), which propose one of the first studies in the field, considered mostly transportation and packaging related emissions. In particular, they estimated the energy generated in the following stages:

(i) the consumer travel to and from the bookstore in the traditional offline model, (ii) the transport of books by shipping and courier services, (iii) production of packaging and (iv) sales point consumption, either at the bookstore or in the consumer's home in the case of e-commerce purchase. This study, even if it considers the energy consumption in the stores, does not include neither warehousing nor fulfilment activities. Sivaraman et al. (2007), which focused on the DVD rental, included not only warehousing activities, but the whole manufacturing (DVD in the specific case) process. In the e-commerce case, it is considered that placing a DVD order require the usage of a computer, lights, and air conditioning/space heating. Emissions related to computer energy consumption are quite commonly considered (e.g. Mangiaracina et al., 2016). Not only the energy spent to make the purchase is accounted, but also computer manufacturing is allocated based on a burden factor, which is usually the ratio between the number of hours the computer is used to place the order and the overall number of hours a computer is used throughout its lifetime (Sivaraman et al., 2007; Van Loon et al, 2014). The energy for computer disposal is also determined and allocated using the burden factor. Weber et al. (2010) study instead the environmental impact of different music delivery methods: emissions are assessed from recording though distribution to a final consumer. The boundaries considered by this study are: (i) warehouse energy usage, (ii) electricity use at home computer to place e-commerce order, (iii) transport from the wholesale warehouse to the retail store, distribution centre, or retail warehouse, (iv) last-mile transport from local distribution centre to customer home or from retail store to customer home, (v) data centre electricity usage to run e-commerce and online music sites, (vi) bulk versus individual cardboard packaging, (vii) energy usage in traditional retail store and (viii) internet network electricity usage for download. In Weber et al. (2010) only differential emissions among purchasing processes are accounted. The approach by Weber et al. (2010) was similarly suggested by Edwards et al. (2010), who stated that the environmental effects of fulfilling a consumer item are compared from the point of deviation to the point of consumption. With the e-commerce growth along years, fulfilment methods become a key significant issue to be tackled. This topic was investigated in particular by Van Loon et al. (2015), who propose an LCA model to compare the environmental impact of different fulfilment methods for Fast Moving Consumer Goods. This study investigates the most common B2C e-commerce models (e.g. pure players, merchants fulfilling orders from a large e-fulfillment center, merchants fulfilling orders from stores, or "drop-ship") and the offline channel. The point of divergence is usually the factory's outbound operation (Potter et al., 2011): all the emissions related to the activities of moving and storing products from the factory to the customer are therefore considered by the study. Emissions instead generated from the production and usage of the item, as well as the primary packaging, are excluded since they do not depend on the channel through which the item was bought.

2.3 Industries

The industry sectors typically tackled are the apparel, consumer electronics and books, since they are the ones were e-commerce has experienced the highest penetration rate (Zhang and Zhang, 2013; Potter et al., 2010). The most recent studies are instead also focusing on grocery (e.g. Heard et

al., 2019; Gee et al., 2019; Fikar, 2018). It is interesting to notice the differences among those supply chains in terms of activities performed during the fulfilment process, as well as variables affecting the carbon footprint. For instance, product temperature and product perishability are influencing exclusively the food supply chain, where emissions related to product disposal are more relevant and the picking process becomes critical also in environmental terms (Gružauskas et al., 2019). High return rate, instead, are typical of the apparel and the consumer electronics market, increasing considerably the CO2 emissions related to transportation.
Anyway, most of the studies does not specify the industry of analysis, thus their conclusions can be generalized to all of the above-mentioned industries. As an example, papers concerning the last-mile delivery problem - several of which including routing optimization - range from different industries and are common for all B2C e-commerce fulfilment processes (e.g. Guo et al., 2019; Pan et al., 2015).

3 Objectives and methodology

The environmental impact of multi-item shopping - intended as the purchase of products belonging to different categories - resulted under investigated in literature. Studies proposing environmental assessment compare the online and offline purchasing processes typically considering (i) one product only, or (ii) one order made of a certain number of products of the same industry, and so bought from the same retailer, either online or offline. Relying on this consideration, the aim of the present work is to propose an environmental assessment allowing to compare different types of purchasing processes - reflecting thus different purchasing behaviors. In order to reach this goal, an environmental assessment model is employed. The model architecture is adapted from the one proposed by Mangiaracina et al. (2016), whose main peculiarity is the possibility to breakdown the total emissions - in terms of kgCO2 - in each phase of the purchasing process, i.e. pre-sale and sale, replenishment, order picking and assembly, delivery and post-sale. More specifically, this modular approach (see ¶4 for further details) allows to combine phases of purchases from different industries into a new multi-item purchasing process. As an example, starting from the environmental impact of the purchase of a piece of clothes and a book as two separate purchases, the impact deriving from the joint purchase of both the items can be derived. This particularly affects the environmental assessment of the offline process. Regarding instead the e-commerce case, it depends on many factors, e.g. if the two items are purchased by two different retailers or, in case the retailer is the same, whether there are separate shipments. According to this premise, the originality of the present work is mainly in the context it aims to investigate, while relying on an established assessment model. The industries considered are among the most tackled in literature, i.e. fashion, consumer electronics, books and grocery.

4 Environmental assessment model

The model grounds on the definition of the reference purchasing processes for both e-commerce and traditional channel. Each of the two processes is divided in macro-phases (i.e. pre-sale and sale, replenishment, order picking and assembly, delivery, post-sale), which are then divided into activities (Mangiaracina et al., 2016). The environmental impact is calculated at the activity level. Processes are in particular affected by the structure of the distribution network (Van Loon et al., 2015). The present study considers two types of distribution networks according to the industry. (i) Fashion, book and consumer electronics industries rely on a distribution network made of a warehouse which replenishes points of sales and where online orders are fulfilled. (ii) The grocery retailer is instead assumed to have points of sales for the shopping in the traditional channel, a dedicated warehouse for fulfilling online orders and a central warehouse which replenishes both the points of sale and the dedicated warehouse. Figure 1 and 2 represent the distribution network of reference respectively for the first cluster of industries (i.e. fashion, book and consumer electronics) and for the grocery one. Illustrations also displays the five macro-phases of the online and offline purchasing processes, which are later described in 4.2 and 4.3.

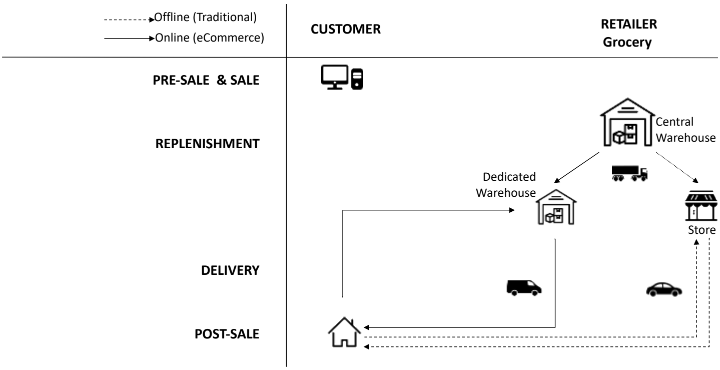

Figure 1: Fashion, consumer electronics and books industries: reference distribution network

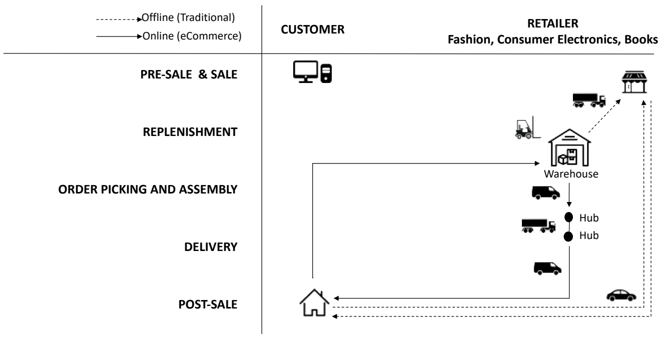

Figure 2: Grocery industry: reference distribution network

4.1 Model structure

The environmental assessment model is made of five parts.
First, input data regarding the customer (e.g. return rate, average distance travelled to reach the store), the order (e,g, product category, number of items, number of order lines), the packaging (e.g. typology, dimension), the characteristics of the warehouse and the store (e.g. dimension, energy performance). Second, activity data regarding the duration of the activities (i.e. online, warehouses, transit point, store and transport). Third, data on consumptions of resources and the related conversion factors. Fourth, model algorithms, which collects all the mathematical formulas connecting the previous sections to the output. In the end, the output data, which is the environmental impact generated (i.e. kgCO2e) by a purchase - online and offline - either considering one purchase at a time and multiple purchases in different stores. The overall result can be broken down by macro-phase and by activity type.

4.2 E-commerce purchasing process

The e-commerce process is made of five phases. For sake of simplicity, the following description is based considering an order from a single retailer. The description of the phases is based on Mangiaracina et al. (2016).
Pre-sale and sale: information about the products are gathered by the customer, who then purchases the item and pays (online).
Order picking and assembly: the retailer receives the order and picks the required items (i) in the dedicated area of the warehouse for the first cluster of industries (fashion, consumer electronics and books); and (ii) in the dedicated warehouse for the grocery sector.

Stock replenishment: in the first cluster of industries, the picking area is replenished with goods from the storage area within the warehouse. In the grocery sector, the dedicated warehouse is replenished by goods from the central warehouse.
Delivery: after the picking and assembly of the order in the retailer's warehouse, it is sent to the customer. The order can be shipped directly to the customer in the case of grocery, or it pass through some transit points (typically two) before reaching the destination.
Post-sale: goods are sent back to the retailer's warehouse. Returns are negligible for the grocery orders.
The environmental impact is computed by summing up the emissions generated in each activity of the macro-phase.

4.3 Traditional purchasing process

Similar to the online process, the offline one is divided into macro-phases and activities. The main difference is that the order picking and assembly phase is included in the "pre-sale and sale" since it is done by the customer in the store.
Pre-sale and sale: the customer goes to the store, where products are collected and then paid.
Replenishment: goods are picked in the retailer's central warehouse and transported to the store.
Delivery: it is the distance travelled by the customer to come back home after the purchase,
Post-sale: the customer comes back to the store and asks for the change. He travels then back home with the changed product.

4.4 Multi-item purchasing process

4.2 and 4.3 were aimed at explaining the process in the case of a single product category purchase. It doesn't mean that only one product is bought, but that the online order is made of a certain number of products from the same category - e.g. grocery, fashion - as well as the traditional shopping is made in one store only - e.g. supermarket, fashion store. Reality displays also other situations, and different purchasing behaviors. Indeed, it happens that a customer buys in more than one store during his traditional shopping tour. In this case, the customer is supposed to reach a mall, or a city center - where there are typically many shops - and makes purchases in different stores. If considering the online shopping, the most common case is that customer buys from different specialized retailers. In this regards, different shipments are performed. The macro phases of the online and offline purchasing processes just presented are detailed below.

When the customer places online orders from different retailers, the number of shipments is equal to the number of orders (the case of more than one shipment for an order is out of the scope of the present study). The total environmental impact is given by the sum of emissions of the different online orders.

In the pre-sale phase of the offline shopping, the customer reaches the mall, the city center or, more in general, the shops. He is supposed to use the car. The customer performs the purchase in the first store, then he walks to next store, make the purchases and so on till the last visited shop. As explained in 4.3, the order picking and assembly phase is included in the sale activities. After visiting the last store, the customer is supposed to drive back home. The replenishment activity is the same explained in 4.3: what changes in the multi-item purchase is that related emissions are accounted for each product category considered.

5 Results

First of all, the environmental assessment model was applied to the single industries - comparing the online and offline purchases made of a product category only. In this regard, Table 1 displays the environmental impact, in terms of kgCO2e/order in the four main industries, i.e. fashion, consumer electronics, book and grocery, in both the traditional and e-commerce purchasing processes, as well as the repartition of the emissions among the five phases. Table 2 shows instead the repartition of emissions by type of activity. Input data typical of the sectors were partially retrieved from Mangiaracina et al. (2016), Mangiaracina et al. (2019a) and Mangiaracina et al. (2019b), respectively for the fashion, consumer electronics and grocery industries. Activity and purchase profile information are primary data from players of each sector. All data regarding consumptions of vehicles and buildings were respectively retrieved from DEFRA (2018) and CENED (2020) reports.

Overall the online purchasing process generates lower emissions than the traditional offline shopping (i.e. 3.93 vs 4.6 kgCO2e in fashion, 3.03 vs 4.31 kgCO2e in consumer electronics, 3.12 vs 4.41 kgCO2e in books, 7.34 vs 8.66 kgCO2e in grocery). Emissions are quite similar - both in value (i.e kgCO2e) and in the repartition among the type of activity - in the fashion, consumer electronics and book industries. Emissions in the grocery sector are instead almost doubled if compared to the just mentioned cluster of industries (i.e. 3.82 kgCO2e as average of emissions for fashion, consumer electronics and books online orders vs 7.34 kgCO2e of e-grocery). Indeed, the order composition and the distribution network of reference differ. On the hand, while the order of the first cluster of industries is made of about 1.2-1.4 pieces, the grocery order counts 65 items. On the other hand, the presence of the dedicated warehouse involves not only additional buildings-related emissions, but also transportation-related ones due to its replenishment. In the traditional shopping, the pre-sale and sale activity accounts up to about the 50% of the overall emissions. This phase indeed considers the travel to the store - which is responsible for about half of the pre-sale and sale emissions - and all the energy consumptions in the store. The replenishment phase is the second source of emissions in the fashion, consumer electronics and book industries (about 30% of total online emissions), but the first one in the grocery (50% of total online emissions). As mentioned, replenishment in the grocery case implies not only transportation activities, but buildings emissions of the whole dedicated warehouse. In this regard, while in the first cluster of industries transportation activities cause about half of the overall emissions, in the grocery sectors they cause about the 30%.

Table 1: Environmental impact single product category purchase - emissions repartition by phase

	Fashion		**Consumer electronics**		**Book**		**Grocery**	
	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce
Pre-sale and Sale	45,10%	0,64%	48,06%	0,72%	47,04%	0,57%	43,93%	0,66%
Replenishment	29,45%	0,02%	25,83%	0,02%	27,90%	0,01%	50,76%	46,06%
Order picking and assembly	-	37,87%	-	41,00%	-	43,00%	-	25,43%
Delivery	23,08%	47,22%	24,60%	56,74%	24,07%	55,44%	5,31%	27,52%
Post-sale	2,37%	14,25%	1,51%	1,53%	0,99%	0,97%	0,00%	0,33%
Environmental impact [kgCO2e/order]	**4,60**	**3,93**	**4,31**	**3,03**	**4,41**	**3,12**	**8,66**	**7,34**

Table 2: Environmental impact single product category purchase - emissions repartition by type of activity

	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce
Transportation	52,43%	47,50%	52,62%	45,31%	50,44%	41,90%	30,42%	42,00%
Warehouse/handling	24,06%	51,51%	22,38%	53,66%	25,10%	57,25%	27,08%	57,07%
Other (Purchasing, Communication, Management)	23,51%	0,99%	25,00%	1,03%	24,46%	0,85%	42,51%	0,93%
Environmental impact [kgCO2e/order]	**4,60**	**3,93**	**4,31**	**3,03**	**4,41**	**3,12**	**8,66**	**7,34**

Table 3: Environmental impact multi-item shopping

Fashion	**Consumer Electronics**	**Book**	**Grocery**	**Purchasing Process**	**Emissions [kgCO2e]**
X	X			Traditional	6,79
				E-commerce	6,96
X		X		Traditional	6,88
				E-commerce	7,05
	X	X		Traditional	6,60
				E-commerce	6,15
	X		X	Traditional	11,45
				E-commerce	10,38
X			X	Traditional	11,74
				E-commerce	11,27
X	X	X		Traditional	9,07
				E-commerce	10,08
	X	X	X	Traditional	13,74
				E-commerce	13,50
X	X		X	Traditional	13,93
				E-commerce	14,30
X	X	X	X	Traditional	16,21
				E-commerce	17,42

Second, the perspective of the multi-item shopping was applied. With the aim of representing different purchasing situations, scenarios displayed in table 3 were investigated. In particular, purchases made in two, three and four shops are considered, as well as different combinations of product categories. When two orders are considered, overall emissions are very similar (e.g. 6.79 and 6.96 kgCO2e for fashion and consumer electronics; 6.88 and 7.05 kgCO2e in fashion and book). Anyway, based on the input data employed, the traditional process gets slightly more environmentally sustainable when fashion and consumer electronics, or fashion and books, are bought in the same shopping process. The peculiarity of the fashion industry is indeed the higher return rate of online purchases (about 30%) if compared to the other industries (less than 5%). When three different purchases are instead considered, and among the analyzed scenarios, the traditional shopping remains slightly less environmentally sustainable when the grocery shopping is done, and no fashion products are bought (13.74 kgCO2e in traditional shopping vs 13.50 kgCO2e in e-commerce). When instead all the four product categories are supposed to be bought in a shopping tour, e-commerce displays the highest environmental impact (17.42 kgCO2e in the e-commerce vs 16.21 in traditional shopping). All these considerations are valid when the online orders for the different products are made in different websites, and so from different retailers. In this regard, each online order corresponds to a shipment.

6 Discussion and conclusions

The present work is aimed at investigating the environmental impact of purchasing processes which have not been so far tackled by literature. In this regard, studies proposing environmental assessment usually compare the online and offline purchasing processes typically considering (i) one product only, or (ii) one order made of a certain number of products of the same industry, and so bought from the same retailer, either online or offline. The aim of the present work was instead to propose an environmental assessment allowing to compare different types of purchasing processes - reflecting thus different purchasing behaviors. In order to reach this goal, an environmental assessment model was employed. First, it was applied to the single industries - comparing the online and offline purchases made of a product category only. Second, different shopping situations were created (see table 3) and the related environmental impacts were assessed.
If comparing the same purchase made in the online and offline channels, for a specific industry, the e-commerce case is generally more environmentally sustainable – even if the results depends on many variables, e.g. customer density, mean of transport. Transportation related activities resulted to be the main source of emissions in the fashion, consumer electronics and book industries, accounting for about the 50% of the overall impact. In the grocery industry, transportation and warehousing related emissions have the same weight in terms of impact, and its mainly due to the peculiar distribution network of reference, which employed a dedicated warehouse for fulfilling online orders. Results overturn when, in the same offline shopping trip, the customer buys in more than one store. Emissions are almost the same when two product categories are bought. When three different orders

are instead placed, the presence of product categories characterized by high return rates make the e-commerce process less environmentally sustainable. In the case of four different orders, e-commerce definitely displays the highest emissions.
The main contribution of the present work does not lie in the development of a new assessment model, but in the in the investigation of the multi-item approach while evaluating the environmental sustainability of the purchasing processes. Even if some real shopping situations are investigated, further scenarios should be assessed by future works. In particular, results are applicable when the online orders for the different products are made in different websites, and so from different retailers. In this regard, each online order corresponds to a shipment. As an example, the case of buying online from general merchandise retailers is not studied by the present work and it represents an interesting and real situation to be explored.

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Public Sustainable Transportation Planning with Service Level Efficiency: Hamburg Case Study

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Purpose: Public transportation in large cities has significant impacts on the environmental, social, and economical perspectives. However, the proper assignment of resources in public transportation creates paradoxical challenges since by increasing service level efficiency, the environmental criteria will be violated. This paper has studied the literature and discussed the considerable gap for the fulfillment of the mutual service level satisfaction and environmental emission considerations.
Methodology: The paper has applied the well-known assignment problem technique and multi-objective planning to propose a novel framework for public transportation resource assignment fulfilling the aforementioned perspectives mutually. The model is capable of analyzing the tradeoffs for increasing public service satisfactions and meanwhile to control the environmental emissions. Using the multi-objective analytical capabilities, the proposed model improves the overall citizens' satisfaction and also manage the operational costs related to the produced emission by transportation resources.
Findings: The real data of Hamburg public transportation has been used to verify the capabilities of the proposed model. The findings first validate the model formulation and also gives insights for effective strategic planning for public resource assignment. The analysis emphasizes on establishing control mechanism for passenger's arrival rate as it affects both waiting times in bus stops and also the transportation vehicle weights which drastically affect the environmental factors.
Originality: This paper has studied the related literature and discussed the gap for the mutual fulfillment of passenger's service level satisfaction using public transportation and also controlling environmental emissions of public transportation.

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1 Introduction

Public network transportation is an indispensable component of every city's infrastructure that affects the daily lives of many citizens (Cao and Wang 2017). Efficient public transportation is an important factor for helping the society to reach long term and daily goals (Joewono and Kubota 2006). Hamburg, as a Hanseatic city, settles a large number of inhabitants inside itself which encounters a significant volume of movements every day (Strunk et al. 2017). Additionally, many logistics enterprises are working in Hamburg, where they need to convey their goods from ports to destinations and vice versa. So, in order to control the flow of passengers, a smooth and efficient transportation system should be considered.

According to the European Commission studies, 40 % of CO2 emissions come directly from urban mobility while up to 70 % of other pollutants also has originality from transportation (Nanaki et al. 2017). This triggers a common challenge to most major cities in Europe, where to intensify movement and increase service level, the congestion, pollution, and environmental criteria should be controlled. Thus, for finding the right responses to this challenge, it is recommended to apply Sustainability Assessment (SA) as a critical tool to analyze the environmental aspects by common SA's criteria (Ribeiro et al. 2020). The importance of sustainability in public transport has got more attention since international laws and domestic regulations are impacting transportation for sustainability concerns. The focus of sustainability is to establish principles on reliably sufficing the requirements of public transportation according to the three pillars: economic, environmental, and social (also known informally as profits, planet, and people). So, SA as an appraisal method can be applied to support long-term and short-term decisions for transportation planning fulfilling three aforementioned pillars.

In terms of environmental criteria, SA encourages governments to consider main prospects that influence the wellbeing of the environment, such as to reduce greenhouse gases and emissions, preserve the ecosystem, and hinder the progress of global warming. In public transportation, the consumption of fuels that produce various air pollutants is the primary concern that effects environmental criteria (Nanaki et al. 2016). These pollutants mostly incorporate of Carbon dioxide, Nitrogen oxides, Methane, and particulates. So, an efficient transport planning system with sustainably considerations must seek to diminish the harmful gases. Simultaneously, from the social and economic perspectives, sustainable transportation must consider the preferences of its citizens with proper transportation service level.

Public transport can be analyzed from two perspectives; in the view of users, the cost of transportation, service level and reliability are among the most favored factors (Mishalani et al. 2006). While from the other perspective, the target is to represent public transport as a viable alternative to self-driving, which both satisfies the logistics requirements of passengers and also will be more successful to fulfill the urban environmental traffic regulations. So, it is a significant challenge that needs a proper solution to fulfill the both citizens' service level and also SA considerations mutually.

The research roadmap is structured as follows. In section 2, the paper has conducted a literature review for sustainability in public transportation and service level efficiency. In section 3, the problem is formulated to both satisfy the service level consideration through minimizing the waiting time of passengers at stations as well as minimizing the environmental emission of buses. Section 4 discusss the problem based on a case study which considers the Hamburg city center and then by an analytical approach, the major factors affecting the sustainability in public transportation alongside high passenger satisfaction is discussed.

2 Literature Review

The public transportation resource assignment is well-known in literature, see Guihaire and Hau (2008) for a comprehensive list of references. Binder et al. (2017) proposed an algorithm for capacitated passenger public transportation in the morning rush hours for Canton Vaud, Switzerland. Their results showed that the ordering of the passengers does not have a significant impact on aggregate performance indicators. Though, on the contrary, the variability at the individual passenger level is substantial. Rafael et al. (2018) applied mix-objective programming to simultaneously maximize the profit and also to minimize the running cost for the regional bus scheduling problem in Tanzania. Cao and Wang (2017) proposed an optimization method for assigning passengers on customized buses. The waiting time and penalty of delay are improved while at the same time traffic congestion was reduced.

One of the vital aspects of public transportation is passenger satisfaction, which is critical for analyzing the customers' service level. In recent years, service level efficiency has been one of the research topics that has been considered in multiple large cities' public transportation service level studies. Fellesson and Friman (2008) compared the level of service in public transportation between eight European countries by organizing a comprehensive survey searching for the respondents' opinions about public transport services. They assessed the internal reliability of the identified factors with Cronbach's coefficient alpha. They indicated important conclusions, including the heavy reliance on technology and infrastructure that is inherent in public transport operations, and the critical role of safety/security, system (supply and reliability), comfort, and staff behavior for traveler satisfaction. Friman and Fellesson (2009) analyzed the relationship between the objective performance measures of public transport services and the satisfaction perceived by travelers. Le-Klähn et al. (2014) studied the service level satisfaction of public transport by visitors in the city of Munich, Germany. They gathered data from a survey with a random sample resulted in four different service dimensions, including traveling comfort, service quality, accessibility, and additional features. They investigated the characteristics of service dimensions with previous studies and proposed some attributes for better service enhancement.

The literature considers the sustainability in public transportation as one of the urban comfort factors. The sustainability is discussed based on three dimensions which the focus is usually on environmental issues. Specially, the emission of different harmful gases to the air is important in environmental issues. For instance, Rebeiro et al. (2019) provided a multi-criteria analysis to evaluate the SA criteria of a bus transportation system in a Portuguese mid-sized municipality. They appended the institutional criteria to other SA pillars in order to calculate the impact of planning and management for public and private agents in the bus system. Three main sources for acquiring data used in their study was: fieldwork, questionnaires, and estimated values. They assessed the SA criteria with ranking and scoring through considering the average evaluation of the values for all urban centers. Errampalli et al. (2020) proposed a methodology for two modes of transportation, including buses and metro in South Delhi, to determine the level of integration by SA criteria consideration. This methodology was applied for evaluating the incorporation of modes and also studied the impacts of public transportation on service level with the multi-criteria analysis. Li and Head (2009) studied the bus scheduling problem by applying a time-space network for evaluating environmental emissions. They followed two primary objectives in their paper, first, minimizing the number of required buses for weekdays and second, minimizing the operating costs.

Qin et al. (2016) studied the impact of using electric transit buses instead of diesel buses on transportation costs and their effects on the environment in Tallahassee, Florida. Using simulation, they attempted to find an optimal charging strategy for fast-charging buses. Feng and Timmermans (2014) focused on tradeoffs between mobility and equity maximization under environmental capacity constraints. They formulated three types of hypothetical policies, including network improvement, population increase, and urban sprawl via using data for Dalian in China.

The waiting time of passengers at the bus stations is a critical component of a passenger's service level efficiency. According to previous studies, the mean waiting time was expressed as half of the transportation headway while passengers were arriving randomly (Osuna and Newell, 1972; Welding, 1957). Hsu (2010) formulated the waiting time based on the characteristics of both connecting service and its feeder service. With the simulation technique, he compared the effects of connecting service variables with the corresponding variables of the feeder service. Mishalani et al. (2006) used regression analysis to estimate the relationship between observed waiting times and actual waiting times at bus stations. Ingvardson et al. (2018) proposed a framework to estimate passenger waiting time in the great area of Copenhagen while passengers come to stations based on two separate groups (as traditional models, one group coming randomly, and the other one coming according to scheduled times). They used a combination distribution consisting of a uniform and a Beta distribution for each group to obtain the waiting time. Vehicle Routing Problem (VRP) is an integer programming that seeking to find an optimal set of routes for vehicles. VRP applications have been used in public transportation problems to assign buses to the routes optimally (Assari et al. 2018, Aghamohammadzadeh et al. 2019). Kim et al. (2011) applied VRP to optimize bus schedules to serve all the given trips. For general cases, they proposed an assignment problem based on a heuristic approach. According to the related literature (Delaram and Valilai 2017, 2018), the mutual service level satisfaction of passengers, and environmental emissions in public transportation are considered as a motivational gap for this research.

3 Problem Formulation

In this section, the main goal is to model and minimize both the waiting time of passengers at stations and environmental emissions of transportation vehicles by a Multi-Objective Optimization Problem (MOOP). The developed MOOP model tries to fulfill the SA criteria in the public transport system based on its three pillars. This motivation is important since transportation system have a significant impact on the environment, economy, and social equity as the main pillars of SA. The target is to support the transportation system for affordable, customer satisficing, and friendly working peace to the environment. So, by optimizing waiting time alongside reducing environmental emissions, SA criteria can be satisfied. For this reason, the assignment problem technique is applied for the public transport system, while based on Vehicle Routing Problem (VRP)problem, stations are assumed as fixed location nodes and buses are optimally assigned to the routes as acres. Therefore, the MOOP has two objective functions that would be mutually optimized.

3.1 Evaluating Waiting Time

The paper assumes passengers are arriving to stations based on a Poisson Process. Consider passengers arrive at station j with Poisson Process rate λ_j and let h_j be the headway in station j. If the first passenger comes at station j exact at the moment when the bus has moved from the station and misses the bus, he/she has to wait for h_j until the next bus arrives.

Continuously, if the other passengers come in an identical separate time until the bus arrives, then all arrival times of passengers would be $\left(0,\ \frac{h_j}{\lambda_j},\ \frac{2h_j}{\lambda_j},\ \frac{3h_j}{\lambda_j}, \dots ,\ \frac{(\lambda_j-1)h_j}{\lambda_j}\right)$, and subsequently, the waiting times for passengers are $\left(h_j,\ h_j-\frac{h_j}{\lambda_j},\ h_j-\frac{2h_j}{\lambda_j},\ h_j-\frac{3h_j}{\lambda_j}, \dots ,\ h_j-\frac{(\lambda_j-1)h_j}{\lambda_j}\right)$. So, the average waiting time at station j, $\overline{W_j}$, can be obtained as equation (1):

$$\overline{W_j} = \frac{h_j+(h_j-\frac{h_j}{\lambda_j})+(h_j-\frac{2h_j}{\lambda_j})+(h_j-\frac{3h_j}{\lambda_j})+\dots+(h_j-\frac{(\lambda_j-1)h_j}{\lambda_j})}{\lambda_j} = \frac{\lambda_j h_j-\frac{h_j}{\lambda_j}(1+2+\dots+(\lambda_j-1))}{\lambda_j} = h_j-\frac{\lambda_j(\lambda_j-1)}{2h_j} \quad (1)$$

3.2 Evaluating Environmental Emissions

Air pollutants are responsible for several adverse ecological effects. Various air pollutants such as greenhouse gases, Carbon dioxide, Methane, and particulates are origins of global warming and also suspected of having a critical impact on regional climates. Environmental perspectives in transportation, particularly in the VRP, may lead the system to achieve less polluting vehicles, use the optimal volume of vehicles, and change the mode of transport. According to Carlos Molina (2014), climate change impacts transport are mainly produced by emissions of the greenhouse gases, including carbon dioxide (CO2), nitrogen oxides (NO+NO2), and methane (CH4). Moreover, tier 2 methodology (EMEP/EEA, 2010) is used for categorizing vehicle fuel combustion and fuel policy legislation to control environmental emissions.

3.3 Mathematical Modeling

According to the Vehicle Routing Problem (VRP), the following parameters are defined:

$$G(V,A):\begin{cases} V=(v_0,v_1,\dots,v_n),\ v_0: depot,\ V'=V\backslash\{v_0\}: Stations \\ A=\{(v_i,v_j)|v_i,v_j\in V, i\neq j\} \end{cases},$$

$K=(k_1,k_2,\dots,k_m)$: Vehicles which are assigned individually to each route,
d_{ij}: Distance between station i and$j$,
t_{ij}: Travel time between different stations,
T^k: Maximum allowing travel time for vehicle k,
S_i^k: Service time at station i.
Decision Variables:

$$x_{ijt}^k:\begin{cases} 1,\ If\ vehicle\ k\ travel\ from\ station\ i\ to\ j\ at\ period\ t \\ 0,\ Otherwise \end{cases},$$

y_{jt}^k: Arrival time of vehicle k at station j in period t,
xy_{ijt}^k: Dummy variable for linearization,
By y_{jt}^k definition, the headway at station j could be obtained as

$$h_j=\sum_K y_{jt}^k-\sum_K y_{j(t-1)}^k \quad (2)$$

Constraints:

$$\sum_{j=1}^n x_{0jt}^k=1 \qquad \forall t,k \quad (3)$$

$$\sum_{j=1,j\neq i}^n x_{ijt}^k-\sum_{j=1,j\neq i}^n x_{jit}^k=0 \qquad \forall i,t,k \quad (4)$$

$$\sum_{k=1}^m\sum_{i=1}^n x_{ijt}^k=1 \qquad \forall j,t \quad (5)$$

$$\sum_{i=1,i\neq j}^n\sum_{k=1}^m x_{ijt}^k\left(y_{it}^k-y_{jt}^k\right)=0 \quad (6)$$

$$\begin{cases} y_{jt}^{k} \geq x_{0jt}^{k}.t_{0j} & \forall k,t \\ y_{jt}^{k} = \sum_{i=1}^{n} xy_{ijt}^{k} + x_{ijt}^{k} * s_{i}^{k} + x_{ijt}^{k} * t_{ij} & \forall j,t,k \\ xy_{ijt}^{k} \leq M.x_{ijt}^{k} & \forall i,j,t,k \\ M\left(1 - x_{ijt}^{k}\right) + xy_{ijt}^{k} \geq y_{it}^{k} & \forall i,j,t,k \\ xy_{ijt}^{k} \leq y_{it}^{k} & \forall i,j,t,k \end{cases} \quad (7)$$

$$\begin{cases} y_{it}^{k} + s_{j}^{k} + t_{ij} \leq y_{jt}^{k} + T^{k}\left(1 - x_{ijt}^{k}\right) \\ t_{0j} \leq y_{jt}^{k} + T^{k}\left(1 - x_{0jt}^{k}\right) \end{cases} \quad (8)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} x_{ijt}^{k}(t_{ij} + s_{j}^{k}) \leq T^{k} \quad \forall t,k \quad (9)$$

$$\begin{cases} xy_{ijt}^{k} \geq 0 & \forall i,j,t,k \\ y_{ijt}^{k} \geq 0 & \forall i,j,t,k \\ x_{ijt}^{k} = (0,1) & \forall i,j,t,k \end{cases} \quad (10)$$

Buses aim to serve passengers throughout routes in an optimal manner. Hence, constrain (3) means for constructing a tour in each period; one bus type k should exit the depot. For creating continuity of each route, constrain (4) is employed, and with constrain (5), each station in each period belongs precisely to one route. Constrain (6) is expressed for sub-tour elimination. Constrain (7) calculate the bus arrival time and since it is not linear, the dummy variable, xy_{ijt}^{k}, is defined. Besides, constrain (8), determined the starting service times. Constrain (9) specifies the maximum allowable time for transportation for each vehicle. Finally, constrain (10) shows non-negativity constrain for assumed values.

Thus, according to equations (1) and (2), the objective function for the minimizing waiting time based on all stations is as follows:

$$\min(\overline{W_j}) = \min \sum_{j=1}^{n}(h_j - \frac{\lambda_j(\lambda_j - 1)}{2.h_j}) = \min \sum_{j=1}^{n}(\sum_K y_{jt}^k - \sum_K y_{j(t-1)}^k - \frac{\lambda_j(\lambda_j - 1)}{2(\sum_K y_{jt}^k - \sum_K y_{j(t-1)}^k)}) \quad (11)$$

The objective function of fuel consumption of buses is obtained based on three factors: the vehicle type, the distance traveled, and the load carrier (Carlos Molina, 2014). The main gas produced by buses is CO2, so the objective function considers the amount of CO2 released in air based on the mentioned factors.

$$\min(F) = min \sum_i \sum_j \sum_k \sum_t ef^{CO_2 r}.d_{ij}.x_{ijt}^K (fe^K + feu^K.L_{ij}^K) \quad (12)$$

The parameters used in equation (12) for objective function are as following:

$ef^{CO_2 r}$: The amount of CO_2 emitted per unit of fuel consumed as an emission factor

fe^K: The amount of fuel consumed while the vehicle is empty

feu^K: The amount of fuel consumed based on the additional load in the vehicle

L_{ij}^K: The load carried by the vehicle between the considered stations

4 Case Study

Hamburg public transportation is structured into five rings centered on the Alster Lakes named from ring A to ring E. Most of the city is covered with rings A and B (called Großbereich). By using rings, C, D and E, passengers can travel up to 60 km far from the city. Moreover, some regional trains are also included in the fare (Gesamtbereich). An extensive range of bus services complements the rail network with metro buses that called frequent services, express buses, sprinter buses, and regional buses. These are connecting to stations and surrounding towns. (For more information see, Hamburg.com website). The paper considers the city center of Hamburg for model evaluation. The graphical view of studied zone is presented in figure 1.

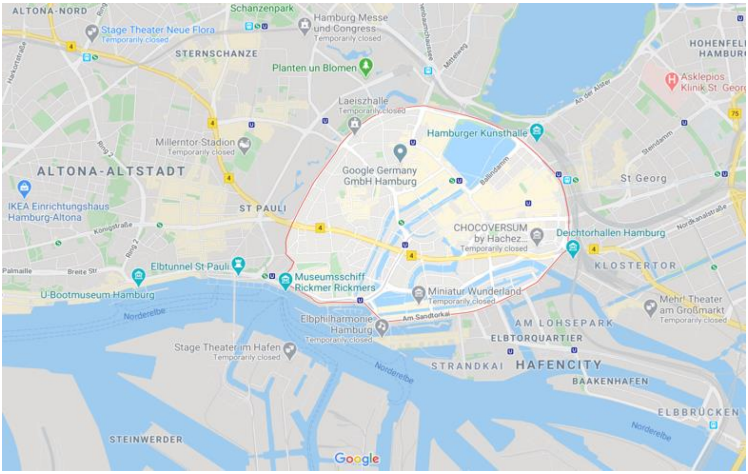

Figure 1: Hamburg city center map obtained from Google© (Date 03/2020)

All bus stations for the city center of Hamburg (Ring A) are illustrated in table 1. These bus stations are crowded with high demand since a large number of people use them every day. Due to the location of the central railway station, called Hamburg Hauptbahnhof, a large number of people commute to the city center, and they need to access to the reliable and efficient public transportation. It is assumed that all stations are fixed as nodes and the model should find the optimum routes which incorporate all stations effectively for minimizing the waiting time of the passengers at stations and also simultaneously yielding the minimum environmental emissions such as CO2. figure 2 shows the Hamburg city center stations and the graph which demonstrates the nodes as stations and acres as the possible route between each two nodes.

Table 1: Bus stations in the Hamburg city center

1	HBF/ Spitalerstraße	9	Handwerkskammer	17	U Rödingsmarkt 2	25	Michaeliskirche
2	Hauptbhf./ Steintorwall	10	Johannes-Brahms-Platz 1	18	Axel Springer Square 1	26	Bei St Annen
3	U Steinstraße (Deichtorplatz)	11	U Stephansplatz	19	Axel Springer Square 2	27	Auf dem Sande (Speicherstadt)
4	Singapurstraße	12	Kunsthalle	20	Johannes-Brahms-Platz 2	28	Meßberg
5	Am Sandtorkai	13	HBF/Mönckebergstraße	21	U Steinstraße	29	US Jungfernstieg
6	Am Kaiserkai	14	Gerhard Hauptmann Square	22	Jakobikirchof	30	U Gänsemarkt
7	Baumwall	15	Rathausemarkt	23	Rathausemarkt (Petrikirche)	31	Valentinskamp
8	Museum für Hamburgische	16	U Rödingsmarkt 1	24	Brandstwiete	32	Dragonerstall

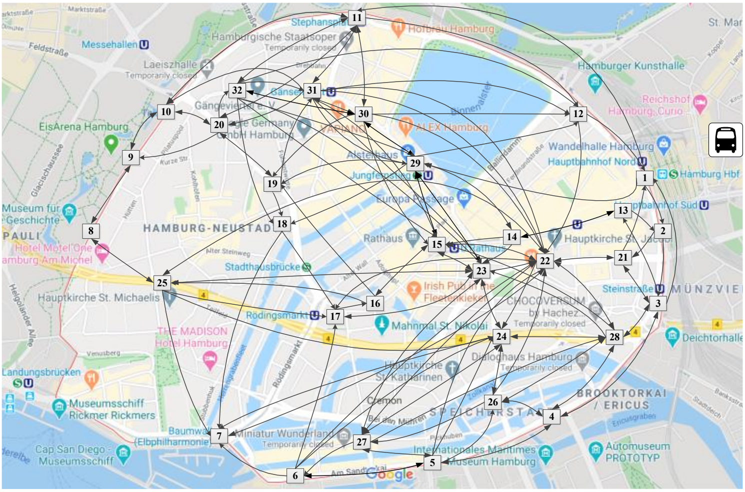

Figure 2: Bus stations in Hamburg city center and related connecting graph

According to figure 2, the time and distance of transportation between two direct stations can be determined based on the available real data obtained from google© map. This problem also considers a depot similar to the Vehicle Routing Problem master model, where buses start and finish their travel routs. It is assumed that the depot location is located near to the Hamburg central train station (Hamburg Hbf).

4.1 Numerical Results

In this subsection, the GAMS© optimization software is used according to the information of table1, table 2, and figure 1. As mentioned earlier, the paper has considered 32 stations in the Hamburg city center and also one central depot for launching buses from near Hamburg Hbf. Three buses are assumed to be active in the problem area. The rate of passengers' arrival is Poisson process in each station, where obviously in high demand stations, this rate considered rationally higher than others. In addition, the mean time of service in each station is assumed in according to the density of passengers in that station. Table 2 shows the values of these parameters for Poisson processes is expressed by the mean number of persons arriving to stations and mean time of providing services in minutes for each station, respectively.

Table 2: The passengers arrival rate and service time mean of buses in each station

1	30, 6	9	10, 4	17	10, 2	25	15, 3
2	25, 5	10	15, 4	18	8, 2	26	15, 3
3	20, 5	11	15, 4	19	10, 3	27	15, 3
4	15, 4	12	30, 5	20	15, 3	28	10, 3
5	15, 4	13	25, 4	21	15, 3	29	10, 3
6	15, 3	14	25, 3	22	15, 3	30	10, 3
7	15, 3	15	30, 6	23	20, 4	31	5, 2
8	15, 4	16	15, 3	24	20, 5	32	3, 1

Each bus can drive in a limited time frame which is defined as the maximum allowed time about 960 minutes.

For calculating the environmental emissions, the amount of CO2 emitted per unit of fuel consumed is considered 2.7 liters. About the amount of fuel consumed while the vehicle is empty per 1 kilometer is 0.3 liters, and based on each additional load in the bus per 1 kilometer is 0.05. The average load carried between two stations is assumed 600 kilograms.

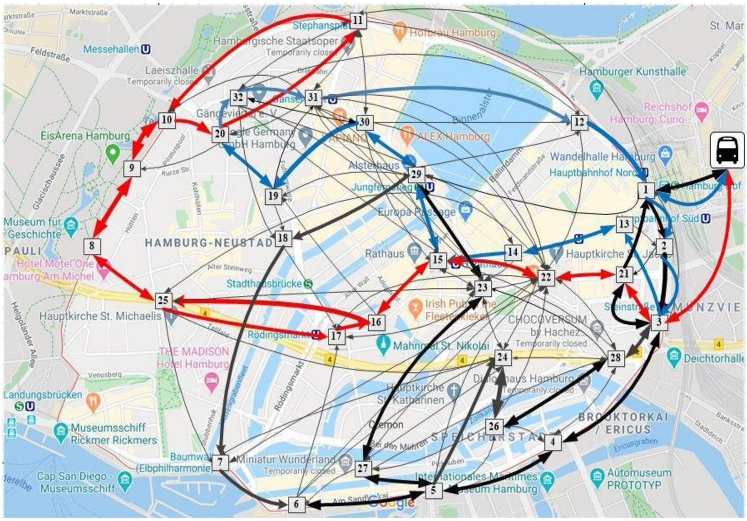

Figure 3: Graph of optimum assigned routes for three buses

The developed model is solved in GAMS© software package, and the optimum routing of buses is obtained and illustrated in figure 3. The waiting time objective function is calculated by considering the Poisson processes for the arrival rate of passengers, which is described in table 2. The comprehensive calculations of waiting times in each station are shown in table 3 based on the resulted routings. In table 3, $\bar{W}_j$ represents the optimum average waiting times (min) in each station that is calculated according to Formula (11). C_j stands for the total cost of waiting times in each station, and it is calculated based on the minimum wage rate for each hour. By assuming the minimum wage as 10 Euro per hour, the value of waiting times can be obtained by $\frac{\bar{W}_j \times 10}{60}$.

Moreover, dividing the total waiting time by λ gives the average waiting time per person in each station that is expressed with W_{pp} in table 3. Similarly, the value of waiting time for each person can be calculated by $\frac{W_{pp} \times 10}{60}$.

Based on calculations of table 3, the total cost of waiting times will be $\frac{2105.75 \times 10}{60} \approx 351$ Euro.

Table 3: Detailed calculation for waiting times

j	1	2	3	4	5	6	7	8
λ_j	30	25	20	25	15	15	15	15
$\overline{W}_j$	146	75.2	213.4	41.75	91.6	45.8	45.8	85.4
C_j	24.3	12.5	35.5	6.9	15.2	7.6	7.6	14.2
W_{pp}	4.8	3	10.6	1.6	6.1	3	3	5.6
C_{pp}	0.8	0.5	1.8	0.3	1	0.5	0.5	0.9

Cont.

j	9	10	11	12	13	14	15	16
λ_j	10	15	15	30	25	25	30	15
$\overline{W}_j$	88	85.4	78	17	21.3	21.3	70.3	85.4
C_j	14.6	14.2	13	2.8	3.5	3.5	11.7	14.2
W_{pp}	8.8	5.6	5.2	0.6	0.8	0.8	2.3	5.7
C_{pp}	1.5	0.9	0.9	0.1	0.1	0.1	0.4	0.9

j	17	18	19	20	21	22	23	24
λ_j	10	8	10	15	15	15	20	20
$\overline{W}_j$	44	46.8	29.5	70.3	136.6	85.4	44	44
C_j	7.3	7.8	4.9	11.7	22.8	14.2	7.3	7.3
W_{pp}	4.4	5.8	2.9	4.7	9.1	5.7	2.2	2.2
C_{pp}	0.7	0.9	0.5	0.8	1.5	0.9	0.4	0.4

Cont.

j	25	26	27	28	29	30	31	32
λ_j	15	15	15	10	10	10	5	3
$\overline{W}_j$	85.4	45.8	45.8	47	78.4	29.5	30.7	30.9
C_j	14.2	7.6	7.6	7.8	13	4.9	5.1	5.1
W_{pp}	5.7	3	3	4.7	7.8	2.9	6.1	10.3
C_{pp}	0.9	0.5	0.5	0.8	1.3	0.5	1	1.7

The second objective function aims to minimize the environmental emissions. For this purpose, the total amount of CO2 (kg) produced in the transportation system is calculated by Formula (12). The parameters are determined in table 4. By considering the total distances for three tours of buses, 2360 kg CO2 is approximately produced that is obtained with multiplying the travel distance by CO2 emissions factor as $10.553 \times [2.7 \times (0.3 + 0.05 \times 600)] + 6.620 \times [2.7 \times (0.3 + 0.05 \times 600)] + 11.670 \times [2.7 \times (0.3 + 0.05 \times 600)]$. Each one-kilogram CO2 emission creates cost of 0.06 Euro according to Duong (2009). Therefore, the total emission cost equals to 141.5 Euro.

Table 4: Detailed calculations for CO2 emissions

K	Total Distance (km)	$ef^{CO_2r}\left(\frac{kg}{lit}\right)$	fe^K(lit/km)	$feu^K\left(\frac{lit}{kg.km}\right)$	$L_{ij}^K(kg)$
1	10.553	2.7	0.3	0.05	600
2	6.620	2.7	0.3	0.05	600
3	11.670	2.7	0.3	0.05	600

These results obtained for the three available buses in service with cost of 141.5 Euro for the amount of CO2 emissions and waiting time of passengers with 351 Euro. One of the crucial factors that have a significant impact on CO2 emission is the weight of the vehicle. This weight includes the weight of the vehicle plus the weight of passengers, so the fluctuation in the number of passengers as a load of the vehicle could affect the emission cost.

Vehicle load reduction will decrease the CO2 emission cost; however, it increases the passenger's waiting time since load reduction means the decrease in the number of passengers.
From the other point of view, by the increase in the arrival rate of passengers at stations, the load for vehicles will be increased and this will affect both waiting time cost of passengers and CO2 emission costs. For example, if the rate of passenger arrival becomes twice, then average waiting time's cost for the current routings will decrease to 280 Euro, which means a 20% cost reduction for passengers waiting times due to more boarding of passengers. On the other hand, passengers' increasing arrival rate leads to enhancing the load of vehicles twice. Calculation of the CO2 emission cost with the new amount of load determines 282 Euro as a CO2 emission cost, which is a 100% cost increment. Therefore, there is a dilemma for policymakers as two objective functions do not behave in the same direction in different possible scenarios. The main focus for strategy making is recommended to be the control of passengers' arrival rate to avoid the crowded buses.

5 Acknowledgment

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6 Conclusions

Public transportation in large cities has significant impacts on the environment, society, and economy perspectives. The proper management of public transportation creates paradoxical challenges for fulfilling the mutual service level for the passengers and the environmental considerations. This paper has studied the related literature and discussed the considerable gap for the fulfillment of mutual service level satisfaction and considerations for environmental emissions. By investigating the literature for assignment problem technique and multi-objective planning, the paper has proposed a model to enable the public transportation resource assignment with the considerations of tradeoffs for increasing public service satisfactions and meanwhile controlling the environmental emissions. The real data of Hamburg public transportation has been used to verify the capabilities of the platform. The designed case study supported the model validity and by the analysis of results, the main factor in the model is recognized to be the weight of buses. So, the model encourages the strategy makers for setting strategies for passengers' arrival rate to avoid the crowded buses.

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Appendix

Please find the GAMS codes as follows:

```
Set
i 'start nodes' /0*32/
k 'vehicles'   /1*3/
t 'period time' /1*2/ ;
alias (i,j); alias (k,m);
scalar
Tmax 'maximum allowable time (16hour=960 min) for driving'   /20/
Q /1000/;
$call gdxxrw.exe time.xls par=tt rng=sheet1!A1:AH34
parameter tt(i,j) distance of time data set;
$gdxin time.gdx
$load tt
$gdxin$call gdxxrw.exe distanceKm.xls par=d rng=sheet1!A1:AH34
Parameter d(i,j);
$gdxin distance.gdx
$load d
$gdxin
parameters
efCo2   'the amount of Co2 (kg) emitted per unit of oil consumed'   /2.7/
feK     'the amount (Liters) of fuel consumed while vehicle k is empty per 1 km'  /0.3/
feuK    'the amount (Liters) of fuel consumed based on additional load in the vehicle per 1 km'   /0.05/
Lij     'the average load carried between station i and j based on kg'     /600/
l(j)    'the rate of arrival of passengers at stations based on Poisson processes' /0 0,1 30,2 25,3 20,……14 25,15 30,16 15,17 10,18 8,1910,20 15,21 15,22 15,23 20,24 20,25 15,26 15,27 15,28 10,29 10,30 10,31 5,32 3/
```

s(j) 'service time (min) at stations' /0 0,1 6,2 5,3 5,4 4,5 4,6 3,7 3,8 4,9 4,10 4,11 4,12 5,13 4,….. 3,22 3,23 4,24 5,25 3,26 3,27 3,28 3,29 3,30 3,31 2,32 1/

Variables

x(i,j,t,k) "vehicle k travells from station i to j in period t"

y(j,t,k) "arrival time of vehicle k at station j at period t"

xy(i,j,t,k) "dummy variable for linearization"

Binary Variable x;

free variables

z1,z2,z;

Equation

objwait 'objective for minimizing waiting time'

objco2 'objective for minimizing co2 emitted in Kt'

Total 'Combination of two Objectives'

cons1 'constrain for constructing a tour in each period'

cons2 'constrain for creating continuity in aech period'

cons3 'constrain for relate each station to exactly one route in each period'

cons4 'constrain for eliminating sub-tour'

cons5 'constrain for expressing equality between time of arrival at station i and time of departure from station j'

cons6 'arrival time 1'

cons7 'arrival time 2'

cons8 'arrival time 3'

cons20

cons21

cons9 ' arrival time 4'

cons9 'constrain for determining the service times'

cons10 'constrain for determination of service times'

cons11

cons12 'y limit interval'

```
cons13   'y limit from lower bound';
*objective functions
objwait .. z1 =e= SUM ((j,t)$(ord(t)>1),abs( sum(k,y(j,t,k)) - sum(m,y(j,t-1,m)) - l(j)*(l(j)
    - 1)/2*(sum(k,y(j,t,k)) - sum(m,y(j,t-1,m)))));
objco2 .. z2 =e= SUM((i, j, t, k),efCo2*d(i, j)*(feK + feuK*Lij)*x(i, j, t, k));
Total..z =e= 0.06*z2 + 10*10*(1/60)*z1 ;
cons1(i,t,k) .. SUM(j,x(i, j, t, k)$(ORD(i)=0)) =l=1;
cons2(i,t,k) .. SUM(j,x(i, j, t, k)$(not sameas(i,j))) - SUM(j,x(j, i, t, k)$(not sameas(i,j)))
    =e=0;
cons3(j,t) .. SUM((i, k),x(i, j, t, k)) =e=1;
cons4(j,t)..sum((i,k)$(ord(i)<>ord(j)),x(i,j,t,k)*(y(i,t,k)-y(j,t,k))) =e=0;
cons5(i,j,t,k)..y(j,t,k)- x(i,j,t,k)$(ord(i)=0)*tt(i,j)$(ord(i)=0) =g=0 ;
cons6(j,t,k)..y(j,t,k)- sum(i,xy(i,j,t,k) + s(i)*x(i,j,t,k) + tt(i,j)*x(i,j,t,k)) =e=0;
cons7(i,j,t,k)..xy(i,j,t,k) - Q*x(i,j,t,k) =l= 0;
cons8(i,j,t,k)..Q*(1-x(i,j,t,k))+ xy(i,j,t,k) - y(i,t,k) =g= 0;
cons20(i,j,t,k).. xy(i,j,t,k) - y(i,t,k) =l=0;
cons21(i,j,t,k) .. xy(i,j,t,k) =g=0;
cons9(i,j,t,k) .. y(i,t,k) + s(j) + tt(i,j) =l= y(j,t,k) + Tmax*(1 - x(i,j,t,k));
cons10(i,j,t,k) .. tt(i,j)$(ORD(i)=0) =l= y(j,t,k) + Tmax*(1 - x(i,j,t,k)$(ORD(i)=0));
cons11(t,k) .. SUM((i,j),x(i,j,t,k)*(tt(i,j) + s(j))) =e= Tmax;
cons12(j,t,k) .. y(j,t,k) =l= 10;
cons13(j,t,k) .. y(j,t,k) =g= 0;
Option minlp = dicopt;
Option domlim = 10;
xy.L(i,j,t,k)=1;
y.L(j,t,k)=1;
Model transport /all/;
solve transport USING MINLP minimizing z;
display x.l, y.l, z1.l, z2.l,z.l;
```

Energy-efficient Supply Chain Design: Data Aggregation and Processing

Lucas Schreiber [1], Jan-Philipp Jarmer [1], and Josef Kamphues [1]

1 – Fraunhofer IML

Purpose: Due to changing customer requirements and political regulations more and more companies strive to optimize their energy efficiency in regards to products and processes. The optimization of processes within supply chain design (SCD) is one lever in this regard. Since required data is often not available, this paper elaborates how data can be generated on a suitable level of aggregation.

Methodology: In order to highlight the research gap, established energy measurement procedures as well as existing energy databases for procurement, production and transportation are analyzed and compared with data requirements for SCD tasks. Based on these findings, necessary methods and procedures for data preparation are presented.

Findings: Firstly, it is shown that addressing energy efficiency within SCD leads to new challenges in regards to data availability and preparation. Secondly, this paper elaborates the requirements for necessary data usable in the context of SCD. The findings are the basis for a comprehensive approach combining collection, aggregation and clustering of energy and product related data.

Originality: This paper works out the gap between usually available energy related information and the requirements of SCD. Since key conditions for optimizing energy efficiency are defined in strategic planning, the findings create a necessary prerequisite for realizing energy-optimized supply chains on a large scale in the future.

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1 Introduction

Energy and raw materials form the basis for the producing economy as well as for a consuming society. The competitiveness of manufacturing companies is therefore always closely linked to the availability of and demand for energy and raw materials. Decreasing reserves of fossil fuels, a globally increasing energy demand and a likewise strongly growing global demand for fossil and renewable raw materials are therefore leading to many challenges for companies. In recent years, companies have begun to rethink their way of business and ecological goals are increasingly being anchored in corporate strategies (Bidgoli 2010). Companies are not only concerned with the energy efficiency of the goods to be produced, but also with the energy efficiency potential of their value-adding activities in production and logistics. The relevance for including the energy aspect in this regard is illustrated by the following number: The production and transport sectors together account for 58% of final energy consumption in Germany (BMWi 2018). Potentials for energy savings are seen primarily in industrial processes that require process heat and mechanical energy, and in the area of freight transport.

Since the essential conditions for the later operation of a production and logistics network are defined within strategic planning, the so-called supply chain design (SCD), the greatest levers for reducing the required energy demand can be expected in these activities. The tasks of SCD include the determination of the production and logistics strategy, the choice of locations, volume allocation as well as the selection of modes of transport (Parlings et al. 2013). The quality of the specifications made in this regard mainly determines energy demand and costs for the products to be produced and transported in the supply chain. Thus, the possibility of being able to evaluate the energy effects of planning decisions in this area is a central prerequisite for being able to influence the overall energy footprint of a product at all.

Right now, companies normally use methods and tools based on Life Cycle Assessment (LCA), which is regulated in the ISO standard 14040 (Principles and Framework) and 14044 (Requirements and Guidelines), to describe the environmental impacts of the entire life cycle of production systems and services in detail (ISO 14040; ISO 14044). LCA studies are valuable but often not practicable as a regular data source for SCD due to their complexity. Over the past decade, initial research and development work has already taken place in the field of ecological assessment of production and logistics processes (see Cirullies et al. 2011; Bretzke 2014a; Lochmahr and Boppert 2014). However, the results achieved in this field are only being used to a limited extent in practice. The reasons for this are manifold and range from the lack of availability of relevant energy data to the lack of manageable models, methods and tools for the energetic evaluation of production and logistics networks. The aim of this paper is to present a solution approach to the challenge of energy-related data availability in strategic planning.

The availability of directly usable energy-related data is a crucial research aspect, as cost and energy do not have a 1:1 relation in their measurand. However, the availability of usable energy data is mandatory, as the implementation of an energy-efficient SCD aims to point out the positive and negative correlations of energy efficiency and cost minimization in the form of corresponding trade-off solutions (Bretzke 2014b). To begin with, the following chapter will show data requirements from a SCD perspective. In Chapter 3, these findings are compared with existing methods of energy measurement and with information from commercial or publicly accessible energy databases. On this basis, an approach for bridging the identified gap between energy-related data requirements and data availability in SCD is shown in Chapter 4. The paper concludes with an outlook on the existing challenges and further steps to finalize the approach.

2 Suitable Level of Aggregation for Supply Chain Design

This chapter aims to point out the necessary data requirements and data granularities for methodologically approaching SCD tasks. SCD consists of several individual design tasks, which influence each other mutually. Experiences from practice and literature show, that there is only a rudimentary consideration of these interactions, since individual planning approaches for the design tasks are integrated isolated from one another (Parlings et al. 2015). For each application area, different analytical and simulative approaches have been considered already, which can be applied as logistics assistance systems for the individual design tasks. If these methods are applied with the aim of improving energy efficiency, special energy measurement procedures are required to gather input data for the underlying target system. However, as the measurement methods do not gather energy related data which can be processed subsequently, further intermediate approaches have to be developed. The first challenge in designing an energy-efficient supply chain is thus to address the individual design tasks in combination and simultaneously detect the resulting dynamic interdependencies in production and logistics processes. The second challenge derives from the requirement to be able to use gathered energy data within the methodological approaches. Considering different measurement procedures with unsuitable data structures as an outcome create special demands on the integration capability of a planning methodology for energy efficient supply chains.

In previous research approaches it was outlined that a combination of analytical optimization methods and event-discrete simulation promises a high quality of results. A feasible way of solving this problem is the modularization of related SCD tasks, which generate partial solutions for individual task modules independently of each other using various analytical models. The SCD tasks can be divided into the areas of procurement, production and distribution. In a sequential feedback-based procedure, these partial solutions are evaluated by an event-discrete simulation, considering the interdependencies of the generated parameter configurations (Schreiber 2019).

In the course of the conception of the models, it was observed that the input parameters in classical SCD require specific forms of data aggregation in order to configure the models appropriately and to generate useful solutions. Since the integrated target values in the models in the literature are mostly cost-driven, a data analogy on the same level of aggregation is required to accomplish a transfer towards an energy-efficient SCD. For this purpose, an analysis of the cost-related input data used in the literature is provided to identify the required aggregation levels of the energy indicators to be included.

2.1 Procurement

In the area of procurement, the design tasks of partner selection and the sourcing process design are to be addressed particularly. Typical approaches often originate from the descriptive decision theory (Analytic Hierarchy Process, Promethee) or combine them with linear optimization.

Hruška et al. (2014) propose an approach based on the Analytical Hierarchy Process (AHP), Jain et al. (2018) add an Fuzzy component to the AHP and combine it with the Technique for Order Preference by Similarity to Ideal

Solution (TOPSIS). Furthermore the so called PROMETHEE method is used commonly (see Abdullah et al. 2019). Torğul and Paksoy (2019) combine approaches from the descriptive decision theory with linear optimization. From the given literature sources, as well as from operational experience, it appears that the following cost-related data granularity must be available for the appropriate use of these models. A differentiation is necessary to identify the current processing stage of the part to be procured. In the case of raw materials, the price per kilogram is usually decisive, whereas the price per piece is usually relevant for semi-finished products. The following common cost-related data granularities can be listed as follows:

- Order cost for one kilogram of raw material *p* from supplier *s* ($\left[\frac{€}{kg}\right]_p^s$)
- Order cost for one piece of a semi-finished product *p* from supplier *s* ($\left[\frac{€}{pc.}\right]_p^s$)

2.2 Production

The production branch in SCD is primarily relevant for the allocation of available capacities. The production and storage capacities of the production network must be used cost-optimally. Due to different machine parks and location conditions, the resulting operating costs can vary depending on the allocation within the network. The common problem-solving tools from the respective literature are linear optimization models. In mathematical modelling, the decision variables represent the production quantities of individual products, semi-finished products and raw materials at the different function areas at nodes of the network with respective destinations. Thus, the allocation of goods to the locations in the network is determined (see Tsao et al. 2018; Serdar and Al-Ashhab 2017; Sabri and Beamon 2000).

The identified models tend to integrate the transport costs in addition to the production costs. These are examined separately in the following section. The required cost-related data granularities of the production side in SCD are as follows:

-Variable production costs at function area f at production site i for product p $(\left[\frac{€}{pc.}\right]^{i}_{f,p})$

- Fixed production costs at function area f of production site i per period $([\frac{€}{period}]^{i}_{f})$

2.3 Transportation and Warehousing

The last relevant module to be considered is transport and warehousing. As already mentioned in the previous section, this area includes generic SCD optimization models which, in addition to transportation and warehousing, also address other relevant fields of SCD (see Lee et al. 2018; Zokaee et al. 2017; Paksoy et al. 2019). In addition, there are specific models which relate mainly to the improvement of transport and storage costs. In this context, the different types of vehicle routing problems or models focusing on the optimization of cross-docks or warehouses should be mentioned (see Lashine et al. 2006, Goodarzi and Zegordi 2016, Perboli et al. 2011). On the one hand, the relevant components of the input data are distance-related data and information on the transport type. Depending on the properties of the product (e. g. base unit) and the selected transport mechanism (e. g. container), a distinction is necessary, as the costs vary in this regard. On the other hand, similar to production, the operation of warehouses and the individual storage of products will lead to costs. The required input data granularities are as follows:

- Variable costs per ton kilometer per mode of transport m and product p ($\left[\frac{€}{tkm}\right]_p^m$)
- Variable costs per container per product *p* and mode of transport *m* ($\left[\frac{€}{TEU\ km}\right]_p^m$)
- Variable warehousing costs at function area f of product p at warehousing site *i* ($[\frac{€}{pc.}]_{f,p}^i$)
- Fixed warehousing costs at function area f of warehousing site i per period ($[\frac{€}{period}]_f^i$)

As the necessary cost-related input data for SCD models with their respective data granularities have been identified for the relevant areas of procurement, production, transportation and warehousing, the following Table 1 sums up the results of this chapter. The results will be revisited to derive the desired energy-related data analogy and the outcome is compared to the given energy data structures which will be shown in chapter 3.

Table 1: Cost-related data granularities for SCD approaches

Task	Description	Unit
Procurement	Order cost for one kilogram of raw material p from supplier s	$[\frac{€}{kg}]_p^s$
	Order cost for one piece of semi-finished product p from supplier s	$[\frac{€}{pc.}]_p^s$
Production	Variable production costs at function area f at production site i for product p	$[\frac{€}{pc.}]_{f,p}^i$
	Fixed production costs at function area f of production site i per period	$[\frac{€}{period}]_f^i$
Transportation and Warehousing	Variable costs per ton kilometer per product p and mode of transport m	$[\frac{€}{tkm}]_p^m$
	Variable costs per container per product p and mode of transport m	$[\frac{€}{TEU\ km}]_p^m$
	Variable warehousing costs at function area f of product p at warehousing site i	$[\frac{€}{pc.}]_{f,p}^i$
	Fixed warehousing costs at function area f of warehousing site i per period	$[\frac{€}{period}]_f^i$

3 Existing Energy Measurement Procedures and Energy Databases

After describing suitable level of aggregation for cost-related SCD, this chapter describes existing energy measurement procedures with linkage to specific data sources. A common way to visualize the energy consumption of products and services over their life cycle is the 'Cumulative Energy Demand' (CED) (VDI-Richtlinie 4600). The CED is considered to be the total of all energy inputs concerning the consumption of primary energy and results shall be expressed in joule (*J*) or multiples thereof, e. g. megajoules (*MJ*) or gigajoules (*GJ*). The score can be used instead of or in addition to detailed LCA approaches, which often take a wide range of impact or damage categories into consideration (see Kaltschmitt and Schebek 2015; Huijbregts et al. 2016; VDI-Richtlinie 4600).
In practice, the CED is subdivided into three phases: production, use and disposal.

$$CED = CED_P + CED_U + CED_D$$

As the phases use and disposal are normally not within the scope of SCD, this paper focusses on the production phase of CED with the mentioned transformation and distribution processes: procurement, production and transportation. In general, calculating the CED is a combination of different approaches covering primary or measured data, generic datasets or scientific estimations. Hence, there are always trade-offs between suitability of data concerning data accuracy and significance for energy-related SCD and data gathering expenditure necessary.

3.1 Procurement

As companies are not only concerned with the energy efficiency of the goods to be produced, but also with the overall sustainability of their products and actions, especially when sourcing input materials globally, the ISO standard 20400 'Sustainable Procurement' assists organizations in meeting their sustainability responsibilities (ISO 20400). The standard highlights the importance of taking energy consumption and energy efficiency as one dimension of sustainability into consideration when communicating to external stakeholders during procurement decisions.

Therefore, ISO 20400 is a valuable overarching framework for integrating the idea of energy efficiency in supply chains. But it is more a selective performance measurement of actions than a consistent energetic evaluation of procurement relationships. It also does not solve the lack of primary data.

For this, additional research and data gathering out of external data sources is necessary, e. g. Life Cycle Inventory (LCI) databases, statistical databases and literature values. In this context LCI databases serve as key data sources, because many LCI databases contain datasets about raw materials, which are sourced externally by the companies. A common LCI database for example is 'ecoinvent' (Wernet et al. 2016).

From this LCI datasets it is possible to calculate the CED, which was introduced at the beginning of this chapter. The primary energy used up to this point, e. g. for the mining, smelting and refining of a metal, can be derived. Some LCI databases also include datasets to identify the CED country- or region-specification for raw materials. This geographical coverage of different datasets for raw materials are of high interest for procurement decisions e. g. comparing a great number of suppliers in various regions for various raw materials. Hence, it is possible to calculate the region-specific (r) energy consumption for raw materials $[\frac{J}{kg}]_p^r$ or semi-finished products $[\frac{J}{pc.}]_p$. The challenge is that the origin and the suppliers of raw materials or the composition of (semi-finished) products are often not known or very vague.

Summing up, due to a lack of primary data in procurement, generic datasets are useful to describe transformation processes from an energetic perspective. Nevertheless, the connection between material related or region-specific energy information and logistics information for strategic network design to calculate the specific energy efficiency potential of procurement decisions is still missing.

3.2 Production

When considering energetic efforts of production sites in SCD, LCI databases also provide average datasets for branch-specific production processes. But these datasets are normally highly aggregated. Deriving the CED gives a first indication of the process energy consumption, but it is not suitable for deriving company specific energetic network decisions on that basis.

For this, it is necessary to gather more detailed information of the companies' network and production characteristics. While the European Energy Efficiency Directive requires the reporting of annual energy consumptions and the definition of energy saving measures (EED 2012/27/EU), the data collected in this way is not directly suitable for SCD. For example, smart metering systems are often obligatory when reaching higher annual electricity consumptions, e. g. >6.000 kWh in Germany (MsbG). But the challenge is, that usually only the global (g) consumption of the production site is measured and known $[\frac{J}{period}]_g^i$. Sometimes this is completed with energy consumption information or energy efficiency measures of single equipment in production facilities. Nevertheless, reliable data for production sites with their related function areas are missing to allocate the energy consumption to the following categories:

- Output independent base load (e. g. lighting)
- Output dependent load (e. g. sawing)
- Output independent additional load (e. g. pre-heating)

Summing up, due to a lack of primary data and data connection, product related energy indicators such as energy consumption per product $[\frac{J}{pc.}]_p^i$ and energy consumption per function area $[\frac{J}{period}]_f^i$ are missing for methodological approaches towards an energy-efficient SCD.

3.3 Transportation and Warehousing

After considering energy-related data gathering for procurement and production, the phase of transportation and warehousing is described from an energy-related perspective. Companies are able to derive primary data out of their transport management or warehouse management systems. For further processing, the Global Logistics Emission Council (GLEC) provides a globally harmonized framework with emission resp. energy consumption calculation methodologies for the transport modes air, inland waterways, rail, road and sea plus logistics sites (Smart Fright Centre 2019). For the transport mode 'road', GLEC refers to the European standard DIN EN 16258, which provides a methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers) (DIN EN 16258). For 'logistics site' it refers to the „Guide for Greenhouse Gas Emissions Accounting for Logistics Sites“, which gives additional information for the calculation of energy consumption and emissions at logistics sites (Dobers et al. 2019).

When primary data is not available, default values from public sources or other databases can be looked up. For example, the 'Handbook Emission Factors for Road Transport (HBEFA)' provides emission factors as well as fuel / energy consumption for all prominent vehicle categories, considering also different traffic situations (Notter et al. 2019).

Summing up, the energetic evaluation of transport is challenging, but by knowing a handful of characteristics it is possible to methodologically integrate respective data with variable energy consumption for transportation of general freight $[\frac{J}{tkm}]_p^m$ or container freight $[\frac{J}{TEU\ km}]_p^m$, while the allocation of the known global energy consumption of logistics sites $[\frac{J}{period}]_g^i$ can be more sophisticated.

Table 2 summarizes the given energy-related data granularities for SCD for the tasks procurement, production as well as transportation and warehousing.

Table 2: Given energy-related data granularities for SCD

Task	Description	Unit
Procurement	Energy consumption for one kilogram of raw material p from region r	$[\frac{J}{kg}]_p^r$
	Energy consumption for one average piece of semi-finished product p	$[\frac{J}{pc.}]_p$
Production	Global g energy consumption at production site i per period	$[\frac{J}{period}]_g^i$
Transportation and Warehousing	Variable energy consumption for transportation per ton kilometer	$[\frac{J}{tkm}]_p^m$
	Variable energy consumption for container transportation	$[\frac{J}{TEU\ km}]_p^m$
	Global g energy consumption at logistics site i per period	$[\frac{J}{period}]_g^i$

4 Data Gaps and approaches for bridging the gap

After describing the data granularity in cost-related SCD and the availability of energy-related data, Chapter 4 discusses the gaps between these two perspectives and suggests approaches for bridging the gaps in the phases of procurement, production and transportation and warehousing.

For the procurement of raw materials generic LCI datasets are useful to describe transformation processes from an energetic perspective. The datasets are available for different materials and processing stages for geographic regions and can be matched with the location of (potential) suppliers and additional information resulting from a structured 'supplier survey'. Then, the connection between material related and region specific energy information and logistics information (distribution processes) to derive the suppliers' CED is done with the help of a 'resource model' (Jarmer et al. 2020), considering global raw material flows.

When procuring semi-finished products, the composition is often not known, but crucial to determine the CED. On the one hand parts list could help to derive material compositions, on the other hand special material characterization, e. g. X-ray fluorescence (XRF) spectroscopy for metals, could help before using the mentioned 'resource model' for calculating the CED for semi-finished products and accordingly create an energy-related data analogy to the cost-related input data structures.

The steps for the transition from cost-related SCD-parameters to energy-related SCD-parameters for procurement are summarized in Figure 1.

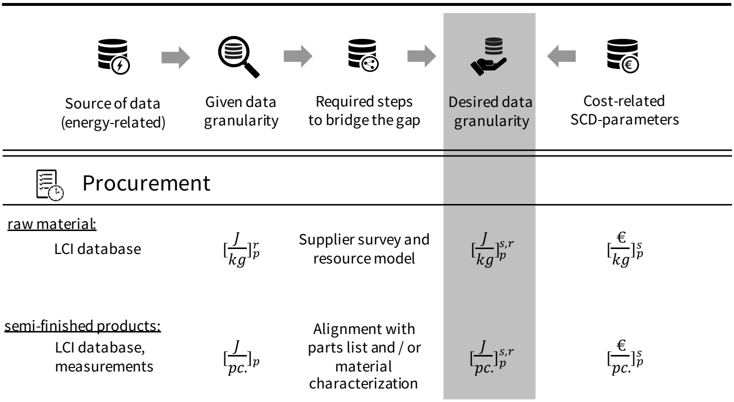

Figure 1: Bridging the data gap for procurement

To overcome the lack of primary data and data connection in the area of production to derive product related energy indicators such as energy consumption per product $[\frac{J}{pc.}]_p^i$ and energy consumption per function area $[\frac{J}{period}]_f^i$, a breakdown by function areas and equipment plus an alignment with the companies' individual production program is suggested. Keeping in mind that for a given production site i the global energy consumption is the sum of the defined function areas:

$$[\frac{J}{period}]_g^i = \sum_f^n [\frac{J}{period}]_f^i \ with\ f = 1, \dots, n$$

Analyzing the correlations and dependencies between energy consumption and the underlying production program (and possibly more parameters), serves to characterize the function areas and to integrate energy-related production data into SCD-approaches. Then, it is possible to prognosticate energy consumptions and plan the re-allocation of products to other facilities with different function areas / technologies from an energetic perspective. The steps for the transition from cost-related SCD-parameters to energy-related SCD-parameters for production are summarized in Figure 2.

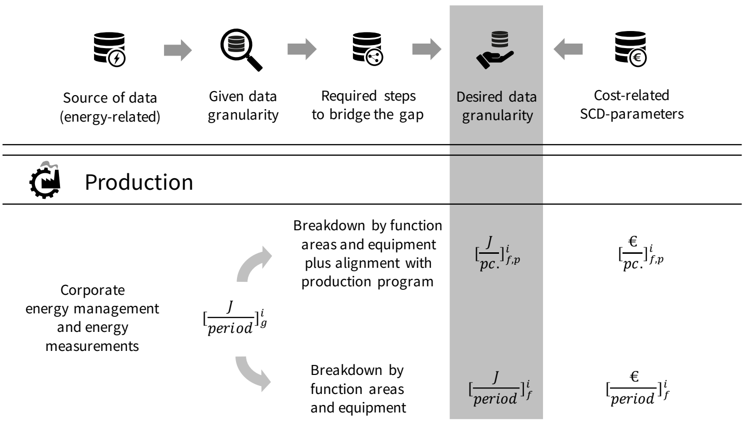

Figure 2: Bridging the data gap for production

Company specific data to characterize transport activities like distances of (potential) transport relations, (potential) tonnage or container as well as fuel consumptions are often available in the companies' transport management or corporate energy management department. On that basis, the energetic evaluation of transport is possible to derive the variable energy consumption for transportation of general freight $[\frac{J}{tkm}]_p^m$ or container freight

$[\frac{J}{TEU\ km}]_p^m$ for SCD-approaches. In order to define appropriate energetic parameters for warehousing activities, it is important to analyze the material flows within the function areas of the logistics sites (e. g. ambient or cooled areas), similar as described for production sites. When distinct data is missing, the default values of different databases, mentioned in chapter 3, are helpful. For further processing, the GLEC Framework is suggested as a guidance for the calculation and allocation of energy consumptions in transport and warehousing (Smart Fright Centre 2019).

The steps for the transition from cost-related SCD-parameters to energy-related SCD-parameters for transportation and warehousing are summarized in Figure 3.

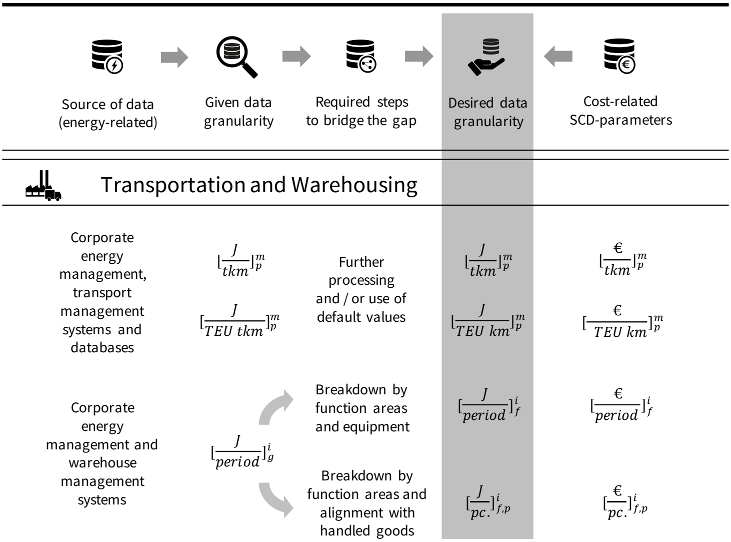

Figure 3: Bridging the data gap for transportation and warehousing

Considering the described steps, the original tasks of SCD including the determination of the production and logistics strategy, the choice of locations, volume allocation as well as the selection of modes of transport can be done from an energetic perspective.

5 Conclusion and Outlook

This paper revealed that the use of common SCD-approaches requires a considerable effort for the measurement, analysis and aggregation of energy data to enable the inclusion of energy-related target values. The creation of an energy-related data analogy to the cost-side data is essential to realize a holistic approach and to consider the component of energy efficiency in all areas of SCD.

In the area of procurement, it was found that the energy data for raw materials is available mostly region-specific. The problem is primarily due to the lack of transparency with regard to the exact origin of all components of the semi-finished product or raw material to be procured. To close the data gap, a material characterization (e. g. XRF) is proposed in order to identify the composition of the products and thus to identify the current energetic footprint already at the procurement stage. In the production area, energy data has to be gathered from the corporate energy management or measurements have to be conducted to collect raw energy data. The main problem with the non-suitability of the data is the lack of breakdown towards functional areas and individual products. Accordingly, a specific alignment analysis of measurement data and the production program must be performed in order to obtain the necessary data granularity. The area of transport is already well equipped with databases and frameworks, so that a data analogy can be created relatively easy. Similar to the area of production, warehouse energy-related data is difficult to break down into functional areas and onto specific products, which can be managed by comparing energy and stocking data.

The findings are the basis for a comprehensive approach combining collection, aggregation and clustering of energy and product-related data. The proposed data processing steps and methods will be tested and validated in further research on different use cases.

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II.
Maritime and Port Logistics

Modelling the IT and Business Process Landscapes at Inland Intermodal Terminals

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Purpose: A wide range of customer relationships, services and organizational interfaces characterizes inland intermodal terminals, which are hubs of combined transport. The purposes of this paper are twofold. The first is to highlight challenges of small and medium-sized enterprises (SME) at the time of digitalization. Secondly, approaches to illustrate the IT and business landscape are presented.
Methodology: This paper is based on a literature analysis as well as interviews and identifies aspects of SME- and branch-specific IT and business process landscapes of inland terminals. Moreover, approaches to visualize those landscapes are highlighted and a distinction is made between different software map types.
Findings: Inland intermodal terminals often use a variety of different small, sometimes self-developed IT solutions. Findings show a lack of means of communications and IT equipment as well as the interlinking of systems, which lead to media breaks and inefficient information flow. Therefore, approaches to visualize relevant processes and their application landscapes are presented.
Originality: Most literature focuses on larger terminals, which use terminal operating systems (TOS) to manage and link computerized applications efficiently. Due to the effort required to adapt TOS to operational conditions as well as resulting costs, these are often not an option for small and medium-sized terminals. This paper provides a basis for SMEs to systematically visualize and improve their IT and process landscape.

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1 Introduction

Economic growth and rising international trade is leading to growing transport volumes worldwide and thus to an increased load at transshipment hubs (UNCTAD, 2020). Seaport terminals as well as inland intermodal terminals, in which loading units are transferred between different modes of transport, are particularly affected. Inland terminals, as the interfaces of intermodal and combined transport, are challenged to meet the increasing demand for high-performing and cost-efficient operations (Ruile, 2018).

Inland intermodal terminals are often characterized by diverse customer relationships, services and organizational interfaces and, especially regarding small and medium-sized enterprises (SMEs), heterogeneous application landscapes using individual IT solutions. The challenge for many SMEs is to achieve a better and more coherent use of IT systems, aiming at integrating diverse business functions (Pighin, 2016). Therefore, IT and business process landscapes are to be further developed in the sense of a future-oriented digitalization. Within the framework of enterprise architecture management (EAM), various approaches to holistically consider the application and business process landscapes and their connections exist. First, the aim of this paper is to highlight general potential for improvement regarding the application landscapes at inland intermodal terminals. Then, adequate approaches to systematically represent complex application landscapes in SME companies are briefly discussed and selected tools are classified.

The paper is structured as follows. In Section 2, a brief overview of functional areas as well as IT landscapes within inland intermodal terminals is given. Then, Section 3 briefly touches on the methodology. In Section 4 the state of research and practice is addressed. Some approaches and tools to represent application landscapes are presented, before pointing out SME- and branch-specific requirements. Finally, further research perspectives are discussed.

2 Theoretical Background

The present paper is a preliminary result of a research project which aims at developing an IT reference model especially for SMEs in the field of application of inland intermodal terminals. Such a model is intended to support terminals in independently pursuing a systematic development of their IT and process landscape. The project therefore includes the identification of need for improvement, the derivation of recommendations and the development of suitable procedure models and tools in order to visualize and systematically improve the IT and process landscapes.
In the following Section 2.1, the basic functional areas within inland intermodal terminals are emphasized. Section 2.2 further deals with application landscapes.

2.1 Functional Areas within Inland Intermodal Terminals

The term intermodal transport defines the "movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes" (UNECE, 2001, p. 17). Combined transport describes intermodal transport where the main course of the journey is by rail or waterway and the pre- and/or post-carriage of the transport is by road (UNECE, 2001).
Inland intermodal terminals provide the operational environment, the space as well as the equipment for transferring transport units between the connected transport modes. Besides, the terminals can offer very different services, ranging from solely providing the transfer between two or three modes of transport (hence bi- or trimodal terminals), to providing various

value-added services (e.g. storage, empty depots, maintenance and repair). (Ballis and Golias, 2002) In addition, terminals also have a buffer function, i.e. they can store and retain goods for a certain period of time, which promotes flexibility in transport networks.
Moreover, several companies can be involved in a terminal. A distinction is usually made between owners, terminal operators and personnel service providers. Furthermore, affiliated companies or business partners, such as rail operators or haulage companies, can also be users of organizational interfaces. For more details, exemplary processes (e.g. pick-up by truck and delivery by train) can be found in Schwientek, et al. (2018). They conducted a desk research (based on websites of relevant logistic nodes as well as studies and reports) and visited intermodal terminals revealing significant differences between the functionalities as well as complexity.
Generally, there are different functional areas within an inland intermodal terminal, which can mainly be divided between the container yard as well as the operational areas (including the entry and exit area) for each of the modes of transport that are associated (Hervás-Peralta, et al., 2019). Figure 1 illustrates a generic representation of different functional areas.

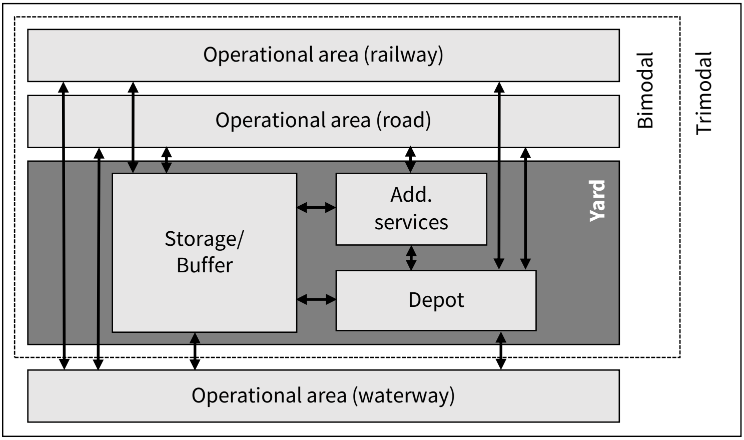

Figure 1: Functional areas within a terminal (based on Böse, 2007 according to Kaffka, 2013)

The functional areas may also cluster business operating activities. Ruile (2018) defines four clusters: order intake, resources, order execution and optimization. Order intake comprises "products and services offered to the market, the customer interface, as well as the sales process". Resources include inter alia the yard layout, handling equipment as well as financial and personal resources. Order Execution covers all necessary activities (processes) to fulfill the customer order. The planning and control systems of the terminal is described by optimization.

2.2 IT Landscapes at Inland Intermodal Terminals

The variety of tasks and services at terminals result in a complex process landscape, which, in SMEs, is often covered by individual IT applications and thus further increases the complexity of the IT landscape. Ruile (2018)

highlights, that even though the primary activities of terminals seem to be simple (load, unload and buffer) complexity rises considering the coordination of resources (people, equipment and space). Inefficient information flows in need of improvement result in inefficient operations. He points out that "the modularization of processes, the availability of smart communication technologies and the capability of module configuration offers opportunities for future process designs and related terminal operating systems."
In the following, core areas for terminals as well as exemplary areas of application for IT systems within are mentioned (Buhl and Schwientek, 2016):

(1) Storage (e.g. storage management)

(2) Input / Output (e.g. crane scheduling, gate operations, rail and barge operations, stowage planning)

(3) Administration (e.g. human resource planning, invoicing)

(4) Internal transport (e.g. resource planning and control)

(5) Management and IT (general support functions, e.g. information technology, decision support systems)

In recent years, a few comprehensive systems that control, monitor and handle processes at intermodal terminals were developed. While large companies are more likely to use a single terminal-wide IT system, a so-called Terminal Operating System (TOS), many SMEs use individual IT applications for various tasks. TOS may be considered as part of the Enterprise Resource Planning (ERP) family. However, they are rather specialized to the requirements of terminals than general ERP systems as they aim to bundle all administrative and operational tasks of the terminal in one system (Buhl and Schwientek, 2016).

There have been efforts in practice, especially in large companies, to deal with the management and strategic development of IT for some time. Since EAM developed simultaneously in different scientific disciplines in the early 1990s it does not yet have a generally valid definition. Lapalme, et al. (2016), for example, propose to understand enterprise architecture (EA) as consisting of the essential elements of a socio-technical organization, its relationships with each other and with its environment, and the principles of design and development of the organization itself. They define EAM as the continuous activity of describing and updating the EA in order to understand its complexity and manage its change. Within the framework of EAM, the application landscape, i.e. the IT systems, business processes and their interactions, are recorded and holistically documented.

3 Methodology

The general methodology of this paper is based on a desk research as well as on qualitative interviews to review the current state of research and practice.

A selection of search terms regarding keywords such as inland intermodal terminal (and similar terms like combined transport terminal, inland port, (container) handling terminal, transshipment terminal, multimodal terminal or inland waterway terminal) and their combination with further keywords like IT or software landscape and enterprise architecture, was used for database searching to review academic publications. The applied literature review framework is based on Moher, et al. (2009) by filtering after abstract and full-text reading and extended by snowballing search. The empirical research applied in the course of the underlying research project include group discussions, interviews and process mapping. Currently applied IT systems and processes were gathered on site at two terminals. In addition, further interviews with representatives and experts of the sector as well as a literature research provide an overview of IT landscapes at terminals. To allow an extensive overview, not only SMEs were considered, but also larger terminals and more comprehensive systems like TOS. SME and branch-specific challenges are derived from this step (see Section 4.2). Moreover, suitable visualization approaches for IT and business landscapes are identified.

4 State of Research and Practice

Trends in the technological as well as market environment regarding TOS were highlighted by Lee and Meng (2015), further pointing out that evaluation and testing of TOS requires high costs and time. Therefore, TOS are often not an option for SMEs due to the large range of functions, the high adaptation effort (especially during ongoing operations) and the associated costs for acquisition, adaptation, maintenance and further development. Smaller handling terminals tend to use a variety of different IT solutions, some of which may be developed in-house. Moreover, some processes may even be carried out solely paper-based or without suitable IT support and therefore causing inefficient and error-prone media breaks. Data consistency and transferability between the different systems are not always given. For example, terminals maintain medium or long-term business relationships with many companies, such as haulage or rail companies, but also with personnel service providers or operating companies. The communication between the terminals and the business partners is often still carried out by e-mail or telephone or via systems of business partners. This leads to a high expenditure of time and to a degree of complexity in use, since these systems often differ in their requirements and operation. Furthermore, the use of different systems leads to a lack of flexibility in the event of changes in operational processes and an increase in data redundancy and inconsistencies. Ruile (2018) shows, based on a multi-case study, that efficiency of multi-modal inland terminals, as part of a highly fragmented network with diverse actors, strongly depends on collaboration regarding the information flow within the order and execution system as well as standards in services and procedures.

Although the number of business processes and IT systems of SMEs is significantly lower than in large companies, their heterogeneous application landscape and the variety of technical interfaces result in a high degree of complexity (Aarabi, et al., 2011). This is particularly problematic because the documentation of the application landscape is often inadequate (for instance due to time or budget constraints or a lack of knowledge of methods and tools). Furthermore, the lack of employees trained for this purpose makes it difficult for companies to adapt complex management processes or software tools adequately on their own (Bernaert, et al., 2014; 2016).
Interviews with representatives of the sector and terminals emphasize that there is currently a need for improvement regarding the business and IT landscape at SME terminals. The challenges are varied, starting with the systematic identification of existing processes, the creation of interfaces to external systems that are often still missing or insufficient, the adaptation of systems to the required flexibility and services and the investment costs for the respective systems.

4.1 Enterprise Architecture and Visualization Tools

Buckl, et al. (2007) outline the importance of visual models of the EA to make the information more perceivable. They further identify issues in utilization, based on an extensive survey of existing modeling tools for EAM. Further, Ernst, et al. (2006a) describe strengths and weaknesses of EAM tools. In the following, the visualization of EA is dealt with based on a literature review focusing on EA modeling approaches that can be used to support the documentation, planning as well as evaluating of the application landscapes.

For example, software cartography aims to systematically represent complex application landscapes in companies by using the knowledge and methods of cartography and thus to facilitate the description, evaluation and designing of application landscapes. Fundamental principles of software cartography, an approach for EA modeling, can be found in Lankes, Matthes and Wittenburg (2005). So-called software maps are based on a layering principle. The lowest level (base map) visualizes (several) instances of different object types (such as process steps, functional areas etc.) depending on the map type and is built up according to the application purpose (Ernst, et al., 2006b). Lankes, Matthes and Wittenburg (2005) have derived different types of software map types. These differ in the underlying structure of the map base, the objective pursued with them and the editing process (automatic vs. semi-automatic vs. manual). Based on this, Wittenburg (2007) derives a visualization model for software maps, which among other things consists of design tools and rules and defines relevant characteristics of application landscapes. For example, a process support map can express the assignment of IT systems to business processes and can be enriched with the interconnections between the IT systems and other key figures and metrics, such as planned usage time or downtime of the IT systems. Figure 2 shows this layered principle. Layers can be used to adjust the information density and together they form an overall map.

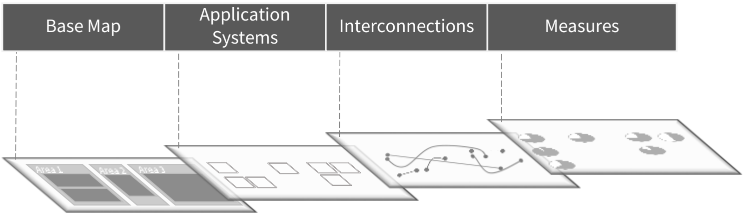

Figure 2: Layering principle of a software map (based on Lankes, Matthes and Wittenburg, 2005)

Several different visualization tools use a cartography metaphor to illustrate information. For example, software visualizations in reverse engineering can be found using elements of cartography (Loretan, 2011). Jeffery (2019) presents a number of tools using the city metaphor to visualize program code. These code cities feature three-dimensional views, several tools offer a virtual reality approach. The visualization of software in reverse engineering comprehends huge amounts of data and is driven by size and complexity (Lanza and Ducasse, 2003). EAM follows a different approach. EAM tools aim to support IT managers to align business and IT (Matthes, et al., 2005). EAM tool surveys (e.g. Matthes, Hauder and Katinszky, 2014; Matthes, et al., 2008; Matthes, et al., 2005) create an overview of various tools in a still growing market, which were investigated with a scenario based approach. The surveys consider the specific functionality (such as creating visualizations of the application landscape or usability) as well as specific EAM support, e.g. landscape or application architecture management. Whether the tools support the creation of certain types of software maps, such as cluster maps, process support maps or time interval maps, is answered. The following Table 1 lists a few tools, classified regarding their capabilities to create visualizations concerning different types of software maps (see

Matthes, Hauder and Katinszky, 2014; Matthes, et al., 2008; Matthes, et al., 2005).

Table 1: Visualization tools regarding the support of software map types

	Type of map		
	Cluster	Process support	Interval
Description	Uses logical units such as organizational units, functional areas or geographic locations; groups application systems into these units.	Shows which business processes (linearly ordered sequence of processes) are supported by which applications.	Representing the time spans (as bars) of e.g. projects or lifecycle phases of applications.
Exemplary tools (and Vendor)	Architect (BiZZdesign); LeanIX (LeanIX GmbH); MEGA Modeling Suite (MEGA International SA); Iteraplan (iteratec)	Architect (BiZZdesign); MEGA Modeling Suite (MEGA International SA); PowerDesigner (SAP Sybase)	LeanIX (LeanIX GmbH); MEGA Modeling Suite (MEGA International SA)

It should be noted that this list is not exhaustive, due to the large number of existing tools. Table rather indicates the variety of tools with multiple approaches of creating visualizations. Most of the tools mentioned provide the possibilities to create software maps with an easy handling, though some visualizations require manual effort or need to be adapted by the user, e.g. by using scripting capabilities. For further information, please refer to Matthes, Hauder and Katinszky (2014).

4.2 SME- and Branch-specific Requirements

The documentation of the application landscape, e.g. with the help of software maps, is a common procedure in EAM for the analysis, coordination and planning of the development of those landscapes. However, EAM is generally used in larger companies. Hanschke (2016), for example, only recommends EAM above a certain size (for medium-sized companies with a very large number of diverse IT applications). Often these EAM approaches are not feasible for SMEs, e.g. because they do not have the necessary financial and human resources and experience for these approaches. New, extensive projects for adjustments and strategic alignment of the system during operation and the development of new knowledge are usually not manageable (Lange, et al., 2014). In order to support SMEs and their integration of individual IT sub-systems into a coordinated overall system, a simple and low-cost procedure model is required, which the SMEs can use as a guideline. In Section 2 it is shown that terminals are characterized by a wide range of customer relationships, services and organizational interfaces, which may lead to heterogeneous IT structures. IT and business process landscapes therefore should be developed in the sense of future-oriented digitalization and thus to establish agility with regard to changing framework conditions and requirements for digital interfaces to partners in the maritime transport chain. Professional IT management is a challenge or not possible due to financial and human resources. In order to further develop the IT and business process landscapes, methods and models for the description and design of application landscapes of handling terminals are relevant. Therefore, an overview of visualization approaches and tools was given in Section 4.1. For the application case of an IT reference model for inland intermodal terminals, it is advisable to refer to functional areas (e.g. as shown in Section 2.1) as a base map. This allows an adjustable representation of the individual functional areas, but also the simple selection and deselection of certain additional services or processes by means of appropriate filters. The positive emphasis on cluster maps was confirmed by feedback from the industry in a discussion round. A visualization based on layers which map relevant aspects like interconnections and measures (that can be shown or hidden as required) would moreover be beneficial. The selection of a suitable software for the creation of software map is necessary. Ease of use and availability as well as comparatively low costs are of particular importance.

5 Conclusion and Future Research

Especially small- and medium-sized inland intermodal terminals still use a variety of different small, sometimes even self-developed IT solutions. Findings show a lack of means of communications and IT equipment as well as the interlinking of systems, which lead to media breaks and inefficient information flow. The paper therefore highlights the potential of comprehensive IT systems. It becomes apparent, that larger terminals widely use comprehensive TOS for managing their IT landscapes. Due to the efforts and costs which are required to adapt TOS to operational conditions, TOS are often not an option for small and medium-sized terminals. Therefore, potential for improvement and approaches to visualize relevant processes and their application landscapes are presented. In the course of this paper, branch-specific requirements and suitable visualization approaches for the demands of the user domain were highlighted. This paper provides a basic approach for SMEs to systematically visualize and improve their IT as well as business process landscape using multi-layered software maps.

The aim of the next project steps is to coordinate with relevant partners in practice in order to ensure the suitability and practicability of the software map types and software for mapping their business and IT processes. It is necessary to develop and define design rules based on the current state of science for creating clear and quickly comprehensible models for this particular application case. In order to make the model as universally valid as possible, it is essential to consider different inland intermodal terminals.

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Impact of Port Layouts on Inter-Terminal Transportation Networks

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Purpose: Major seaports consist of several terminals with different functions. The different locations of terminals in relation to each other influences the organization of inter-terminal transportation as well as transports into the hinterland. The focus of this study is to understand how terminals are arranged in relation to each other to draw conclusions about the effect of the terminal locations on processes and transports.

Methodology: The paper provides a comprehensive overview for the locations of terminals and depots within a port. Based on this, a detailed analysis is carried out to develop a classification scheme for ports, which categorizes them according to their geographical characteristics.

Findings: Based on the examples of characteristic ports and terminals, we provide findings regarding advantages as well as barriers to transport containers within ports**.** The aim is to determine the impact of geographical characteristics of ports for handling port-internal traffic.

Originality: The existing literature provides an overview of ports and maritime networks, as well as various port concepts. Furthermore, different approaches for the design of container transports between terminals are discussed. However, there is no overview of the geographical location of terminals and depots in ports and their impact on inter-terminal transportation.

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1 Introduction

Global maritime trade keeps growing and underlines its importance for the global economy. The United Nations Conference on Trade and Development (UNCTAD) expects average annual growth of 3.4 percent between 2019 and 2024, largely driven by the increase in containerized goods (UNCTAD 2019). In this context, a sustained growth in the size of container vessels has been taking place in the last few years. By deploying even larger vessels, shipping companies are profiting from the economies of scale by saving operating and personnel costs. As a result, only selected container terminals (CT) in the major seaports, which have sufficient space and depth on the quay as well as suitable equipment for handling the container giants, can be called at. However, large seaports typically consist of multiple terminals with different handling equipment as well as different types of hinterland connection (Tierney et al. 2014). Terminals that are suitable for handling large container vessels often serve as so-called transshipment nodes, from where the containers are transported to adjoining terminals for onward shipment. These transports between terminals as well as terminals and other logistics nodes in a port are called inter-terminal transportation (ITT), in which trucks are the dominant transportation mode (Kopfer et al. 2016).

A further consequence of growing vessel sizes is the decrease in frequency of terminal calls and the increase in handling volume per call, which results in an additional coordination effort to handle ships in the terminals. In addition, different geographical and structural characteristics affecting intra and inter terminal operations have to be taken into account when handling container vessels at terminals (Ramírez-Nafarrate et al. 2017).

This paper compares and classifies large seaports with regard to their geographical structures and creates an approach to draw conclusions about ITT based on this classification. First, chapter 2 provides drivers for the development of seaport container terminals and gives an overview of the relevant literature. The method by which the relevant seaports are selected is introduced in Chapter 3. Chapter 4 presents the literature classification, including possible forms of the individual categories. Furthermore, the analysis of seaports is given in chapter 4, followed by a detailed presentation of selected ports in chapter 5. The paper closes with an analysis of the results obtained by applying them to the performance of ITT. At the end, a conclusion is given and future research topics are outlined.

2 Seaport Container Terminals

Seaports with their container terminals are a central part of this research. Chapter 2 introduces the development of seaports in port industries to analyze the relationship between the terminals and to identify useful categories for classification. This includes the presentation of relevant papers and related works.

2.1 Developments of seaport terminals in port economics and competition

Seaport Container terminals are important nodes in the maritime supply chain and operate as an interface between the modes of transport water, rail, and road (Gharehgozli et al. 2016). Especially large seaports are in tough international competition with each other. The performance of a seaport depends on its contribution to the successful operation of the overall supply chain. One criterion for success is the competitiveness of ports, which is strongly determined by their accessibility, besides other factors (Notteboom et al. 2005). However, increasing handling volumes also require an adjustment of port management and hinterland processes. There are three main aspects that are currently influencing the port industry (UNCTAD 2019):

(1) Globalization and supply chain integration of the port industry

(2) Pressure to reduce costs and optimize processes

(3) Trend of growing ship size

Ship routes mainly run along large hubs. Even though ports have been upgraded in recent years and new CT have been built in many areas, the number of dominant ports is limited. The position of a seaport in international competition is also determined by its vertical integration of upstream and downstream logistics processes (Ducruet 2015).
The existing competition between terminals requires fast and smooth handling of containers to and from ships. Due to the continuing growth of global maritime trade, many terminals worldwide are operating at their capacity limits and at the same time there is considerable pressure to increase terminal throughput and shorten ship turnaround times. To overcome the geographical limitations of many ports, a continuous optimization of their performance is necessary. Thus, the relevance of optimizing terminal internal processes is constantly increasing (Bish et al. 2005).
Aspects such as the ability to handle ultra-large container ships are increasingly important. The largest container ships currently have a loading capacity of just under 24,000 TEU (Moore 2020), although an end to the size trend is still not in sight. Experts estimate that the ships could reach a size of up to 30,000 TEU by 2025 (Malchow 2017).

2.2 Background

Several publications have dealt with different aspects of the development of seaports and terminals in port economies and in the field of competition. A well-known conceptual model of port development is Bird's Anyport Model, which describes the spatial and temporal development of traditional ports. According to this model, port development takes place in three phases: settlement, expansion and specialization. Historically, most ports were built adjacent to the city center and have been increasingly expanded through maritime development and improved cargo handling facilities. Due to the specialization in cargo handling and the incipient growth in ship sizes, the areas had to be further expanded and, due to lack of space, extended to remote locations (Bird 1980). This model has been extended over time by various scientists, such as Notteboom et al. (2005), to include additional phases.

A number of publications also deal with competition between terminals or seaports. For example, Malchow and Kanafani (2004) examine the question of which factors influence the choice of ports and how ports compete with each other. In addition, the authors analyze in their paper which strategies ports pursue in order to increase their market share. Furthermore, Notteboom (2016) examines the capacity expansion of container terminals along rivers to maintain their competitiveness (Notteboom 2016). Sanchez et al. (2011) investigated the attractiveness of ports based on a factor analysis, whereas Ng (2006) applied an extended survey analysis (Ranking and causes of inefficiency of container seaports in South-Eastern Europe).

Geerlings et al. (2017) offer a general overview of ports and maritime networks including definitions, functions and the presentation of different port concepts. Steenken et al. (2004), or Gharehgozli et al. (2016) give an overview of the operation of seaport container terminals and describe their logistical processes and procedures including further information on transport and handling equipment.

In addition, several studies have examined container transport within ports and container terminals (see Heilig and Voß 2017; Gharehgozli et al. 2017; Tierney et al. 2014).

3 Methodology

Given the background described in the last section, this paper addresses the follow-ing research question:

(1) Which regional similarities and differences exist in the structure of container ports?

(2) How do regional characteristics effect transports between the terminals (ITT)?

In this section we present the procedure by which we have selected and analyzed the most important global container ports.

The most important trade routes in global container traffic run along the east-west container trade lane. The three main trade routes as shown in Figure 1 are Asia-Europe, the Trans-Pacific route, and the Transatlantic route (UNCTAD 2019). This can also be seen from the location of the major container ports (Figure 2).

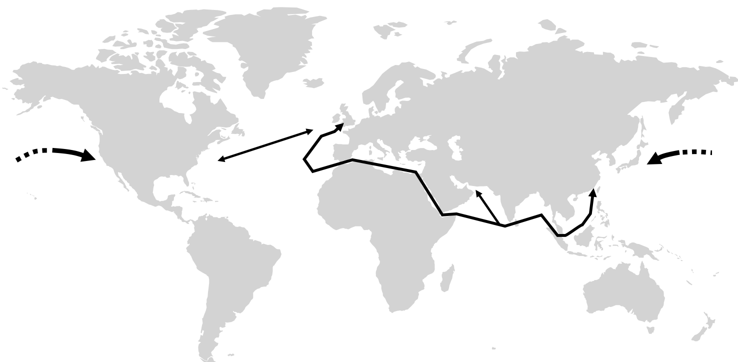

Figure 1: Main global trade routes

Both figures illustrate that Asia plays a central role in global maritime trade. Accordingly, 15 of the top 20 container ports are located in Asia. In order to obtain a comprehensive overview of the characteristics of container terminals, we analyzed the major seaports of the world. The study focuses on industrial and emerging countries whose ports have a state-of-the-art standard in terms of handling volume and technical equipment. As there are large regional differences in the volume of containers handled, we have structured the analysis according to continents. The 10 largest ports in Asia, Europe and America, as well as the four largest ports in Australia, are taken into account. On the African Continent, we chose the three most relevant ports. Figure 2 illustrates the location and shipping volumes of each port included in the investigation (Lloyd's List 2019).

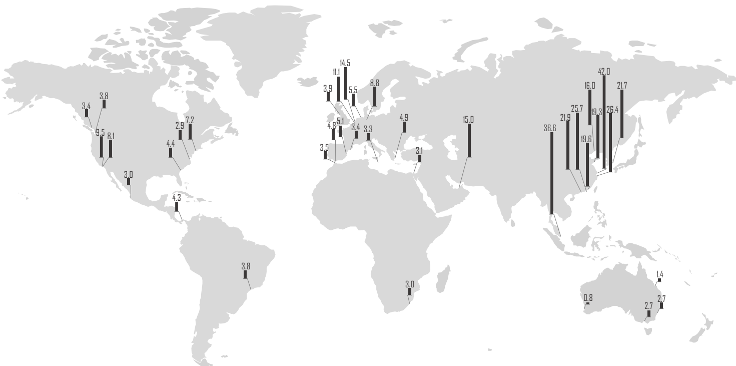

Figure 2: Selected ports and their TEU throughput in 2018 (in million TEU)

The methodology of the paper is structured as follows: The first step was to carry out a data analysis, in which the total transshipment volumes of ports on each continent were determined by TEU. Thus, the 10 ports with the highest turnover per continent could be determined. For Africa and Australia, we identified three, respectively four ports which showed a significant transshipment volume. All the collected datasets refer to the reference year 2018. Datasets were collected for each of the 37 ports. In the second step we used satellite images using material from OpenStreetMap (Openstreetmap 2020). The analysis of the satellite images was supported by online search, i.e. by visiting the homepages of each port. Based on our findings we have developed a classification scheme with individual characteristics for each category.

4 Analysis of Port Layouts

This section shows the classification of the analyzed container ports, so that a continental comparison can be made. The classification scheme is divided into six categories, shown in Table 1. The individual specifications of the categories are assigned to numbers, which are used in the classification table. Whenever several criteria are applicable (e.g. a port has terminals at the river and the coast), the criterion with the highest level of agreement is highlighted and the other criterion is marked with a dotted line.

Table 1: Classification categories with their specifications

Category	#	Specification	Category	#	Specification
Number of CT	1	Less then four	*Positioning of CT*	1	Adjoining
	2	Four to six		2	Lined up
	3	More than six		3	Spread out
Annual container volume (Million TEU)	1	Less then five	*Average distance (km) between CT*	1	Less then ten
	2	Five to ten		2	Ten to twenty-five
	3	Ten up to twenty		3	More than twenty-five
	4	Twenty or more			
Location of CT	1	Along coast / river	*Infrastructure between CT*	1	Mostly public
	2	Around bay		2	Mostly dedicated

The **Number of CT** is categorized in up to three terminals, four to six and more than six. The largest port (Busan) contains ten container terminals.

The **Annual Container Volume in TEU** gives an overview of the shipping volumes per year. We categorized them in the following clusters: Less than 5m TEU; 6m-10m. TEU; 10m-20m TEU; more than 20m TEU.

The **Location of the CT** can be classified depending on whether they are located on the coast-side or a river. Some ports have terminals that match with both categories. In these cases we have marked the criterion that the majority of terminals meet and the other criterion is marked as being partially fulfilled.

With regard to the **Positioning of the CT**, three main types can be distinguished. The first type consists of a continuous row of terminals, this means that there are no clear lines between the terminals and the terminals appear as one large terminal. However, most of these types involve different operators and have several entrances and exits. The second type comprises connected terminals. We defined terminals as generally connected when they are located in less than 1 km linear distance to each other. Above 1 km distance, we considered the terminals as spread out.

The **average distance between CT** considers the distance when using transport infrastructure, i.e. road transport. We categorized the terminals in the clusters: less than 10 km; 10-25 km; more than 25 km.

Furthermore, we categorized the terminals whether the used infrastructure is public or private (**Infrastructure between CT**).

In the following, the individual ports, sorted by continent, are analyzed in detail (see Table 2 to Table 6).

Container port handling in Africa will grow by 1.8 percent in 2018 compared to 2017 (UNCTAD 2019). Nevertheless, African ports play a subordinate role in international container traffic, as can be seen in Table 3. Africa has three major ports with more than one container terminal, all of them with annual throughput of around 3m TEU in 2018.

Tangier Med, Africa's largest container port is located in Morocco on the Strait of Gibraltar and has four lined up container terminals. Port Said is notable for its location and the distance between its terminals. Durban is the only port in Africa considered to have dedicated infrastructure between terminals (see Table 2).

Table 2: Classification of African ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Marokko / Tager Med	■					■		■			■		■			■	
Port Said	■				■			■				■			■	■	
Durban	■				■			■			■		■				■

Comparing the ports of America, it is apparent that container handling on the continent is largely dominated by the United States: Six of the ten largest ports are US ports. These include New York/New Jersey, Savannah and Virginia on the Atlantic coast and Los Angeles, Long Beach on the Pacific coast. With regard to the annual transshipment volume, none of the ports meets the category 3 or 4 (10m. or more TEU per year) (UNCTAD 2019). Most of the ports have few terminals – Los Angeles is the only port that contains 7 CT. The terminals at the port of Savannah are located in line and directly adjacent to each other. Therefore, the terminals are connected via non-public roads. Every other port uses public infrastructure for inter-terminal transportation (see Table 3).

Table 3: Classification of American ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Los Angeles		■					■		■	■			■			■	
Long Beach		■				■			■	■			■			■	
New York/ New Jersey		■				■			■			■		■		■	
Savannah	■				▤			■			■		▤				■
Colòn	■				■				■			■	■			■	
Santos	■					■		■				■		■		■	
Seattle	■					■			■	■			■			■	
Vancouver	■					■			▤			■		■		■	
Manzanillo	■				■				■			■	■			■	
Virginia	■					■			■			■	■			■	

In recent years, Asian ports have grown rapidly. In 2018, Asian container ports will increase at a rate of 4.4 percent, with throughput rising by 7.6 percent compared to 2017. With Shanghai, Asia has the largest container port in the world. In 2018 Shanghai had an increase of 2m TEU in container port traffic (UNCTAD 2019).

The importance of the Asian ports is highlighted by the container throughput in 2018. Six of the ten ports in Asia have an annual container throughput greater than 20m TEU. Shanghai has by far the largest throughput with 42m TEU, followed by Singapore with a throughput of 36.6m TEU. Ports seven to ten still have a high container throughput with a minimum of 14.95m TEU (Dubai) (Lloyd's List 2019).

It can be seen that the Asian ports all have more than four container terminals and almost half of the analyzed ports have more than six (see Table). The terminals are mainly spread out, which can be explained by the growth in throughput and the associated expansion or relocation of ports. Thus, average distances of more than 25 km between the ports occur in some cases. Only three of the ports analyzed have (mainly) dedicated infrastructure between them, as shown in Table 4.

Table 4: Classification of Asian ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Shanghai				■			■	■				■			■	■	
Singapore				■			■	■				■	■				■
Ningbo-Zhoushan				■		■		■				■		■		■	
Shenzen				■		■			■			■		▤		■	
Guangzhou				■		■		■				■			■	■	
Busan				■			■		■			■	▤				▤
Hong Kong, China			■				■	■		■			■				■
Qingdao			■			■			■	■			■			■	
Tianjin			■			■			■			■	▤			■	
Dubai			■			■		■				■		▤		■	

As shown in Table 5, the major Australian container ports have a comparably small container throughput. Melbourne, Australia's largest container port, is ranked 59th in the world in 2018 with a throughput of 3,018,671 TEU.

In total, Australia has only four container ports with more than one terminal. However, all Australian ports have less than four terminals, which are located close to each other. The terminals in each port are linked by public roads (see Table 5).

Table 5: Classification of Australian ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Melbourne	■				■			▤				■	■			■	
Botany	■				■				■	▤			■			■	
Brisbane	■				■			■			■		■			■	
Fremantle	■				■			■			■		■			■	

The ten largest ports for container handling in Europe are listed in Table 6. The largest port is Rotterdam (Netherlands) with 14.51m TEU in 2018 followed by Antwerp (Belgium) with 11.1m TEU (UNCTAD 2019). Both ports are located at river mouths on the North Sea coast of their countries. In addition, the ports are located relatively close to each other - the distance between the ports is slightly less than 100 km via the main transport routes. The ports of Hamburg, Bremerhaven, Felixtowe also have a connection to the North Sea and are located close to economically strong regions in Central Europe (e.g. Greater London in Britain or the Ruhr Area in Germany). The ports of Valencia, Piraeus, Algeciras, Barcelona and Marsaxlokk, on the other hand, are located in the Mediterranean and thus have a direct connection to the important sea route to Asia via the Suez Canal. Except the port of Rotterdam, which has two small terminals located in the city center and most of its deep-sea terminals at the coast, all of the European ports have terminals that are located less than 10 km to each other.

Table 6: Classification of European ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Rotterdam			■				■		▤			■		■		■	
Antwerp			■			■		■				■	■			■	
Hamburg		■				■		■				■	■			■	
Bremerhaven		■			▤			■			■		▤				■
Valencia		■			■			■		■			■			■	
Piräus	■				■			■		■			■				■
Bahía de Algeciras	■				■				■	■			■			■	
Felixstowe	■				▤			■			■		▤				■
Barcelona	■					■		■		■			■			■	
Marsaxlokk	■				■				■	■			■				■

5 Selected Terminal Examples

In chapter 5, one selected seaport each from Asia, America and Europe is presented in detail. The positioning of CT has a major influence on logistic activities, like the ITT. Differences in the ITT occur because of the properties of a seaport, e.g. positioning, location, infrastructure between CT. In order to underline the impact on the ITT, specific characteristics of the seaports are discussed and the location of the terminals is illustrated in detail. Furthermore, local concepts for the ITT are outlined by means of the given examples.

5.1 Port of Rotterdam

The Port of Rotterdam is the largest port in Europe. It contains seven container Terminals. Five of the terminals (1-5) are located on a man-made peninsula at the mouth of the river Nieuwe Maas which is part of the Rhine delta (Figure 3).

Figure 3: Location of Container Terminals in the Port of Rotterdam

The terminals 6 and 7 are located near the city center. The average distance between the terminals at the peninsula is 7.2 km. Including the terminals 6 and 7, the average distance increases to 20.3 km.

The deep sea terminals are connected to the city of Rotterdam via the N15 highway. The N15 then becomes the A15 motorway, which forms an important link between the port of Rotterdam and the German Ruhr area. The A15 is an important import and export axis and is therefore used to a large extent by commercial traffic. Furthermore, over 400 international rail connections run from and to Rotterdam. Especially for the transport of containers, general cargo, dry bulk and, chemical products the rail connection is suitable. The goods can be transferred directly onto a train at various terminals.

Short transit times also make the connection attractive. By rail, the goods reach the German border within 3 hours. Other European destinations can be reached within 24 hours. Within Rotterdam, the port offers a neutral rail solution for the exchange of containers between the deep sea terminals and the intermodal terminals (Port Shuttle service). For the exchange of containers between the deep sea terminals, the port is currently constructing a container exchange route that links the container companies and further reduces the costs of container exchange. The container exchange route is used to transport containers on the Maasvlakte using a dedicated road network. Autonomous vehicles move the containers between all terminals, container depots, and distribution centers and customs facilities through the dedicated network. The container exchange route is expected to handle over one million containers per year when it opens in late 2021. (Port of Rotterdam Authority 2020)

5.2 Port of Busan

Busan Port is located on the southeastern tip of the Korean Peninsula. With a throughput of 21.7 million TEU, Busan Port is the largest container port in Korea and the sixth largest container port in the world in 2018. The Port of Busan has ten container terminals in total, divided into two areas: Five of the terminals are located in Busan New Port (1-5) and five in Busan North Port (6-10) (see Figure 4).

Figure 4: Location of Container Terminals in the Port of Busan

Due to lack of space and limited geographical expansion possibilities of Busan North Port, Busan New Port was opened in 2006. The distance between the two port areas is 25 km straight line. Busan New Port is located to the west of the Naktong River estuary in a deep, protected bay, outside

the city center, and Busan North Port is located to the east of the river estuary in the middle of the city center of Busan.
A "hinterland road" connects both port areas. It runs from Busan New Port to Busan North Port via the South Port Bridge and the North Port Bridge. Both bridges were built especially for port traffic, the overall hinterland road runs outside the city. In addition, Busan New Port has its own road and rail network for the transportation of containers.

5.3 Port of Savannah

The Port of Savannah is the fourth largest port in America, behind the ports of Los Angeles, Long Beach and New York/ New Jersey, with a throughput of 4.1m TEU in 2018. The port is located at the east coast of the USA in the state Georgia at the Savannah River. It consists of one CT, the Garden City Terminal, which includes nine berths. The berths are lined-up along the river over an approximate length of 3.2 km and connected through a road network.

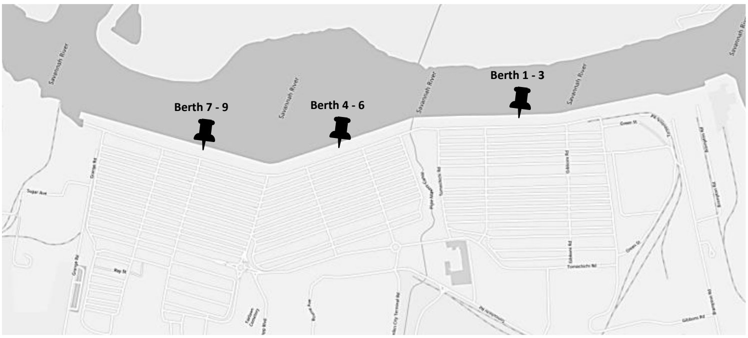

Figure 5: Location of Container Terminals in the Port of Savannah

Transports between berths take place via internal transports, no additional processes like registration and weighting are necessary (Georgia Ports 2020). The layout features of the Port of Savannah represent the category ‘lined up’ which are designated because of their private road network and united resource usage. However, lined up ports differ in the amount of operators. In the Port of Savannah one authority is responsible for the terminal. The Port of Bremerhaven and Felixstowe are further examples of this category of ports.

From the container terminal of the Port of Savannah the interstate 16 (east/west) and interstate 95 (north/ south) are reached within a few kilometers. In addition, an on-terminal railway service is available for transports e.g. to Atlanta or Chicago. Per week the Port of Savannah handles 35 trains of import and export containers (Georgia Ports 2020). The port of Savannah is planning an expansion of the ports capacity of 45 percent over the next decade. The increase in capacity includes enhanced container storage capacities, further container cranes as well as an improvement of the berths.

6 Impact on ITT

Based on the classification of the world's largest seaports, the influence of port layouts on ITT in ports is discussed below. Overall, the analyzed ports show a wide variety in terms of size or handling volume, number of terminals, location and dis-tance between terminals. These differences can be observed both between conti-nents and within continents.

The classification shows that container throughput is significantly higher in the top ten Asian ports than in the other ports. All analyzed Asian ports reach at least level three; the first six ports were even classified as level four, corresponding to an annu-al throughput of more than 20 million TEU. In contrast, only two European ports were able to reach level three in this category, which means an annual throughput of more than 10 million TEU. The throughput of ports in Africa, America and Australia is clearly behind. Furthermore, it is noticeable that Asian ports all have four or more CT, whereas in Australia none of the ports has more than three terminals. Overall, a correlation between annual container throughput and number of terminals can be seen. Besides, there are probably more additional nodes in large ports, such as empty container depots or packing stations. Between these nodes, containers will also be transported. Accordingly, the infrastructure network around the ports is affected by different levels of pressure, depending on the volume of cargo handled, the number of terminals and the number of other service nodes.

Especially in Asia, the terminals are spread around the port, whereas in European ports the terminals are often in line or adjoining. This could be because European ports play a historic role in maritime transport and have grown continuously with the increasing handling volumes. On the other hand, the growth of Asian ports has only begun in recent years, so that existing space and resources are no longer suffi-cient and locations have to be expanded or alternative locations with sufficient space availability have to be built. Large port areas or geographically separated terminals within a port area complicate the performance and coordination of ITT. The plannability of container transports by truck decreases with distance and at the same time the risk of delays increases. One possibility to improve planning reliability and minimize the risk of delays is to use dedicated infrastructure for container transports in the port. The classification shows that 28 out of the 37 analyzed ports use public roads for ITT. Only nine ports (partly) have dedicated infrastructure for ITT and four of the nine ports are located in Europe. It is notable that a dedicated infra-structure in Africa, America and Europe is only used in ports with less than four CT. Here the distances between terminals with such infrastructure are limited to less than 10 km. In Asia, ports with more than four terminals are also connected by a (partially) dedicated infrastructure. Apart from the fact that a dedicated infrastruc-ture in ports is less sensitive to traffic congestion, autonomous systems can be used to transport containers. Especially ports that fall into the categories "lined up" and "adjoining" with regard to the position of their CT are suitable for a connection through a dedicated infrastructure using autonomous vehicles. It should be noted that autonomous systems usually mean structural challenges for the port and the terminals. In addition, these concepts often have a strong impact on port processes. Overall, a lack of available space on route sections, geographical or structural barri-ers and long distances between terminals make the integration more difficult.

All in all, it shows that the performance of ITT depends strongly on the geographical characteristics of the ports. No general solution can be found. In fact, the systems and their organization have to be adapted to the specific situation.

7 Conclusion and Outlook

Seaports are facing great competitive pressure due to increasing transport volumes, which makes it necessary to optimize internal terminal processes as well as the processes that run along the maritime supply chain. This paper has provided an approach to identify geographical similarities and specifications in the design of container ports. Based on comprehensive research, a classification scheme was developed to classify the ports. Later on, the impact of port layouts on ITT networks were examined.

In total 37 seaports from Asia, America, Australia, Africa, and Europe could be classified. The amount of annual container throughput and the number of container terminals were taken into account for the selection of the ports. Thus, only the largest seaports of each continent or seaports with more than one container terminal are relevant for the classification. In summary, ports are characterized by great diversity in terms of size or volume of container handling, number of terminals, location, and distance between terminals.

It can be seen that the major ports are located in Asia and Europe. Furthermore, it is noticeable that the terminals are mostly located close to each other and are connected by public infrastructure. Overall, it is shown that terminals located far away from each other can have negative effects on ITT. The ability to plan road transports decreases with distance and the risk of delays increases. It can be seen that a dedicated infrastructure only exists between terminals that are close together. Therefore, autonomous vehicles can be used for the transport of containers between terminals and further nodes in the port, as it is planned in Rotterdam.

For future research, the function of the port could be taken into account. It will be interesting whether the structure of transshipment ports differs from typical import - export ports. Furthermore, the preferred mode of transport for ITT, as well as the expansion of the rail network and the share of rail transport in the port area, should be included. It should also be examined how "value added services" can be located in ports in order to optimize ITT. Finally, it is to mention that we have only analyzed container terminals. The inclusion of other terminals in the study could also be interesting.

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Defining the Quota of Truck Appointment Systems

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Purpose: Truck appointment systems (TAS) are a widely used method to alleviate peaks in truck arrivals at container terminals in seaports and in the hinterland. One big advantage is the opportunity to reduce operation costs for the terminals and the truck queue length in front of the terminal gate. This study aims to analyze and classify different approaches used in science and industry to determine the quota of allowed trucks per time window.

Methodology: A comprehensive systematic literature analysis is applied to identify the different approaches to determine the quota of time windows in science and in industry.

Findings: The results of the study show that many approaches have been based on experience and are mostly used to improve individual terminals rather than the port as a whole. Methods used to improve and analyze interrelationships are mainly methods of mathematical optimization and simulation.

Originality: The question under consideration was mostly only marginally considered in existing investigations, even though it has a major impact on the success of a TAS. Furthermore, only individual solutions have been examined so far and not the suitability of the approaches compared.

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1 Introduction

The volume of goods transported by sea, especially in container traffic, has risen continuously over the past 10 years (UNCTAD, 2019). This also applies to the competition among shipping companies resulting in declining margins. Therefore, shipping companies are increasingly trying to use economies of scale and thus reduce the costs per TEU (twenty-foot equivalent unit). Due to the associated growth in ship size, ports are facing increasing peak loads. In addition to the loading and unloading of ships on the seaside of the container terminals, this also applies to the handling of containers in the yard and the handling on land by truck. A widespread solution to distribute truck arrivals evenly throughout the day is the introduction of a truck appointment system (TAS). This requires trucking companies to book time slots in advance for the delivery or collection of containers at terminals. These time slots are binding for them. If they fail to comply, the trucks are usually not dispatched. The quota is the central element of the TAS, with which the terminals can control the number of arrivals. The quota determines how many trucks are allowed per time slot. Despite the central importance of the quota, its determination, however, is only marginally considered in most scientific publications, is by-product of research or is carried out with very simple means such as empirical values or simple rules of thumb. It can be assumed that many terminal parameters, from the land side as well as from the yard and seaside, have to be considered in order to adjust the quota to all relevant processes. It should also be considered whether external factors, such as demand, load on the port infrastructure and weather, should be taken into account when determining the quota. In order to provide a basis for such an assessment, this study will conduct a comprehensive literature analysis of the procedures for quota determination. In particular, answers to the following research question are to be found:

Which methods are currently used in science and practice to set the quota? This research question set the research objective to descriptively analyze the state of the art in determining the quota for TAS. Within this analysis a secondary focus is set on how the current practice effects terminals, trucking companies and the entire port. Depending on the outcomes of the analysis, implications on how to improve the determination of the quota are given. Chapter 2 first gives an overview of the state of research on TAS in ports. Chapter 3 presents and explains the methodological approach of the analysis. Chapter 4 presents the developed classification scheme. Furthermore, chapter 4 presents the findings of the literature analysis and answers the research questions as the relevant factors are analyzed individually and in relation to each other. Chapter 5 gives a summary and an outlook on future research.

2 State of Research on Truck Appointment Systems

Seaport container terminals form the nodes in maritime transport chains. They are mostly trimodally connected, i. e. containers can be transported to and from them by water (both ocean-going vessels and inland waterway vessels), rail and road. They are divided into three areas: seaside, container yard and landside (see Figure 1). Seaside handling is usually carried out with specialized ship-to-shore cranes (STS), which guarantee a high productivity of 30 moves per hour on average compared to other types of seaside cranes. From the seaside, the import containers are transported to the container yard with terminal internal transport equipment. Depending on the type of terminal, the equipment either stores the containers in the yard itself (e. g. straddle carriers (SC)) or transfers them for storage (e. g. tractor trailers (TT), automated guided vehicles (AGV)) to storage cranes (usually rubber-tired gantry cranes (RTG) or rail-mounted gantry cranes (RMG)). Similar transfer to the collecting means of transport, usually rail or road, is carried out. It may be necessary to transport containers with internal vehicles from the yard to the rail handling (usually executed by RMG). The delivery of export containers takes place vice versa. For a more detailed overview of structures and processes at container terminals, refer to Brinkmann (2011), Stahlbock and Voß (2007) and Carlo, Vis and Roodbergen (2014).

Container terminals are closely linked to many other companies in the seaport. Empty container depots store containers for longer periods of time in order to save space at the terminals. They also provide additional services such as cleaning, repair and classification. If containers are loaded with goods from more than one customer, the containers will usually be packed in so-called packing stations. Customs and the veterinary office carry out prescribed inspections. Transportation in the port is usually carried out by trucking companies.

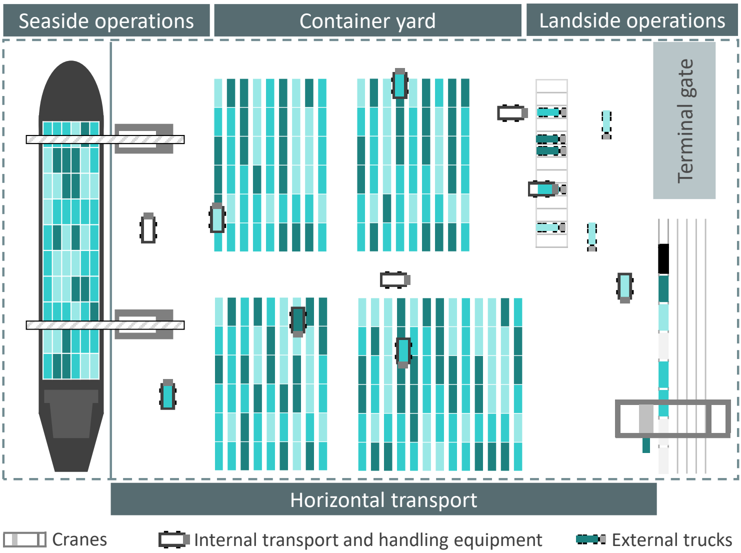

Figure 1: Exemplary container terminal layout

The continuing growth in the size of ships and the restrictive opening hours of other companies in the port and the surrounding area, especially for the recipients of the goods, but also for empty depots and packing stations, result in peaks in truck arrivals during the course of the day. If a terminal does not influence truck arrivals and does not receive advance information on when which containers will be delivered or collected, the planned terminal resources often do not match the demand. As a result, these peaks lead to congestion at the terminal gate and the terminal site. This increases the transport time for the trucking companies and thus endangers their profitability. It is also possible that urgent containers do not reach the terminal in time. Due to the bottleneck at the gate, congestion can build up throughout the port area. This also leads to increased emissions from waiting vehicles. In order to smooth the arrival of trucks, the implementation of a TAS has proved particularly effective. The terminal sets a quota per time window (usually one to two hours). This quota corresponds to the number of trucks that can be handled in this time window. It should be set in such a way that the terminal's resources are used as efficiently as possible without causing congestion. The trucking companies book time slots for each delivery or collection of a container at the terminal, which fits as well as possible into their route planning and whose quota has not yet been reached. Depending on the design of the TAS, the truck is only granted access to the terminal site during the assigned time window. Furthermore, it may be denied access to the terminal if it arrives late. In this case, a new time window needs to be booked, which usually results in waiting times as the following time window are booked up and no longer available.

TAS are very advantageous for terminals, as in addition to smoothing truck arrivals, they are able to provide extensive information about the arriving trucks and their cargo. If this data is evaluated, the terminal processes can be adapted to the arrival times and, if necessary, even the sequence of the trucks. In this way, equipment can be used more efficiently and unnecessary container restacking processes can be avoided. For the trucking companies, the waiting time in front of the gate and at the terminal can be significantly reduced, provided that the quota is suitably defined. The handling times are thus more predictable. At the same time, the trucking companies lose some of their freedom of action, as they have further constraints to take into account when planning the routes.

Since the introduction of the first TAS around 2004, many scientific studies have looked at its design and impact. Overviews of the related publications can be found in Davies and Kieran (2015), Huiyun, et al. (2018) and Lange, Schwientek and Jahn (2017). The focus is often on the consideration of the effects on container terminals (e. g. Chen, Govindan and Golias (2013), Zhao and Goodchild (2013)). Some publications deal with trucking companies. There, for example, dispatching strategies (e. g. Namboothiri and Erera (2008), Fan, et al. (2019)) or cooperation possibilities between different trucking companies (e. g. Gharehgozli, Koster and Jansen (2017), Schulte, et al. (2017)) are examined. Significantly fewer publications consider the effects of TAS on several participants. The most common type is the combined consideration of container terminals and trucking companies (e. g. Phan and Kim (2016), Yi, et al. (2019)). To the authors' knowledge, interactions with other stakeholders in the port or with the road infrastructure are not considered.

TAS can have very different structures. Possible distinctions are, for example, the length and allocation (e. g. in the case of export containers to the ship) of the time window, the booking rules (how many hours/days in advance, possibilities and time limits for rebooking, cancellation and re-booking), the binding nature of the booking (voluntary/binding TAS for all arriving trucks, penalties for non-compliance with the specifications, grace periods before and after the actual time window) and the definition of the quota. The specification of TAS affects not only the gate and yard, but also, reciprocally, the areas in advance and those beyond in the processes, such as the port infrastructure and seaside handling. Due to the high interdependencies of the terminal processes and the poor predictability of demand and the traffic situation in the port, the determination of the quota is a major challenge that has not been extensively investigated either in practice or in research.

The research usually aims to determine how the performance (measured in trucks or containers) of the terminal can be improved. Usually not a quota is calculated, but a maximum performance that can be achieved under the constraints of the respective research. To what extent these findings can be used to determine a quota at all or to what extent this quota is meaningful (possibly practical) remains unsaid. In order to close this research gap, a classification scheme is developed, in which the different approaches to determining the quota are compared with relevant factors such as the aim of the research, the focus of consideration and the methods used. With this a new perspective on current approaches is given, which might lead to additional research approaches on the determination of the quota.

3 Research Methodology

According to Cooper's taxonomy (Cooper 1988) this literature review focuses on research outcomes and practices and applications. The focus on research is derived directly form the research question. The research question also has a strong practical relevance. We therefore also identify a focus on practices and applications. The analysis of the relevant publications accordingly includes an investigation how the results of publications give insight in and can be transferred into practice. The literature review is based on the guidelines for literature reviews by vom Brocke et al. (2009), especially by selecting sources and databases and coverage, identifying key terms and developing the search string and conducting an additional backward search. The way of screening and analyzing the found publications is based on Liberati's et al. (2009) PRIMSA statement and adapted as follows:

The initial literature search was based on English publications. In order not to falsify the results, the authors have refrained from translating papers in languages they do not speak. An initial, comprehensive screening showed, that English publications on the topic are considerably more numerous than the German publications, so that the focus was placed on the English publications. Since English is also the language of science, publications can be recorded worldwide. The search was based on electronic databases for scientific publications. A total of eight electronic databases were searched: The database of Springer Nature Switzerland AG (link.springer.com), Google's search engine for scientific publications with the German interface (scholar.google.de), Elsevier's Scopus database (scopus.com), ITHAKA's

JSTOR database (www.jstor.org), the EBSCOhost database (search.ebscohost.com), Elsevier's ScienceDirect database (sciencedirect.com), Clarivate Analytics' Web of Science database (webofknowledge.com) and IEEE's Xplore database (ieeexplore.ieee.org).

The initially defined search terms were derived directly from the research question: ‘container terminal’, ‘truck appointment system’ and ‘quota’. These search terms were then extended by similar or possibly synonymously used search terms to obtain additional hits. Each database was searched with the following search string (see Figure 2):

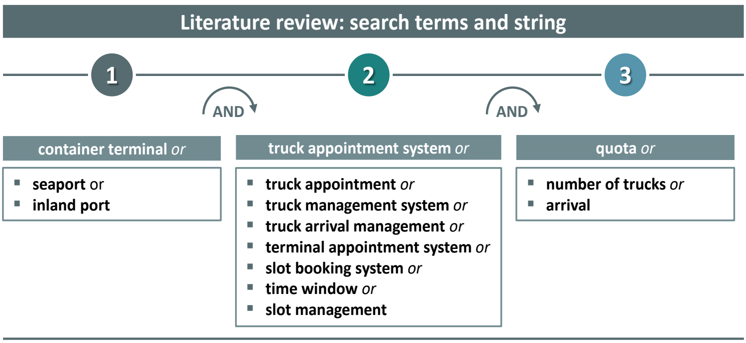

Figure 2: Search terms and string

The search returned 7,525 results, so that it was additionally restricted to publications from 2015 to the time of the search in April 2020. With this restriction, the search still returned 1,984 results. To review these publications, a methodological procedure was established (see Figure 3). In order to handle the vast number of publications efficiently, firstly the search results were viewed by title only. Two general selection criteria were defined, after which it was decided to examine the paper more detailed or to exclude it at this stage. It was also determined that the title had to indicate clearly that the publication referred to container terminals or seaports. In addition, the title did not necessarily have to contain one of the other search terms, but it had to clearly indicate the search term of the category 'truck appointments system' or 'quota'. All papers whose title could not clearly establish this reference were sorted out. With this procedure, a total of 59 publications were identified, which were classified as relevant and used for further analysis. In the next step the abstracts and keywords of the papers were read and examined. It was determined that the abstracts must refer to at least one of the topics: ‘defining the quota of TAS’, ‘slot or truck management and queuing’, ‘enhancing performance or reducing negative impacts at container terminals’ and doing either of the before mentioned by an explicitly named method. If one of these topics was clearly mentioned in the abstract, the paper has been read in full.

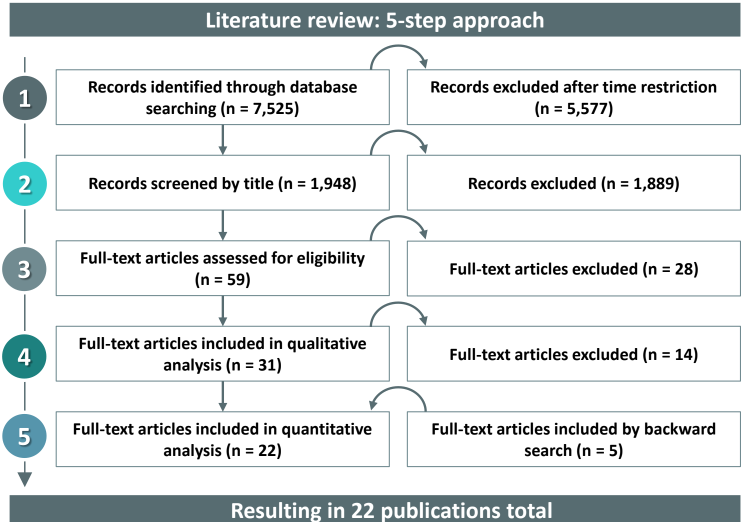

Figure 3: Five-step approach of literature review based on Liberati et al. (2009)

Altogether 31 of the 59 papers could be identified which were to be investigated in depth. In step three, the papers were read fully and examined using a previously defined classification scheme (see Figure 3). For this purpose, the papers had to meet at least one criterion in each of the categories "type of quota definition" and "factors in quota definition" of the classification scheme. If none of the criteria was met, the papers were classified as not relevant. Thus, 17 papers were identified that made statements on the research question. Based on these 17 papers, a backward search was conducted (Webster and Watson, 2002; vom Brocke, et al., 2009). This backward search was carried out on the basis of the bibliography of the papers already classified as relevant. Accordingly, this backward search focused on the period prior to 2015, which brought to light five additional publications. The five-step approach resulted in 22 publications total relevant for analysis.

The classification scheme is central element for the analysis of the 22 relevant publications. In addition to bibliographic information (authors, year, title, keywords etc.), the classification scheme comprises seven content-related categories. These categories were defined before analyzing the papers. The seven categories can in turn be divided into three groups. ‘Aim’ and ‘method’ are categories that describe the paper methodologically. The category ‘aim’ was chosen to determine whether the primary objective of the paper is to determine the quota or whether this is a by-product. The category ‘method’ was chosen to establish a reference to the way quotas are set. This is to check the extent to which there are interdependencies between the general method and the method used to set the quota. The categories ‘TAS’, ‘quota definition’ and ‘relevant factors’ are categories that directly examine the results of the papers in terms of their contribution to the research question. Thus, these categories constitute the core of this literature review. ‘Focus’ and ‘application’ are categories that classify the relevant papers in terms of their practical approach. These two categories allow a more detailed examination with regard to the transfer or transferability into practice. Thus, it is assumed that papers whose point of view is not the terminal, hardly provide any practice-relevant information on the determination of the quota (by the terminal). Similarly, it is assumed that papers with explicit practical relevance apply a practical determination of the quota or have already been applied in practice. The respective characteristics of each category were developed during the analysis and not before the analysis. Therefore, it must be noted that possible values that do not occur in the papers examined must also be identified. Furthermore, this procedure means that each proficiency has occurred at least once in the relevant publications.

4 Results of Literature Review

To answer the first research question the sources are classified on the basis of seven categories with their respective sub-items (see). In the following, the seven categories are presented with regard to their respective evaluation criteria and their mutual dependencies.

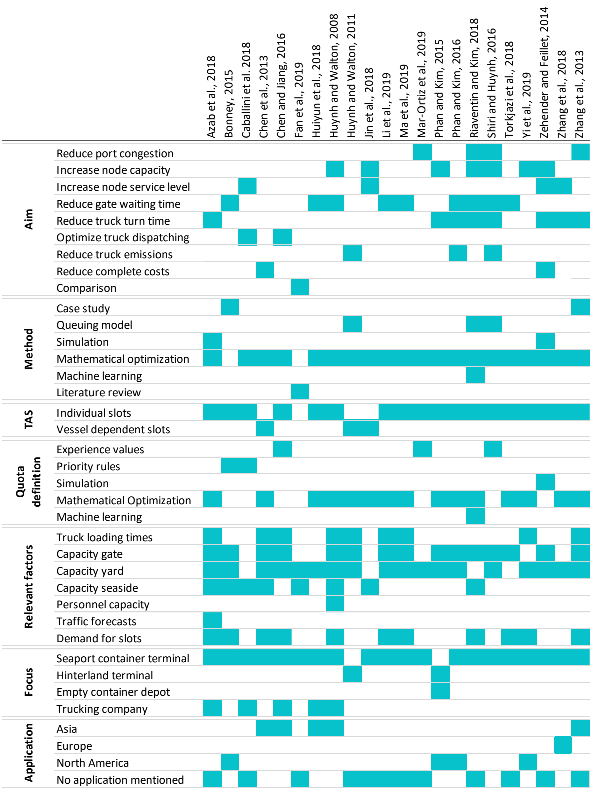

Figure 4: Classification scheme for defining the quota of TAS

4.1 Aim of the Analyzed Publications

The category *aim* comprises the motivation or focus of the scientific publication under consideration. The allocation of the publications examined to the various research objectives and the corresponding development over time is shown in Figure 5.

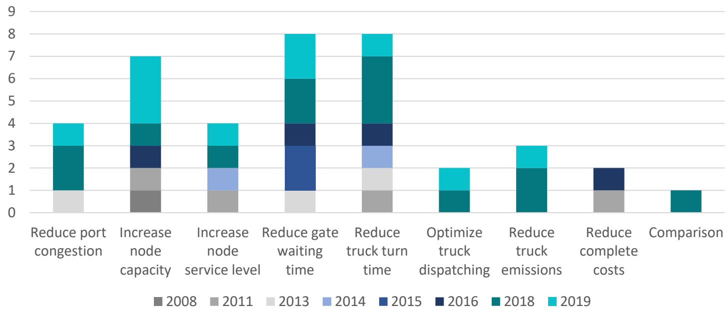

Figure 5: Allocation of publications to category aim

Two essential evaluation criteria are the *reduction of the gate waiting time* and the *truck turn time*. The gate waiting time focuses on the loss of time of the trucking companies due to a delayed access to the site. Truck turn time comprises the time required by the trucking companies from registration, loading and unloading, to leaving the premises. With eight mentions each, both criteria are the most frequent target of the publications considered. These two criteria are also the focus of port authorities, trucking companies and terminal operators. With seven mentions, the criterion *increase node capacity* is almost as often in focus. Linked to this is the aim to increase the efficiency of the node by ensuring that the water and land resources and interfaces of the terminal and those of the carriers are well matched to the incoming and outgoing transport volumes. The resulting challenges also motivate the relatively high number of related publications. Although a *traffic jam in the port* has a significant impact on gate waiting time and truck turn time, this criterion is only in focus in four of the 22 publications analyzed and therefore just as often as increase node service level. The remaining four criteria are *optimize truck dispatching* (2), *reduce truck emission* (3), *reduce complete costs* (2) and *comparison* (1). Until 2015, all publications essentially deal with only one of the first five criteria. In all subsequent scientific work, several of the criteria mentioned are usually examined in combination. In addition, the criterion 'reduce truck emissions' is gaining in importance as a result of social change and the associated political discussion.

4.2 Used Research Method in the Analyzed Publications

The category *research method* describes how the aforementioned criteria of the category *aim* were examined. Figure 5 shows an overview of the used research methods and their time of publication.

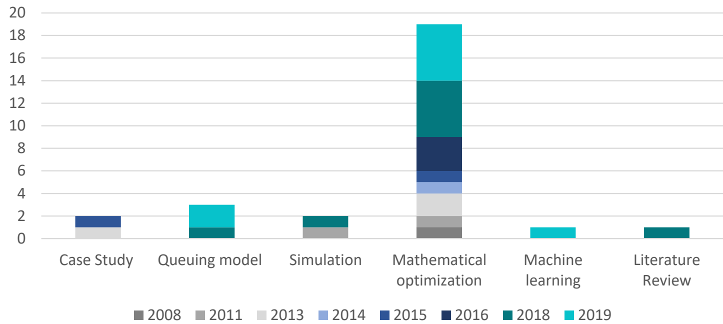

Figure 6: Allocation of publications to category method

Essentially, the *mathematical optimization*, which is used as a method in 19 publications, should be mentioned here. With the aim of maximizing truck utilization and thus reducing costs, the aim function assumes, for example, costs for missed or postponed time slots or waiting at the gate. At the same time, restrictions such as the average loading time, the number of containers to be loaded and the maximum number of available time slots for a TAS are taken into account. In recent years, the mathematical optimization models have increasingly (3) been combined with *queuing models*, for example, in order to map the operation of external and internal vehicles as well as the yard cranes used and to be able to determine a better basis for the mathematical optimization. In a few cases (2) the mathematical optimization is used in combination with *simulation*. Here the focus of the simulation is on the trips and activities around the terminals and less on the traffic that goes beyond. Until 2015, (2) *case studies* and very rarely (1) *literature reviews* were also used as a method, which were only in one case combined with the mathematical optimization method. In summary, it can be said that the use of mathematical optimization as a method predominates and new possibilities such as *machine learning* are not yet frequently (1) used.

4.3 Type of TAS in the Analyzed Publications

In the category *TAS*, a basic distinction is made between two different types. The first type allocates an *individual time window* for each truck and each container to be delivered or collected. Depending on the capacity of the TAS and the availability of import containers, the trucking company is free to choose this. The second type are the so-called *vessel-dependent time windows* (VDTW). Here, containers may only be delivered and picked up in specific time periods that are assigned to the handling of a ship. These time windows are usually considerably longer than the individual time windows, but cannot be freely selected. 18 of the publications considered examine individual time windows and only three VDTW. In a publication on the state of the art in research and technology both types are compared. This distribution can have several reasons: In principle VDTW are more likely to be found in the Asian region. In the rest of the world rather individual time windows are used. Furthermore, the quota considered in this study is particularly relevant for individual time windows. For this reason, the selection of search terms tended to find publications on individual TAS.

4.4 Used Approaches to Define the Quota in TAS

The category *quota definition* is the core of the literature review. This is where the quota of the applied TAS is defined in the examined papers. A total of five different approaches were identified that were used in the papers (see Figure 7).

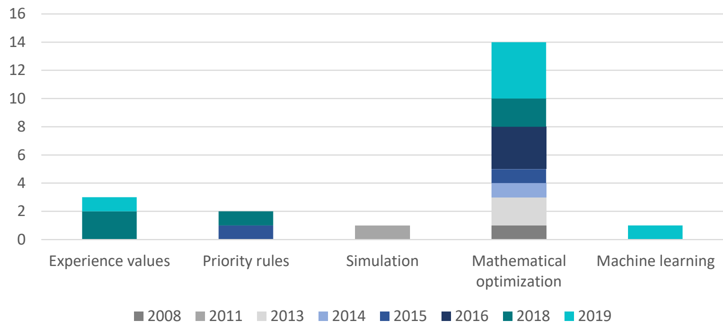

Figure 7: Allocation of publications to category quota definition

Mathematical optimization (15) is mainly used to determine the quota. The quota is usually not the decision variable, but a parameter or variable that is determined as a by-product during the solution of the problem. Other ways of determining the quota are *experience values* (3) and *priority rules* (2). Experience values are based on experience or expert knowledge. Priority rules are also often based on knowledge. This knowledge is formalized and stored as rules. Two methods are only used once for defining the quota: *simulation* (1) and *machine learning* (1). The fact that only little work was done with machine learning can probably be explained by the fact that this method is only used for a relatively short time in in research. Also, it is noticeable that simulation has rarely been used in the recent past. It was assumed that TAS, as an interface between two systems is heavily shaped by unplanned and poorly predictable influences, which as stochastic elements are more likely to be represented by simulation.

4.5 Relevant Factors for Defining the Quota in TAS

The category *relevant factors* summarizes all key figures and parameters used in the publications which are used to determine the quota. A distinction is made between two types of factors. Some publications list factors that can be used to calculate or define the quota, but they are not used in any of the papers. These factors are either actually not used in practice for the definition of quota or they are not used in scientific papers. Here it should be clarified which of the assumptions is correct and why the described discrepancy arises. The factors that are mentioned but not used are not considered in this category. Only factors that were actually used in the definition of the quota have been included.

In total, the category comprises seven relevant factors: *truck loading times* (9), *capacity yard* (18), *capacity gate* (15), *capacity seaside* (8), *personnel capacity* (1), *traffic forecasts* (1) and *demand for slots* (11) (see Figure 8).

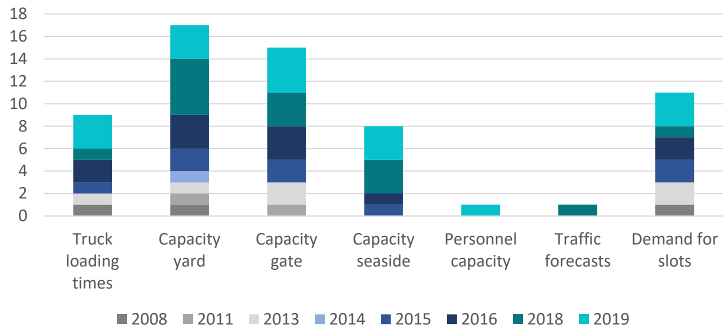

Figure 8: Allocation of publications to category relevant factors

The distribution of the relevant factors opens three perspectives. First, capacity yard and gate are the most commonly used to determine the quota. Therefore, the definition of quota is mainly derived from infrastructural capacities. Secondly, with *capacity yard* (18), *capacity gate* (15) and *capacity seaside* (8), the majority of papers refer to the terminal, which is consistent with the observation of the category focus. Thirdly, with *truck loading times* (9) and *demand for slots* (11) the framework conditions of landside freight transport are also considered. A possible interpretation of these results is that one research focus is to make the best possible use of existing (expensive and long-lasting) port infrastructure and that another focus is to adapt the port infrastructure to cope with the volume of landside transport. Furthermore, it is striking that usually several factors are relevant for the definition of quota. The 22 papers contain a total of 63 references to relevant factors, so that on average almost three factors per publication are used to determine the quota. The number of factors used in a single paper varies between one and six.

4.6 Focus on Specific Stakeholders of the Publications

The category *focus* comprises characteristics that indicate from whose perspective the quota is determined or whose problem situation is addressed with the solution found. The characteristics are accordingly actors who cooperate in the TAS system. Basically, they are divided into actors of the transhipment node in question (i. e. hinterland or terminal) and actors of land-side transport. In particular, the focus of the publications under consideration is on: *seaport container terminals* (20), *hinterland terminals* (2), *empty container depots* (1) and *trucking companies* (5). The clear focus is not surprising, since the papers under consideration deal with a TAS or elements of a TAS that are used and owned by transshipment nodes. In particular, seaport container terminals have to face the problem described in the introduction and hope to be able to deal with it effectively with a TAS. In the future, this focus may be extended to hinterland terminals in particular, as they will face similar challenges as the capacity of seaport container terminals increases.

4.7 Application of the Research

In the context of the literature search, the category *application* covers the geographical areas where the truck appointment systems are used. In the majority of cases (12), the exact location is not specified. If the location is described, the terminals are usually located in Asia (5), North America (4) or Europe (1). This can be explained, firstly, by the fact that TAS are introduced in particular when the terminals are under increased pressure due to the growth in the size of ships and the increasing volume of cargo handled, while at the same time there is little space available to expand the terminal. Secondly, this can lead to an accumulation of research, as they usually examine the same applications in different publications.

4.8 Analysis of the Mutual Dependencies

In the following the mutual dependencies between the categories *quota definition* and *relevant factors* with all other categories will be analyzed. Independent of the time of publication, the research objectives focus on reducing the waiting time of trucks or the truck turn time and increasing efficiency. The second priority is to reduce congestion in the port and increase the service level. Irrespective of the focus of the research objectives, 80 percent of the methods used are mathematical optimization for defining the quota. The simulation would offer the advantage of being able to take more stochastic factors into account. Due to its complexity, however, it is rarely used. Machine learning may provide new approaches for this.

In order to reduce truck waiting time or truck turn time and to increase efficiency, the authors often focus on the capacity of the gates (17) and the yard (15). Both factors are usually considered in combination to determine the quota. The demand for slots (11), truck loading times (9) and capacity seaside (7) are also considered to a significant extent in order to determine a suitable quota for the above-mentioned goals. In all cases the focus is therefore on internal factors of the terminal. Influencing factors such as inbound and outbound traffic are not taken into account.

Due to the strong dependence between the quota definition and the method, the distribution is not conspicuous.

The distribution of the relevant factors and the method is not uniform. On the one hand, the *capacity yard and gate*, the *demand for slots* and the *truck loading times* are considered. On the side of the method the mathematical optimization dominates. With the help of mathematical optimization, three relevant factors are mostly considered at once to determine the quota.

In total, VDTW was only considered in three publications. For this reason, the figures are only of limited significance. Nevertheless, it is noticeable that in the three publications with VDTW, mathematical optimization was used to determine the quota. The remaining methods were all applied to individual time windows.

The factors that are taken into account when setting quotas are very similar for individual time windows and VDTW. There is a slight tendency for individual time windows to take a wider range of factors into account (including personnel and traffic forecasts). However, this may also be due to the larger number of publications on individual TAS considered.

The various methods of setting quotas take account of different and varying numbers of factors (see Figure 9).

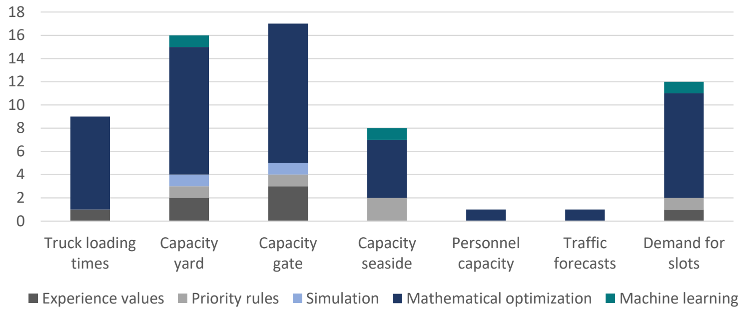

Figure 9: Dependencies of quota definition and relevant factors

Only in mathematical optimization are all factors taken into account, although not always. In the priority control methods, the second most factors are considered. Both simulation and machine learning would have the potential to consider more factors and to investigate these and their influence in more detail.

The way the analyzed publications define the quota as well as the focus of the publications is distributed unequally. Both categories show a clear accumulation for one characteristic. The quota definition is mainly done by means of mathematical optimization. The focus of the publications is clearly on seaport container terminals. It is therefore not surprising that the tuple *mathematical optimization* & *seaport container terminal* with 13 combinations clearly stands out in the comparison of the two categories. In addition, the seaport container terminal is also the focus of the methods *machine learning* and *simulation*. One conclusion could be that a larger amount of research has already been carried out in the focus seaport container terminals, so that new methods, especially machine learning, are based on past experience. The relative accumulation of the *methods experience values* and *priority rules* with focus to *trucking companies* is also striking. Out of a total of only five projects focusing on trucking companies, experience values and priority rules for quota definition are both used once. This may be due to the fact, that a quota definition, which is based more on experience values and practical knowledge, corresponds more to the operational practice of trucking companies.

For the predominant focus *seaport container terminal*, the distribution of relevant factors is very similar to the distribution of relevant factors without considering the focus pf the publications. However, the specification of the relevant factors in relation to the focus *trucking company* is striking. Contrary to previous assumptions, the relevant factors used to determine the quota are not primarily oriented towards demand for slots or traffic forecasts that are more closely related to trucking companies. Instead, the relevant factors with focus on trucking companies are distributed almost equally over *truck loading times* (3), *capacity yard* (4), *capacity gate* (3), *capacity seaside* (3) and *demand for slots* (3). One possible interpretation is that the set up models have a comprehensive character, so that the entire port system with its interfaces to both land and sea side are considered. Therefore, despite the focus on trucking companies, factors such as *capacity seaside* would be considered relevant.

It was generally expected, that more practical methods, especially the definition of quotas by experience, would have a more specific application. The same applies to methods that are more data-based, such as machine learning in particular, since data from practice are usually required as in-

put. For the method 'mathematical optimization', however, this connection cannot be recognized. Due to the rarer occurance of the other characteristics, no statement can be made either.
The distribution of the relevant factors over the application areas does show any specific or distinctive feature. It was also not expected, that the factors used to calculate or derive the quota would differ from region to region.

4.9 Discussion

Based on the approaches described above to determine the TAS quota, the question arises why no uniform approach exists or has been developed so far. This may be due, among other things, to the individual framework conditions of the individual container terminals and the availability of the relevant information: Depending on the requirements, the equipment used and its quantity varies. The processes, such as receiving and issuing containers, are just as different as the control of the associated interfaces. For this reason, individual terminal operators usually concentrate on improving their own operations, such as improving the performance of individual areas, rather than supporting a holistic approach.
In the best case, a standardized approach to a solution involves all the players involved. However, they pursue different goals: While terminal operators and forwarders usually focus on high equipment utilization and efficient processes, the surrounding municipalities tend to pursue the political will and the associated transport policy goals. Against the background of the resulting complexity and conflicts of interest, it seems plausible that in the past only partial aspects were considered and improved.

Furthermore, it can be stated that methods such as mathematical optimization are already being used in operations to solve partial problems. However, due to the complexity and the associated time expenditure, the entire system is not considered. The challenge is therefore to identify the best method for the individual sub-areas in order to enable an overall view of the system in a relatively short time by networking them.

5 Conclusions and Outlook

The analysis focusing on the effect on terminals, trucking companies and the entire port does not provide clear results. The mainly used research method *mathematical optimization* might lead to the situation that stochastic influences cannot be represented comprehensively and that simplifying assumptions have to be made. Especially when considering and investigating several stakeholders, this can lead to a rather abstract representation of port reality. On the other hand, the various relevant factors are used to determine the quota. The relevant factors include both the perspective of the container terminals and the shipping and trucking companies. This points to a comprehensive, systemic approach that takes into account the interests of the different stakeholders. The comprehensive use of the different relevant factors seems to be one of the major strengths of the papers examined. However, the analysis has shown that the use does not necessarily lead to a result that takes the interests of the different stakeholders into account.

Although the factors are described as relevant, they are not taken into account. Their qualitative analysis is also not carried out. This is associated with the risk of considering factors that can be neglected in practice when determining the TAS quota. It would therefore be desirable for future scientific work to also examine and assess the interdependencies between the factors. Furthermore, a key finding of the present study is that only the node and its actors have been considered so far in determining the TAS quota. Their effects on the immediate (urban) surroundings and the connected road network are not taken into account. In addition, different methods, such as simulation and machine learning, should be integrated in the already existing approached for detail questions.

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Stowage Planning for Inland Container Vessels: A Literature Review

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Purpose: The focus of this publication is literature on the Stowage Planning Problem for small container vessels. The problem is important not only for safety reasons concerning stability, but also for enhancing efficiency, as restacking of containers is time consuming and therefore expensive. Small vessels are often competing with other modes of transportation. Optimization of loading operations keeps them competitive.

Methodology: A systematic literature review taking into account journal articles, conference proceedings as well as book chapters has been conducted. The literature is analyzed and categorized to identify directions for further research.

Findings: The problem has been researched extensively for large container vessels. The findings are not always applicable for small vessels. Publications focusing on those are still scarce, but the number has increased in recent years. Nevertheless, multiple new directions for further research are identified.

Originality: An extensive literature review for the stowage planning problem with a focus on small container vessels has not been published to the authors' knowledge.

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1 Introduction

The quantities transported by maritime container vessels have risen steadily over the last decade (UNCTAD 2019), creating the need to transport huge amounts of containers between container seaports and their hinterland origin or destination. This task is fulfilled by inland container vessels, trucks or trains. The advantage of inland container vessels is that they are more environmentally friendly and are able to transport many containers at once, saving multiple train or truck voyages by using a single vessel (Moura et al. 2013). Disadvantages are longer traveling times compared to the other transportation modes and less flexibility, being dependent on rivers. Therefore, in order to compensate the disadvantages, inland vessels have to maximize their capacity utilization in order to remain competitive by economies of scale (Zuidwijk und Veenstra 2015).

Unlike the ever-growing maritime container vessels, the size of the inland container vessels is limited by the river and channel dimensions. Therefore, vessels rely on the optimization of stowage plans to maximize capacity.

In practice stowage planning for inland container vessels is usually done manually by the captain, using his experience to generate a stowage combination that is then tested by a stowage simulation software for stability. This process is repeated until the software accepts a plan as sufficiently stable (Gumus et al. 2008). This does not always lead to an optimal solution in terms of capacity utilization and is highly dependent on the captain's experience.

Therefore, research focusing on methods to solve the container stowage problem for small container vessels is needed and cannot be replaced by

the large amount of existing research focusing on the container stowage problem for maritime container vessels.
This leads to the following research questions:

1. What is the state of the art in current research on the stowage planning problem for small container vessels?

2. What are the needs and gaps in current research?

3. What are the differences between stowage planning for inland container vessels and maritime container vessels?

To answer these questions, the rest of this publication is structured as follows: In section 2 a problem description of the stowage planning problem is given. In sec-tion 3 the research methodology for identifying the relevant literature is explained and a classification scheme is developed. This scheme is applied to the found litera-ture in section 4. Finally, in section 5 the research questions are answered and an outlook for future research is given.

2 Problem description

2.1 Maritime container transportation

Maritime container transportation is divided in three phases: pre-carriage, carriage and on-carriage. Pre-carriage and on-carriage include all movements of containerized goods before and after they are transported by a maritime container vessel. Container transportation via maritime vessels is called voyage. The capacity of maritime container vessels is measured in twenty-foot equivalent unit (TEU). One TEU corresponds to one standardized, twenty-foot long container. The largest container vessels have a capacity of 24 000 TEU.

Container vessels usually operate on fix routes with multiple ports, for example between Asia and Europe. Before and after the container vessels enter a port, a huge amount of containers has to be transported from the hinterland to the port and vice versa. This work is split between trucks, trains and inland container vessels, so called barges.

Since the large container vessels only call at a few terminals along their routes due to efficiency reasons, smaller feeder vessels distribute the container volumes to other seaports, e.g. in the Baltic Sea. This leads to a hub-and-spoke system between seaports.

2.2 Stowage planning

The stowage planning problem deals with the assignment of containers to a concrete position, called slot, inside a container vessel (Wilson und Roach 1999). In most container vessels, each slot can hold one 40-foot container

or two 20-foot containers and is uniquely defined by its longitudinal position (bay), latitudinal position (row) and vertical position (tier). For further details see Ambrosino et al. (2004). Since multiple containers in a tier are stacked on top of each other and tiers can only be accessed from the top, containers are loaded and unloaded following the 'last in, first out principle'. Therefore, any container that needs to be unloaded could possibly be blocked by another container destined to stay on the vessel, which then has to be moved to gain access to the container below. These unproductive moves are called over-stows. One objective of stowage planning is usually to avoid these, since they are time-consuming and cause unnecessary handling costs. Another typical objective is to maximize capacity usage of container vessels. When constructing a stowage plan, one or more objectives being formulated as a minimization or maximization problem have to be solved to create an optimal stowage plan. Simultaneously a number of constraints have to be fulfilled, such as stability and strength of the vessel, thus making the problem complex. Avriel et al. (1998) proved the problem to be NP-complete.
After an initial review of the literature, the following differences between the container stowage for maritime container vessels and inland container vessels are assumed to be existing and will be examined in the literature classification:

1. Stability constraints are much more crucial for inland container vessels. On the one hand, this is due to the smaller size, such that positioning of a single container has a much higher impact on the stability of smaller vessels as opposed to larger vessels. On the other hand, small container vessels

usually only have limited, if any, ballast tanks for stabilization (Li et al. 2017).

2. As stated before, capacity utilization is highly important for inland container vessels. It is more difficult to achieve, due to strict stability constraints (Li et al. 2020b), whereas in maritime container shipping, handling time minimization is usually the main focus of stowage plans optimization and stability constraints are sometimes not included at all, see for example (Avriel et al. 1998; Pacino et al. 2011).

3. Stowage planning for inland container vessels usually focuses on creating stowage plans for every port along the route simultaneously, whereas in maritime stowage planning most publications only consider single ports (Li et al. 2020b), see for example (Avriel et al. 1998; Parreño et al. 2016; Wilson und Roach 2000; Delgado et al. 2012).

3 Research Methodology

3.1 Literature Research

A structured literature research was conducted. First, the different possible terms for the considered optimization problem ("Container Stowage Problem", "Container Storage Problem", "Master Bay Planning Problem") and different terms to restrict the problem to the small use-case, either by naming the environment or the specific ship type ("Short sea shipping", "Inland", "River", "Barge", "Feeder") were identified (see Table 1).

The term "Container Storage Problem" describes the problem to allocate storage positions to containers in a container yard, as opposed to on a vessel (see for example (Luo und Wu 2015)). It was nevertheless included to observe, whether the differentiation of those closely related problems is made in the small scale version of the problem as well. Feeder vessels were included to investigate if stowage planning for feeder vessels is comparable to stowage planning of inland container vessels due to their similar size.

Table 1: Terms for literature research

Optimization problem	Localization
Container Stowage Problem	Short sea shipping
Container Storage Problem	Inland
Master Bay Planning Problem	River
	Barge
	Feeder

In a second step, each optimization problem term was combined with each localization name to generate the different search strings being used in several scientific databases and search engines such as Scopus, Web of Science, IEEE and Google Scholar. For example, the exact search string for Scopus that produced 2566 initial results (02.05.2020) was:
((container AND stowage AND problem) OR (container AND storage AND problem) OR (master AND bay AND planning AND problem)) AND ((short AND sea AND shipping) OR inland OR river OR barge OR feeder)
The search strings for the other databases were similar, with adaption according to the syntax of the search engine. All publications presenting a model for solving the container stowage optimization problem in a small scale, written in English, are defined as relevant literature. To identify fur-

ther publications of interest, the list of references of all relevant publications as well as a backwards citation search was conducted, with the same definition of relevance.

3.2 Classification scheme

The classification considers five sections: (1) Problem description, (2) Objectives, (3) Constraints, (4) Algorithm and (5) Validation.
In the first section "problem description", the individual configurations of the investigated stowage problem are classified in seven categories (Figure 1). The sections were chosen regarding the different problem configurations observed in the literature.

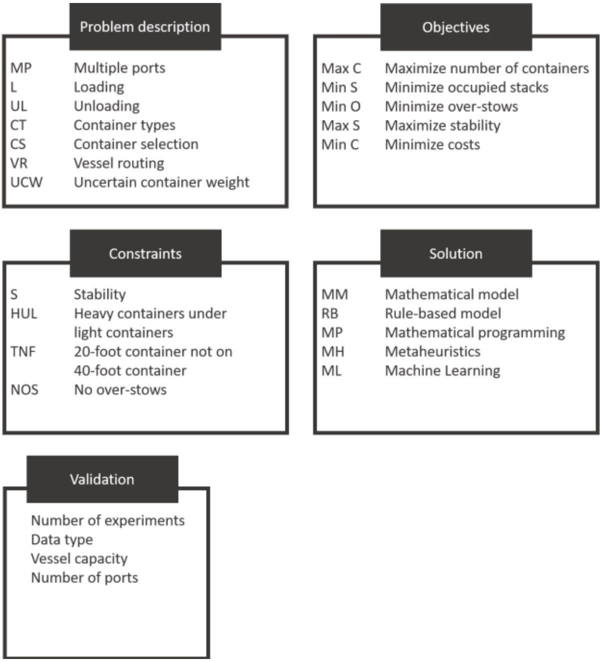

Figure 1: Sections and categories of classification scheme

The first category in this section "Multiple ports" is used to classify, whether the storage plans are computed for a single port or for every port along the route simultaneously. As stated before, the former is often used in maritime container shipping. The next category "Loading" specifies, whether the publications consider loading of containers on every port along the route. This category is only considered as fulfilled, if the loaded containers are not restricted by number, destination or container type. The same holds for the category "Unloading". This category is fulfilled if the vessel can unload any type of container at every port. The fourth category "Container types" classifies whether different types of containers are considered, the category is considered as fulfilled if 20-foot and 40-foot containers are differentiated. Other possible container types include 45-foot containers, reefer containers, with content that needs to be temperature-controlled and thus these containers need an electric plug; high-cube containers, containers with dangerous goods and open top containers. All of these types have different restrictions that have to be taken into consideration when building a stowage plan. The fifth category "Container Selection" is fulfilled, when the publication considers the additional optimization problem to assign containers to vessels, as opposed to building a stowage plan for a fixed number of containers. The sixth category "Vessel routing" applies, when the route of the vessel is not fixed and the two optimization problems of selecting a route and making a stowage plan are solved simultaneously. The last category "Uncertain container weight" is fulfilled, when the actual weight of the containers to be stowed is not certain.

In the second section "Objectives" the different objective functions that are minimized or maximized to solve the stowage plan optimization problem are examined. All objectives that are found in at least one of the considered publications are chosen as categories for this section. The first objective "Maximize number of containers" deals with capacity utilization of the vessel by maximizing the number of containers transported by the vessel. The second objective "Minimize occupied stacks" also maximizes the capacity utilization. As mentioned before, containers are stowed in the vessels in different stacks. By minimizing the number of occupied stacks, the space used by a number of pre-assigned containers is minimized, and if the number is not maximal, room for additional containers in form of empty stacks is left. The third objective is "Minimize over-stows". As previously stated, over-stows are unnecessary container moves caused by a container with a later destination blocking a container with an earlier destination below it. Moving a container takes time, produces handling costs and thus needs to be avoided. Minimizing the number of over-stows is one way to achieve this. The fourth objective is "Maximize stability". Vessel stability is a prerequisite for the feasibility of any stowage plan. Instead of checking if a given stability threshold is fulfilled, stability can be maximized to reduce the chance of accidents and save fuel, since optimal stability conditions lead to lower fuel consumptions. The last objective "Minimize costs" aims at maximizing profit by minimization of costs. The objective is incidentally achieved by the first three objectives, but since it is stated in this unspecific formulation in the considered publications, it was included as a separate objective for the classification.

In the third section, different constraints unique to the container stowage problem are identified. Necessary constraints for making sure that the output represents a stowage plan, such as 'no flying containers - every container is stacked on top of another container or the floor of the vessel' or 'every container occupies at most one slot and every slot is occupied by a maximum of one container' are not considered since they are mandatory. The first constraint is "Stability". If considered as a constraint, it is observed whether the stowage plan fulfills necessary stability restrictions. The category is only considered as fulfilled, if the stability was computed for the overall vessel. The second constraint "Heavy containers under light containers" specifies, that in every tier containers should be stacked in order of

weight, from heaviest at the bottom to lightest at the top, which contributes to the stability of the vessel. The third constraint is "20-feet container not on 40-feet container". Container vessels are designed with slots big enough to fit one 40-foot container or two 20-foot containers. Container corners are reinforced with castings that have to lie on top of the corner-castings of the container below, for stability reasons. Therefore, a 40-foot container can be placed on top of two 20-foot containers but two 20-foot containers cannot be stacked on top of a 40-foot container (Rodrigo de Larrucea 2009). The fourth constraint "No over-stows" prevents over-stows by design. This is achieved, if a container can only be stacked on top of another container when both have the same destination or if the destination of the upper container is visited before the destination of the container below.
In the fourth section "Solution" it is classified how the stowage plan is generated. The first category is fulfilled, if a mathematical model is proposed. That is a mathematical formulation mirroring the real-life problem. It consists of one or more objective functions and a number of equations stating the different constraints. The subsequent goal is to find an optimal parameter configuration that minimizes or maximizes the objective functions, while making sure that all constraints are fulfilled. This configuration describes the desired stowage plan. The second category "Rule-based model" evaluates, whether a model based on rules is presented for the generation of the stowage plan. If used alone, then it consists of a set of rule that, when followed, produce the desired stowage plan. If used together with the mathematical model, then it is either used to generate an initial solution that is needed to solve the model, to solve parts of the problem or to further optimize a possibly found solution.

If a mathematical model was chosen, then one algorithm or a combination of multiple algorithms is needed to solve it. The last three categories in this section specify the types of algorithm used to solve the proposed model. The category "Mathematical programming" is fulfilled, if mathematical programming is used to generate a solution. This approach can possibly guarantee that an optimal solution is found, likely resulting in long computation times. The fourth category "Metaheuristics" is fulfilled if a metaheuristic algorithm is used to solve the proposed model. Hereby, it is not guaranteed that the best solution is found. Instead an initial solution is generated and thereafter improved, following a defined strategy such as local search or a population based approach. The last category "Machine Learning" assesses, whether a machine learning algorithm is used to generate a stowage plan. These algorithms are able to generate solutions by using recognized patterns extracted from existing data.

In the last section "Validation" it is classified, if and how the proposed method for the generation of stowage plans is validated. The first category "Number of Experiments" compares the number of conducted experiments. The second category "Data type" evaluates the data used in the experiments. Either data from real life instances, computer generated data based on real life instances or computer generated data that do not model any real life instances. The third category evaluates the capacity of the used test vessels in TEU. The last category lists the number of ports that are considered in the evaluation as origin and or destination and for which the stowage plans are computed simultaneously.

4 Classification

Despite the thorough approach, the literature search produced only thirteen publications, nine of them published within the last five year, indicating a growing relevance of the researched topic (Figure 2). As anticipated, no publication using the term "storage location" was identified to be of interest. Surprisingly, no publications concerning the stowage planning of feeder vessels were identified either.

The publications consisted of nine conference contributions as well as four journal publications in the following journals: Transportation Research Part E, International Journal of Shipping and Transport Logistics, Journal of the Operational Research Society, Journal of Mathematical Modelling and Algorithms in Operations Research.

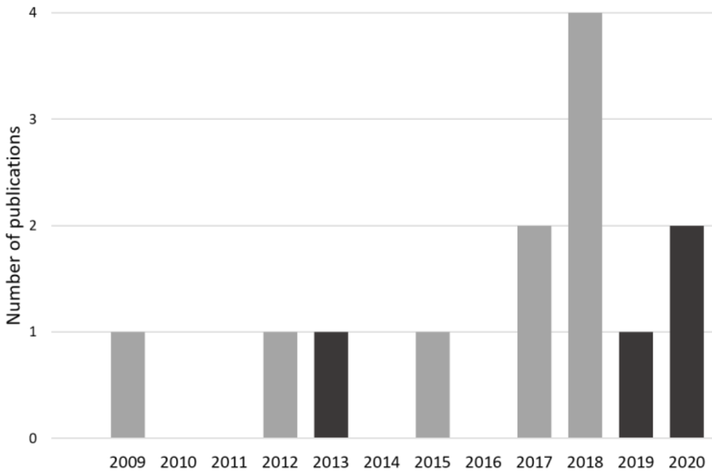

Figure 2: Number of publications per year

The rest of the chapter is structured according to the five sections of the classification scheme. In each chapter the results of the classification for one of the sections are presented and discussed.

4.1 Problem description

Seven categories were used to classify the problem description of the container stowage problem in the different publications (Table 2).

Table 2: Classification of problem description

	MP	L	UL	CT	CS	VR	UCW
El Yaagoubi et al. (2018)	■		■				
Fazi, S. (2018)	■	■	■	■	■		
Fazi, S. (2019)	■		■	■	■		
Hu, M. et al. (2017)	■	■	■	■			
Li, J. et al. (2017)	■	■	■	■			
Li, J. et al. (2018a)	■	■	■				■
Li, J. et al. (2018b)	■	■	■				■
Li, J. et al. (2020a)	■	■	■	■			
Li, J. et al. (2020b)	■	■	■	■			
Martins, P.T. et al. (2009)	■		■				
Martins, P.T. et al. (2012)	■	■	■		■	■	
Moura, A. et al. (2013)	■		■		■	■	
Moura, A. et al. (2015)	■		■	■	■	■	

The first category "Multiple ports" is fulfilled by all publications, meaning that the stowage plans are created simultaneously for all ports along the route. This confirms the previously mentioned difference to the stowage plan problem for maritime container vessels, where usually only one port is considered.

The second and third categories are "Loading" and "Unloading". All publications consider variable unloading actions at every port along the route. Eight publications consider variable loading actions at every port along the route as well (Figure 3 - Variable Loading and Unloading). Two publications consider only loading actions at the start port (Figure 3 - Loading restricted to the start port). The other three publications consider only restricted loading actions. Moura et al. (2015) consider only loading of empty containers along the route, Fazi (2019) considers one dryport terminal where the vessel starts and finishes its route, as well as different sea port terminals along the route. All containers loaded at the sea port terminals along the route have to be transported to the dry port terminal at the end of the route (Figure 3 - Dry Port and Sea Port scenario). Finally, in the considered problem of Martins et al. (Martins, P.T.a, Lobo, V.a, Vairinhos, V. 2009), at every port along the route the number of loaded containers is equal to the number of unloaded containers, thus the vessel is always fully loaded. Not all of these scenarios are chosen to simplify the optimization problem, but mirror the variety of transportation scenarios in different geographical regions, which should thus be taken into consideration when dealing with this problem.

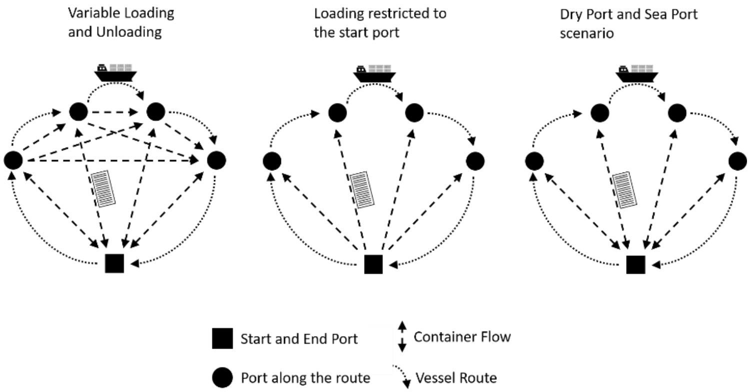

Figure 3: Types of container flow

The fourth category is "Container types". Five publications do not distinguish between different container types. Six publications only distinguish between 20-foot and 40-foot containers. Two publications consider a third type, either high-cube containers (Fazi 2019) or reefer (Moura und Oliveira 2015). Four publications name more types of containers than they are considering in their model, these include 45-foot containers, containers with dangerous goods as well as open top containers. Li et al. (2020b) explains that these are rarely used in inland container liner shipping. Nevertheless, omitting container types only reflects the reality of the stowage problem to a limited extend and could thus hinder the application of the developed model in practice.

The fifth category "Container selection" is fulfilled by five publications. Two of them include this problem, because they chose to maximize the number of containers, as will be mentioned later. The other three are the only publications that fulfill the sixth category "Vessel routing", and combine it with

the assignment of destination ports to different vessels, which is solved when containers are already selected for the different vessels.
Finally, two publications include uncertain container weights. Both of them are from Li et al., which deal with inland container liner shipping on Yangtze river, where actual weight of containers is often uncertain (Li et al. 2018a; Li et al. 2018b). However, Fazi (2019) states, that previously specified container weights can be assumed as accurate in several western ports. These findings highlight the need to analyze the specific needs of a geographic region, when dealing with inland container shipping.

4.2 Objective function

Six publications use only one objective function, five use two objective functions and two publications use three objective functions in their model (Table 3).

Table 3: Classification of objective function

	Max C	Min S	Min O	Max S	Min C
El Yaagoubi et al. (2018)			■	■	
Fazi, S. (2018)	■				
Fazi, S. (2019)	■				
Hu, M. et al. (2017)			■	■	
Li, J. et al. (2017)		■	■	■	
Li, J. et al. (2018a)		■			
Li, J. et al. (2018b)		■			
Li, J. et al. (2020a)		■	■	■	
Li, J. et al. (2020b)		■			
Martins, P.T. et al. (2009)			■		■
Martins, P.T. et al. (2012)			■		■
Moura, A. et al. (2013)			■		■
Moura, A. et al. (2015)					■

The first two objectives, "Maximize number of containers" and "Minimize occupied stacks", both aim at maximizing the capacity utilization of the vessel. Seven of the considered publications use one of the two objectives, five of those even use it as the sole objective function of their model. Only one other objective function, minimization of costs, is used as a sole objective in one case. These findings reflect the importance of the capacity maximization for small container vessels.

The objective "Maximization of the number of transported containers" implies, that container selection has to be incorporated in the model, thereby increasing the complexity of the optimization. Therefore, only the publications of Fazi (2018, 2019) have chosen this objective and both do not use any additional objective functions. Furthermore, this is the only objective that has not been considered together with any other objective by at least one publication, further indicating the complexity of this objective.

Other publications seeking to optimize capacity utilization of the vessel have focused on "Minimization of the number of occupied stacks". This results in a considerably smaller number of variables and thereby supports fast generation of feasible solutions. Nevertheless, when applied in practice, the success of capacity maximization depends on the method for container selection as well.

The third objective function "Minimize over-stows" used to avoid unnecessary handling costs is used in seven publications. For big container vessels this objective is of high importance and is often used as the sole objective function, as mentioned before, but for small container vessels other factors are equally, if not more important. This is mirrored by the fact that the objective is always combined with at least one other objective in all considered publications.

The fourth objective "Maximization of stability" is the only objective aiming at safety instead of profitability. It is used in four publications and is always combined with the minimization of over-stows. Even though stability is of high importance for small container vessels, this indicates that profitability cannot be omitted due to their need to compete with trucks and trains.

The last objective aims at minimization of costs. This objective is achieved by the first three objectives as well. Nevertheless, four publications specifically minimize costs. All of these and only these four publications include the vessel routing problem and the cost function is made up of costs associated to the routing problem instead of container stowage problem.

4.3 Constraints

Two publications did not include any of the considered constraint categories and one publication included all four (Table 4).

Table 4: Classification of constraints

	S	HUL	TNF	NOS
El Yaagoubi et al. (2018)	■	■	■	
Fazi, S. (2018)	■	■		
Fazi, S. (2019)	■		■	■
Hu, M. et al. (2017)	■		■	
Li, J. et al. (2017)	■	■	■	
Li, J. et al. (2018a)	■			■
Li, J. et al. (2018b)	■			■
Li, J. et al. (2020a)	■	■		
Li, J. et al. (2020b)	■	■	■	■
Martins, P.T. et al. (2009)	■			
Martins, P.T. et al. (2012)				
Moura, A. et al. (2013)				
Moura, A. et al. (2015)				■

Ten publications have included constraints regarding the stability of the vessel in their model, thus fulfilling the first category. The other three publications did not consider the whole stowage plan for checking the stability of the vessel, but they took into consideration the weight capacity of single stacks instead. These findings highlight the importance of stability for inland container vessels, as mentioned before.

Five publications include the second constraint "Heavy containers under light containers". The publications omitting stability constraints are not included in those five, neither are the two publications dealing with uncertain container weights, for obvious reasons. This leaves three additional publications who do not include this constraint.

The third constraint is "20-feet container not on 40-feet container. In practice, this rule must be followed. Nevertheless, only five of the eight publications that are differentiating between 20-foot and 40-foot containers include this constraint in their model.

The last constraint "No over-stows" is fulfilled by five publications. Two publications (Li et al. 2018a; Li et al. 2018b) even use a more restricted version of the rule, by only allowing containers in one stack that all have the same destination and origin. Seven of the remaining eight publications use minimizing of over-stows in their objective functions, leaving only one publication that is not concerned with over-stows.

The analysis of the constraints used in the models for the creation of stowage plan shows, that even constraints that need to be followed in practice are omitted by numerous publications, leaving room for further research.

4.4 Solution

All publications propose a method to obtain a stowage plan as a solution (Table 5).

Table 5: Classification of solution

	MM	RB	MP	MH	ML
El Yaagoubi et al. (2018)	■				
Fazi, S. (2018)	■		■		
Fazi, S. (2019)	■		■	■	
Hu, M. et al. (2017)	■	■			
Li, J. et al. (2017)		■			
Li, J. et al. (2018a)	■		■		
Li, J. et al. (2018b)	■	■	■		■
Li, J. et al. (2020a)	■	■		■	
Li, J. et al. (2020b)	■	■		■	
Martins, P.T. et al. (2009)	■		■	■	
Martins, P.T. et al. (2012)	■			■	
Moura, A. et al. (2013)	■		■		
Moura, A. et al. (2015)	■		■		

To formulate the problem, all but one publication proposed a mathematical model for the stowage plan generation. Li et al. (2017) only used a rule-based approach. Four other publications used rule-based approaches in addition to their mathematical problem.

The publication by El Yaagoubi et al. (2018) was the only one that just presented the mathematical model, but did not solve it. Out of the other twelve publications, mathematical programming was used by six and metaheuristics by five publications, including two publications that used both approaches. Only Li et al. (2018b) used a machine learning algorithm, by implementing a neural network to solve the stowage plan problem.

The results show that most publications focus on the implementation of a mathematical model and solve it by mathematical programming or a metaheuristics approach. Further research needs to be done to evaluate the benefit of using machine learning algorithms for solving this problem.

4.5 Validation

Eleven publications conducted experiments to test their proposed model and solution approach, with the number of experiments ranging from 1 to 72 (Figure 4). For clarity, the two publications that did not conduct any ex-

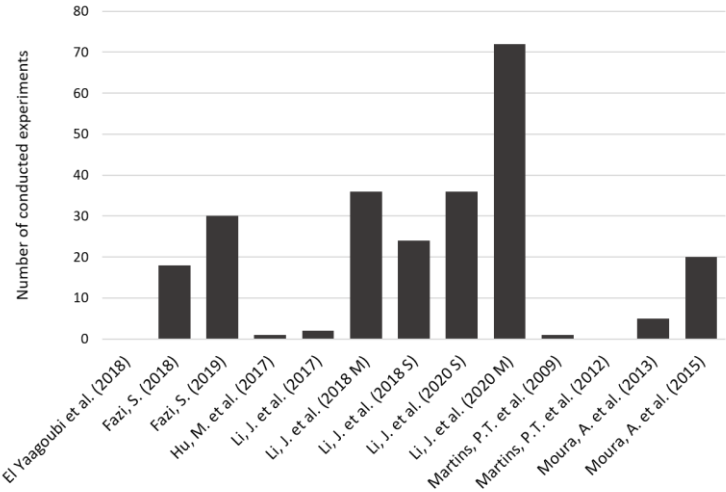

Figure 4: Number of conducted experiments

periments (El Yaagoubi et al. 2018; Martins, P.T.a, Lobo, V.a, Moura, A 2012) are omitted from the analysis of the remaining subchapter.

Fazi (2018) is the only publication that used real life data. Eight publications used computer generated data based on real life instances. Hu et al. (2017) and Martins et al. (2009) used computer generated data (Figure 5). Future research could focus on testing the proposed models with real life data.

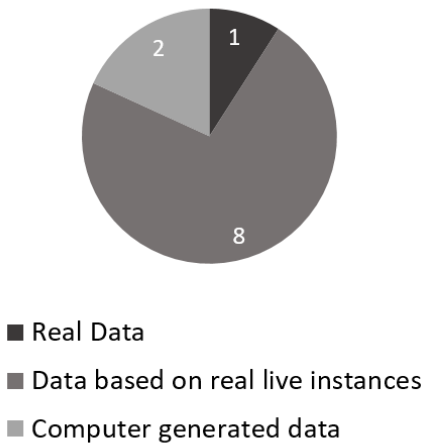

Figure 5: Number of publications per data type

The last two categories focus on the vessel capacity and the number of ports. All but one of the publications listed the vessel capacity of the used test-vessels (up to three different vessels per publication), ranging from 24 TEU up to 5000 TEU (Figure 6). The case of 5000 TEU was only used to test the capacity of the model, since vessels of this size are not used in real-life short sea shipping (Moura und Oliveira 2015). All other test vessels had capacities of less than 1200 TEU, which are significantly smaller than maritime container vessels.

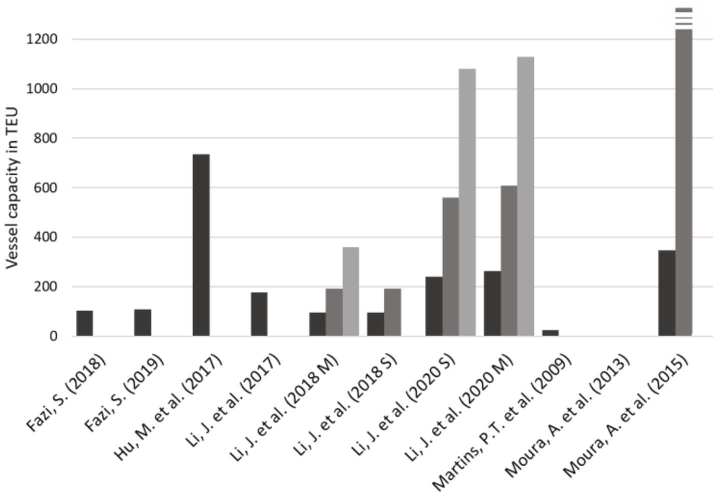

Figure 6: Capacity of test vessel

The maximum number of ports that were used in experiments range from five to fifteen (Figure 7). Eight publications considered different numbers of ports but only two publications considered number of port configurations with differences of more than four between the highest and the lowest number. Li et al. (2017, 2018a, 2018b, 2020a, 2020b) considered ports along the Yangtze river and Fazi (2019) considered Dutch inland terminals, active in the Brabant region. The other publications did not mention any specific ports. As stated before, it is needed to analyze the specific needs of a geographic region, when dealing with inland container shipping. Only few geographic areas have been covered in the examined literature, thus leaving room for future research.

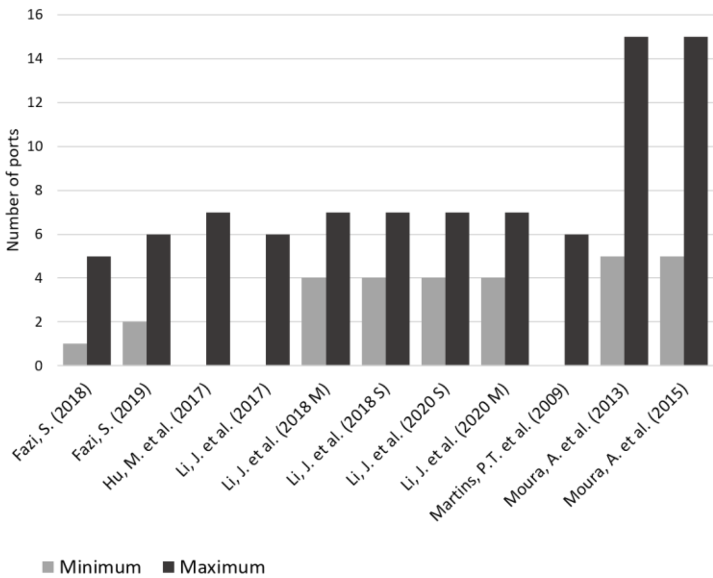

Figure 7: Minimum and maximum number of ports

5 Conclusions and Outlook

The focus of this publication is the container stowage problem for inland container vessels. The problem is described and identified as relevant for the maritime sector. The following aspect unique to the container stowage problem for inland container vessels, as opposed to maritime container vessels, are identified:

1. Stability constraints are crucial.

2. Maximization of capacity utilization is important.

3. Stowage plans can be made for all ports along the route simultaneously.

Despite its relevance, only few publications have been found, that tried to solve this problem. Most of them were published within the last years, hinting towards a growing interest in this important field of research. The publications are analyzed and categorized regarding their problem description, objectives, constraints, solution and validation. The aforementioned differences are confirmed by the findings of the analysis. Furthermore, several research gaps have been revealed, hinting that future publications on the container stowage problem for inland container vessels can focus on:

1. Considering all common container types, such as 20-, 40-, and 45-foot container, reefer, high-cube, containers containing dangerous goods and open-top containers.

2. Analyzing and considering the needs of a specific geographic region.

3. Combining the problem with other optimization problems such as Container selection and Vessel routing.

4. Considering all important constraints that a stowage plan has to fulfill in order to be used in practice at the same time. These include stability, stacking heavier containers underneath lighter ones and not stacking 20-foot containers on top of 40-foot containers.

5. Trying out different machine learning algorithms to solve the presented problem.

6. Testing the proposed models with real life data, conducting multiple experiments and a wide range of different number of ports.

An additional finding is, that no publication considering the stowage planning problem for feeder vessels was identified. One explanation could be, that it is similar to the container stowage problem of maritime container vessels. But it is equally conceivable that it has not been researched up until today and thus could be another interesting topic worth considering in future research.

Our findings are mainly based on the analysis of the limited number of publications found. It could be of interest to analyze publications on the container stowage problem for maritime container vessels in a similar matter, to further validate the differences and identify methods that can be applied for solving the small-scale problem as well.

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Tactical Planning in Tramp Shipping – a Literature Review

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Purpose: This paper discusses the current state of research on tactical planning in tramp shipping problems. The constantly changing demands in operative tramp shipping make tactical or strategical, i.e. longer-term planning, in comparison to operative planning more complex. The purpose of this paper is to describe solutions to tactical planning difficulties in tramp shipping and to point out future research directions.

Methodology: For this paper, a systematic literature review of journal articles and book chapters of the last ten years is conducted. The findings of this search are analyzed and reviewed. Thus, different planning problems and their solutions are identified.

Findings: Planning problems in tramp shipping are clearly distinct from planning problems in liner shipping as tramp shipping is subject to considerably more uncertainties. Due to the high degree of uncertainties in tramp shipping longer-term planning is challenging. Consequently, the results of research on tactical planning problems in liner shipping cannot be transferred directly to tramp shipping.

Originality: This paper provides a comprehensive overview of strategic and tactical planning in tramp shipping as presented in the literature.

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1 Introduction

Maritime transport is not only important for all sectors of the economy but also for everyday life, as more than 80 % of world merchandise trade by volume is transported by vessel. It is expected that the global seaborne trade is continuing to grow by 3.4 % annually until 2024. Although most people think of containerized trade when hearing of maritime transport, main bulks (iron ore, grain, coal, bauxite/alumina and phosphate), other dry cargo and tanker trade (crude oil, refined petroleum products, gas and chemicals) account for more than three quarters of the goods transported annually measured in ton-miles (United Nations Conference on Trade and Development, 2020). Most goods in these segments are transported by vessels operating in tramp shipping.

Usually a distinction is made between three different modes of shipping: liner, tramp and industrial shipping. In liner shipping, vessels sail on fixed routes according to a schedule. In tramp shipping, vessels follow the cargo, which consists of contract and optional spot cargo, with the objective of maximizing profit. In industrial shipping, the company that owns the cargo also operates the vessels and thus tries to minimize the transportation costs (Christiansen, et al., 2013). Tramp shipping is characterized by a high degree of uncertainty, as tramp owners or, in some cases, industrial owners seek to improve their operating business through short-term, one-off orders (spot cargoes). Volatile freight rates and fluctuating crude oil prices increase the uncertainties and complicate long-term or medium-term planning in tramp shipping. Especially, in the dry bulk shipping market, which is close to a perfect competition market, freight rates and charter rates are highly volatile (Clarkson Research Studies, 2004). Thus, planning in tramp shipping differs clearly from planning in liner shipping. Due to the high degree of uncertainties in tramp shipping long-term and mid-term planning is challenging.

The aim of this paper is to provide a literature review of tactical planning problems in tramp shipping and how these problems can be distinguished in terms of content or timeframe between strategic or operational problems. Typically, strategic, tactical or operational problems are distinguished according to their planning horizon. As in Bektaş (2017), this is often defined as long-term, medium-term or short-term for strategic, tactical and operational. This information is rather vague and the understanding of short-term and long-term is strongly dependent on the industry. In regards to tramp shipping, the assessment of the duration of a planning horizon in the long or short term can also differ depending on the shipping company's orientation towards deep sea shipping or short sea shipping, as the duration of a voyage in deep sea operation is considerably longer than in short sea operation.

The remainder of this paper is structured as follows: Section 2 gives a brief overview about existing literature reviews in the optimization of maritime transportation. In Section 3 the research methodology is explained, Section 4 presents the results of this literature review, and Section 5 draws a conclusion and presents further research possibilities.

2 Existing Literature Reviews

Christiansen, Fagerholt and Ronen (2004) presented a literature review on ship routing and scheduling for the years 1991-2001. Ten years later Christiansen, et al. (2013) have published a follow-up literature review for the years 2002-2011. The literature reviewed is classified according to shipping mode: industrial, tramp and liner. Although a distinction between strategic and tactical is made, tactical and operational problems are treated as one. The authors define problems around fleet composition or fleet size and mix as strategic issues and routing and scheduling problems as tactical or operational issues.

Zak (2010) provides a comprehensive overview about computer based decision support systems for a range of different modes of transportation. The author concludes that the definition of the planning horizon is highly dependent on the industry, as, for example, the lifespan of vessels is considerably longer than the lifespan of trucks. Furthermore, there are comparably few computer-based decision support systems for the shipping sector.

Lun, Cheng and Lai (2010) discuss business strategies in shipping, in addition to chapters about intermodal transportation and port management, and give an overview of the shipping and logistics industry. The concept of strategy is divided into three categories: corporate strategy (what kind of business), business strategy (how to compete in the chosen business), and functional strategy (how to support the business strategy). As the authors' main focus is on liner shipping, tactical problems and / or tramp shipping is barely discussed.

The most recent literature review on optimization in maritime transportation is on linear programming in liner shipping as well as in tramp and industrial shipping (Pradana and Noche, 2019). Other optimization approaches are not considered in the literature review. The authors define strategical planning problems as "mostly about the optimal fleet size", while tactical planning "involves constructing a set of routes which [is] known as ship routing and scheduling" and the operational planning "focus[es] on the cargo routing problem" (Pradana and Noche, 2019, p. 1). Although tramp shipping is different from liner shipping, the authors do not distinguish between liner and tramp shipping in the literature classification in terms of strategic and tactical.

Tactical planning in tramp shipping has not yet been covered independently in any literature review / educational book. To understand tactical planning in tramp shipping and how it differs from strategic planning and operational planning, a structured literature review is conducted.

3 Research Methodology

3.1 Literature Search

A structured literature search is carried out using search terms. The following limitations apply: the literature must be published in English in a referred journal or edited volumes. Therefore so-called grey literature, conference proceedings and theses are excluded. The databases *Scopus, ScienceDirect, Web of Science* and *IEEE Explore* were searched for literature between 2000 and March 2020 using the search string in Figure 1 for all databases.

When choosing the search key words, a focus was placed on tactical and strategic, as well as planning problems in tramp shipping. As tramp shipping is often not referred to as such, bulk, which can refer to dry bulk (e.g. iron ore, coal ...) or liquid bulk (e.g. crude oil), was included in the search string. In the past it was found that dry bulk is also written as "drybulk", so this term was added as a search key word.

The continuous improvement of the computing power in the last years enables the solution of optimization problems that were unthinkable until recently. Therefore, the literature of the last ten years is examined. Using the above described key words a total of 957 publications published since 2000 until the end of 2019 is identified. After reading the titles 123 publications remain. Many publications found either refer to bulk power electrical systems, power grids or design and construction of bulk carriers or tankers. These research fields are not related to the problem investigated here. The amount of publications is further reduced to 68 publications by reading the

abstracts and eliminating conference publications. After removing duplicate publications, 48 publications remain. Of these, 9 more, which are older than ten years, are dropped.
Figure 2 shows the number of publications over the publication year. No clear trend can be identified here, although it can be noted that the number of publications tends to increase with a more recent year of publication.
The 39 publications examined were published in 26 different journals or volumes. *Transportation Research Part E: Logistics and Transportation Review* is the most frequently occurring journal with 15.4 % of the publications followed by *Maritime Policy & Management* with 7.7 % of the examined publications.

Figure 1: Search keywords used for the structured literature search

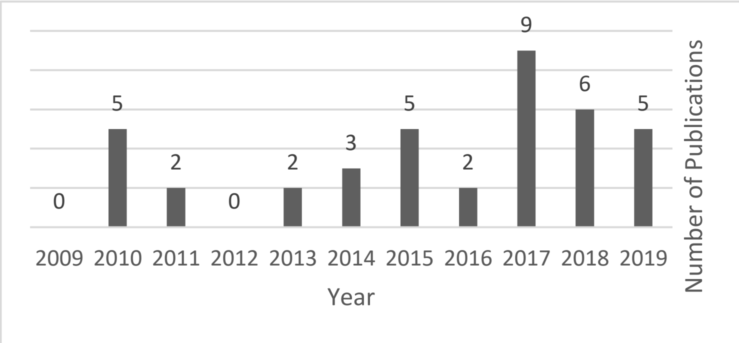

Figure 2: Number of publications per year

3.2 Classification Scheme

The planning horizon is often not clearly defined or is not attributed to the categories strategic, tactical or operational. At the same time, it can also be seen that the planning horizons differ from one specific problem to another. To answer the question how tactical planning in tramp shipping is defined in research and how it differs from strategic or operational planning, the following five classification criteria were examined in the found literature:

(1) Shipping mode: tramp, industrial or liner or the whole supply chain in one of the shipping modes

(2) Planning horizon: strategic, tactical or operational (as defined in the respective publications)

(3) Vessel type: bulk carrier, tanker or other (Container vessel, Ro/Ro vessel)

(4) Intended audience of the publication: ship owners or shipping companies, shippers, authorities and policy makers, investors, researchers, and port or terminal operators

(5) Voyage distance: short see shipping or deep sea shipping

The first classification criterion is the shipping mode (*tramp, industrial, liner*). The shipping mode has a considerable influence on decision making and planning problems. There are usually no spot cargoes, spontaneous orders which are accepted to prevent idle times of vessels, in liner shipping. Since spot cargoes are short-term in comparison to contract cargoes, planning is conducted with more uncertainty if spot cargoes are part of the business model. In industrial shipping, there are only a few spot cargoes, whereas in tramp shipping spot cargoes are an integral part of the operational concept. The publications are also analyzed to check whether they really address a problem in tramp shipping or whether it is a problem in industrial or liner shipping. Publications that define the planning problem as one in liner shipping, assume fixed timetables or focus solely on container shipping were identified as liner shipping. Some publications address the whole supply chain in one of the shipping modes. These publications are categorized as *supply chain*.

The second classification parameter is the planning horizon, which can be *strategic, tactical, operational* or a combination of these types. The literature was not classified according to a general definition of the planning horizon, but according to the definition in the publication. This is due to the fact that the general definitions of planning horizons are quite vague.

The third classification parameter considered is the type of vessel. In this publication a distinction is made between *bulk carriers* for dry bulk and general cargo, *tankers* for liquid bulk and *other vessels*. In this publication vessel types that are not usually operated in tramp shipping, such as container vessels or Ro/Ro vessels, are referred to as other vessels.

The fourth parameter is the target audience of the publications. It is investigated to whom the research is directed, who can benefit from the results. In many cases, in the conclusion it is described who can benefit from the research presented or the solutions in a publication are specifically developed for a real-world problem. The following categories were identified: *ship owners or shipping companies, shippers, authorities and policy makers, investors, researchers, and port or terminal operators*. This classification parameter is based on the idea that publications dealing with real planning problems from practice could have a different definition of planning horizons than publications that develop scientific methods or conduct fundamental research.

The fifth classification parameter examined is distance, i.e. whether the vessels operate in *deep sea shipping* or *short sea shipping*. Although many of the decision support models or optimization models found can be applied to both deep sea and short sea problems, the duration of the voyage can influence the definition of the planning horizon.

4 Literature Classification and Research Findings

The literature classification is based on five classification parameters, which are evaluated in the following. A total of 39 publications were examined, of which 4 are literature reviews or educational books (Lun, Cheng and Lai, 2010; Zak, 2010; Sahebi, Nickel and Ashayeri, 2014; Bektaş, 2017) and therefore not categorized, as they may fulfill all classification parameters without defining them or implementing different parameters in a model. Table 1 shows the investigated publications and the classification parameters. A filled field means that this parameter applies to the publication, a dashed field means that this parameter was not explicitly defined in the publication, but the publication can be assigned to this classification parameter. Literature reviews and educational books are omitted in Table 1.

In the following the individual classification parameters: shipping mode, planning horizon, vessel type, intended audience, and voyage distance are evaluated and analyzed. The found results for each classification parameter are discussed.

Table 1: Classification table of investigated literature, continued on next page

		Mode				Planning			Ship Type			Intended Audience						Dis-tance	
Authors	Year	Tramp	Industrial	Liner	Supply Chain	Strategic	Tactical	Operational	Bulker	Tanker	Other	Companies	Shippers	Authorities	Investors	Researchers	Terminals	Short Sea	Deep Sea
Cheng, L. et al.	2019	▤				■				■				■		■			■
Gu, Y. et al.	2019			■			■	■		■		■							■
Guan, F. et al.	2019	■					▤	▤	■			■							■
Hoorn, S.V.; Knapp, S.	2019	■	■	■		■			■	■	■			■				■	
Yu, H. et al.	2019	▤				■				■				■	■				■
Papageor-giou, D.J. et al.	2018	■				■			■	■		▤				▤		■	■
Wang, P.; Mileski, J.	2018	▤	▤	▤		■			■	■	■					■		■	■
Wang, X. et al.	2018	▤					■			■		■							■
Wu, L. et al.	2018		■			■	■	■	■			▤							■
Zhang, X.; Lam, J.S.L.	2018	■		■				■	■		■		■						■
Zhao, Y.; Yang, Z.	2018	■					▤	▤	■			■							■
Abouarghou b, W. et al.	2017	■				■				■		■			■				■
Alexandridis, G. et al.	2017	▤				▤			■					■	■	■		■	■
Arslan, A.N.; Papageor-giou, D.J.	2017		■				■		■			■	■						■
Calatayud, A. et al.	2017			■	■	▤					■	■		■					■
Guan, F. et al.	2017	■					▤	▤	■			■							■

		Mode				Planning			Ship Type			Intended Audience						Dis-tance	
Authors	Year	Tramp	Industrial	Liner	Supply Chain	Strategic	Tactical	Operational	Bulker	Tanker	Other	Companies	Shippers	Authorities	Investors	Researchers	Terminals	Short Sea	Deep Sea
Lin, H.-F.; Chang, K.-L.	2017	■				■			■			■				■			■
Stavroulakis, P.J.; Papadi-mitriou, S.	2017					■								▤		▤		■	
Yang, D.; Wang, S.	2017	▤		▤		▤			■					■			■	■	
Kou, Y.; Lou, M.	2016	▤				■			■			■							■
Laake, J., Zhang A.	2016	■				■			■			■			■				■
Dai, L. et al.	2015	▤	▤			■			■			■			■				■
Kang, H.-W. et al.	2015	■	■	■		■			■	■	■	▤			▤			■	■
Meng, Q. et al.	2015	■						▤	■			■						■	
Norstad, I. et al.	2015	■		■			■		■			■							■
Pujawan, N. et al.	2015		▤		■	■		■	■			▤					▤	■	
Bakkehaug, R. et al.	2014			■		■					■	▤							■
Dinwoodie, J. et al.	2014	▤	▤			▤			■			▤				▤		■	■
Al-Yakoob, S.M.; She-rali, H.D.	2013		▤					■		■		■					■	▤	▤
Morales-Fusco, P. et al.	2013			■	■	■					■	■	■	■				■	
Alvarez, J.F. et al.	2011	■	■			■			■			■			■				■
Veenstra, A.W.; van Dalen, J.	2011	▤	▤			■			■	■		▤	▤					■	■
Fagerholt, K. et al.	2010	■	■			■		■	■			■						■	

		Mode				Planning			Ship Type			Intended Audience						Distance	
Authors	Year	Tramp	Industrial	Liner	Supply Chain	Strategic	Tactical	Operational	Bulker	Tanker	Other	Companies	Shippers	Authorities	Investors	Researchers	Terminals	Short Sea	Deep Sea
Lagoudis, I.N. et al.	2010	■		■		■			■	■	■	▤	▤			▤			■
Li., J. et al.	2010		▤					■		■		■	■					■	■

4.1 Operational Mode

Most of the publications deal with planning problems in tramp shipping, which can be expected with the chosen search terms. Surprisingly, almost as many publications deal with tramp shipping and liner shipping (4 publications) at the same time as with tramp shipping and industrial shipping (5 publications). Although the shipping modes tramp and industrial are resemble each other and clearly distinguish from liner shipping. A detailed distribution of publications by shipping mode is shown in Figure 3. The intersecting circles show the overlaps of the individual classification parameters, thus publications which can be assigned to two or more operational modes. The intersections are highlighted in a darker shade.

Of the identified publications, only 3 address the entire supply chain, two of them with a focus on liner shipping. No publication considers a supply chain in tramp shipping. This could be due to the fact that spot cargoes in tramp shipping make it more difficult to plan and optimize supply chains, in particular if irregular shipments are involved.

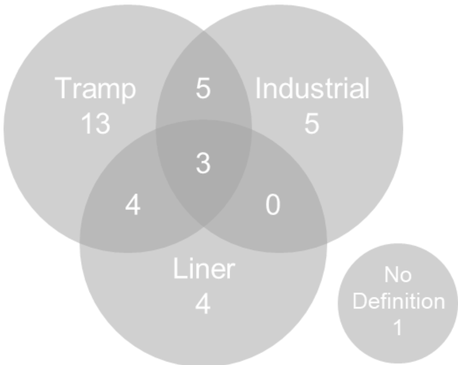

Figure 3: Evaluation of the publications by shipping mode

4.2 Planning Horizon

In Figure 4 the number of publications categorized according to the three different planning horizons: strategical (long-term), tactical (medium-term), and operational (short-term) is shown. The amount of publications that can be assigned to more than one planning horizon is listed in the darker, overlapping areas in Figure 4. The evaluation according to the classification parameter planning horizon in Figure 4 shows that no publication combine strategic and tactical planning at the same time, but there are two publications that combine strategic and operational planning. Pujawan, et al. (2015) present methods to combine the operational problem shipment planning with the strategic decision of storage capacity planning. In their simulation model the authors use the example of a cement company, that operates its own ships (categorized as industrial shipping) as well as its own storages (categorized as supply chain). The second publication combining operational and strategic decisions is by Fagerholt, et al. (2010). Fagerholt, et al. (2010) investigate two strategic problems: acceptance or rejection of long-term transport contracts and determination of an optimal fleet (fleet size and mix problem). The authors combine these strategical planning problems by implementing a simulation framework around an optimization based approach for short term routing and scheduling.

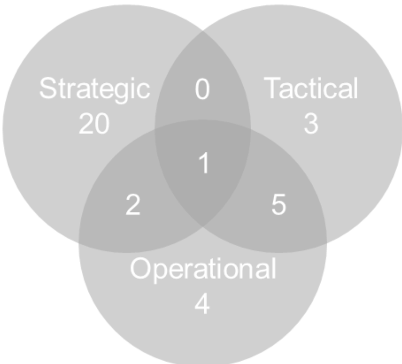

Figure 4: Evaluation on the publications by planning horizon

As already noted in the existing literature reviews, tactical planning horizons are often considered together with operational ones, or there is no clear distinction between these planning horizons. In this review 5 publications address tactical and operational planning horizons together.

Only 3 publications identify a solely tactical problem, these are briefly described in the following. Wang, Fagerholt and Wallace (2018) describe their investigated problem as a tactical fleet composition problem in which charter decisions are investigated. The authors use a planning horizon of one year and based on their problem description the shipping mode in the publication is categorized as tramp shipping. Arslan and Papageorgiou (2017) investigate a fleet sizing and deployment problem in industrial bulk shipping. The authors aim it to determine the amount of charter vessels and the respective charter duration. They describe their problem as a tactical planning problem with a planning horizon from six months up to three years divided in time periods of three or six months. Norstad, et al. (2015) define the fleet deployment problem as a tactical planning problem, as the aim is to find a fleet schedule for the next few months. The authors investigated a company that operates in both liner and tramp shipping, as its business model is a mix of both shipping modes. In summary, the tactical planning horizon can be described as a few months to years, depending on the investigated problem or company under consideration.

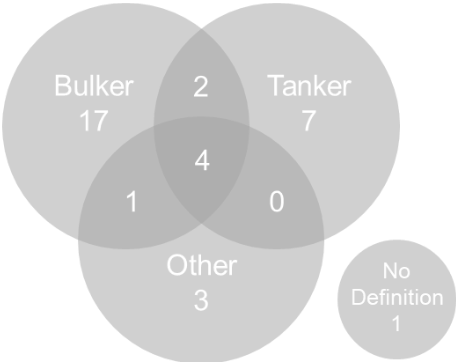

Figure 5: Evaluation of the publications by vessel type

4.3 Vessel Type

The number of publications that can be categorized in terms of vessel type is shown in Figure 5. One publication (Stavroulakis and Papadimitriou, 2017) could not be categorized according to vessel type and thus are listed in a separated circle in Figure 5. The majority of the investigated papers relate to bulk shipping and are classified as bulk carriers (Bulker in Figure 5). Publications that address bulk carriers, tankers as well as other vessels (4 publications), all indicate a strategic planning horizon. Otherwise, the overlap between the individual vessel types is small. *Publications that are categorized as other vessel types are also categorized as liner shipping. Other vessel types are mainly container vessels, which usually operate in liner shipping.*

4.4 Audience

Several indented audiences can be addressed in one paper, as shown in Table 1. 21 publications address at least two different audience groups. For 14 publications only one audience could be identified, which does not mean that the research cannot be of interest to other groups as well. The audience most frequently addressed is shipping companies with 27 publications. It is noticeable that publications aimed at investors, authorities or researchers always refer to a strategic planning horizon. While papers aimed solely at shipping companies mainly address tactical-operational (4 publications), tactical (2 publications) and operational problems (2 publications). This distribution of intended audiences may be caused by the tendency of investors and authorities to plan long-term projects and investments with a strategic character. Why researchers in particular investigate mainly long-term problems, i.e. strategic problems, is unclear. However, it can be assumed that these problems are characterized by a very high degree of uncertainty, so that solutions found might have a more theoretical character. The distribution for publications addressing shippers or ports and terminals is balanced between the planning horizons.

4.5 Voyage Distance

More than half of the papers found (20 papers) deal with planning problems in deep sea shipping. 8 publications deal with both deep sea and short sea shipping, 7 publications only refer to short sea shipping. This is also shown in Figure 6. The darker area shows the number of publications dealing with both deep sea shipping and short sea shipping.

All found publications addressing ports or terminals can be categorized as short sea problems in the respective publications. This could be due to the fact that the duration of the voyage in short sea shipping is significantly shorter than in deep sea shipping and thus the planning uncertainties caused by heavy weather, for example, are also smaller. Publications in which planning problems for both short sea and deep sea are examined, mostly consider problems at the strategic level (6 publications), only 2 publications consider both short sea and deep sea shipping at the operational level; none of the publications considers a tactical planning horizon.

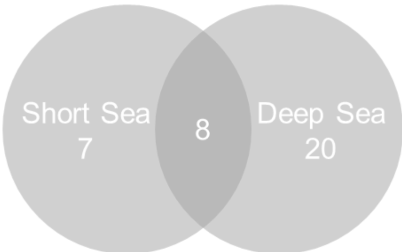

Figure 6: Evaluation of the publications by voyage distance

5 Conclusion and Outlook

A clear classification of planning problems by planning horizon in tramp shipping cannot be made. Neither is it possible to give exact time spans of long, medium and short term in order to improve this vague definition. Nevertheless, it can be stated that decisions that have an impact on several years, such as fleet size and composition, are considered strategic. Decisions that affect time periods of a few months up to about one year, such as charter-in or charter-out decisions, are considered tactical. Operational problems refer to a period of a few weeks to days.

In the literature examined, the planning horizons (strategic, tactical and operational) are often considered separately. This neglects the influence that long-term strategic decisions, for example, can have on the operative business. In particular, the link between strategic planning and operational optimization, the tactical planning horizon, is examined in less than a quarter of the literature reviewed. This may be due to the fact that tactical and operational problems are considered together or no distinction is made between planning horizons. Like prior literature reviews and publications, this one concludes that both business and research would benefit from a linked consideration of the different planning horizons in optimization and market analysis. Since decisions from the three planning horizons influence each other and cannot be strictly separated in practice, this link should also be reflected in research.

Despite the authors' thorough literature research, it cannot be guaranteed that individual sources have been overlooked, thus this literature research cannot claim to be complete. The evaluation of the individual literature sources has shown that the search string cannot cover all possible terms used in the literature. Often tramp shipping is not described as such or the words strategic or tactical are not explicitly mentioned. Therefore this literature review would benefit from an extensive snowballing search in the future.

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Sustainability in Arctic Maritime Supply Chains

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Purpose: The sustainable development of Arctic maritime supply chains requires an effective balance between economic growth, environmental protection and social relations. Existing Arctic development projects are often distinguished by single-criterion decision making - economic growth to the detriment of other components. The paper aims to analyze existing approaches and practices of Arctic supply chains development from a sustainable development viewpoint.

Methodology: Best practices of other industries are identified by a thoroughly literature research of relevant publications and developing a model for sustainability issues in Arctic maritime supply chains. The model compromises relevant indicators in regard to economic, social and environmental performance for the Arctic region.

Findings: The result of this paper will be a thoroughly overview over current sustainability issues in the Arctic framework (economic, social and environmental). Findings for example will be how companies adjust to the ban of using heavy Sulphur fuel in the Arctic or social and economic changes in remote areas due to more shipping in the Arctic.

Originality: The originality of the research is defined by the sustainability viewpoint on the problem: the combination of social, economic as well as environmental issues is the main focus of this paper especially with a focus on remote areas of the Arctic.

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1 Introduction

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, 1987). Sustainable development is needed for long-term global development. This principle, announced in 1987, is being discussed by world leaders and international community representatives on a global level to ensure coherent, secure and sustained development of the world economy since then. In 1992 in Rio de Janeiro commitments of 172 states to reach a sustainable development were formulated in the “Agenda 21” declaration. (United Nations, 1992).

A sustainable development entails the unity of economic, environmental and social development. The economic approach to the sustainable development concept considers the economy as a waste less, environmentally friendly, energy-efficient and material-efficient system aimed at creating an environmentally acceptable product. Environmental development is the base sustainable development and must ensure the safety and viability of natural systems, with a view to ensure global stability of the planet's biosphere. The social dimension of sustainable development is aimed at achieving equal distribution of social benefits among all members of human society.

In 1995 the Sustainable Development Commission of the UN adopted indicators to be used by countries during the strategic decisions implementation on the national level for the work program of sustainable development (United Nations, 1995). These indicators are categorized into four dimensions: social indicators, economic indicators, ecological indicators, and institutional indicators.

The shipping industry nowadays is under pressure in regard to social, economic and ecological factors. It is an industry in a maturity stage, which is characterized by declining income growth, structural overcapacity, and changes in demand. At these stage, companies – need to develop new strategies, aimed at increases in efficiency, creating new markets and fulfillment of requirements.

The Arctic regional development as a transport corridor is defined in the Russian government set of strategic initiatives. There are a number of targets and documents developed at these regards, including the national container operator implementation on the Arctic Maritime Road to increase cargo turnover by 2024 to 80 million tons per year, mainly on the Northern Sea Route (NSR) and to 160 million tons per year by 2035, including at least 40 million tons per year of containerized cargoes (News Agency TASS, 2019).

The sustainable development of Arctic maritime supply chains requires an effective balance between economic growth, environmental protection and social relations. Existing Arctic development projects are often distinguished by single-criterion decision making - economic growth to the detriment of other components. This paper aims to analyze existing approaches and practices of Arctic supply chains development from a sustainable development viewpoint to allow alignment in accordance with international and local legislation, research and best practices.

2 Research Overview

The following section shall give an overview of existing literature of supply chain management in the Arctic in regard to sustainability issues. The overview will start with the general literature in regard to sustainability and then moves on to the literature regarding sustainable supply chain management. Then papers about sustainable supply chains in the Arctic and the used approaches in Arctic supply chains will be introduced.

2.1 Sustainable Supply Chain Management

The UN defines sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). In 1994 the term "triple bottom line" was invented as a more holistic concept. In "Cannibals with Forks: The Triple Bottom Line of 21st Century Business" Elkington stated that "companies should account not only for the traditional financial profit and loss bottom line, but also for both the social and the environmental bottom lines" (Elkington, 1997). "The first - people's bottom line - measures the level of social responsibility of the company, whereas the second - planet's bottom line - records the environmental impact of its operations. This three-pillar perspective became synonymous of a more comprehensive approach to business sustainability". (Martins and Pato, 2019).

Sustainable supply chain management (SSCM) became one of the most prolific research areas over the last years, but the concept of sustainable supply chains must be preceded by a thorough understanding from both theoretical and practical standpoints. In "World class sustainable supply chain management: critical review and further research directions" the authors mentioned: "There is a growing body of literature related to sustainable supply chain management but on the other hand, there are overlaps between green supply chain management or environmental supply chain management literature and sustainable supply chain management literature, as well as other areas that have attracted significant contributions, such as environmental supply chains, ethical supply chains and responsible supply chains" (Dubey et al., 2017). A number of SSCM definitions were defined, thus in (Dubey et al., 2017) a list of definitions of sustainability in supply chain literature was developed, which contain sixteen definitions of SSCM. Dubey also states that "the majority of the SSCM literature focuses mostly on the environmental and economic dimensions and there is a lack of research that identifies and tests the impact of factors such as culture, geography, and company size on SSCM practices. To eliminate this gap, the new term – World Class Sustainable Supply Chain Management (WCSSCM) was introduced as a continuous development of the appropriate organizational culture, use of innovative technologies, and awareness and involvement of the top management, employees, and society to consider and translate external pressure into strategic and operational performance as well as economic stability while considering the impact of these practices on social equity, ethical values and welfare, and the environment." (Dubey et al., 2017). WCSSCM consists of six constructs and eighteen items, which are conceptualized as follows: (Dubey et al., 2017)

1) "Environmental: Green Design, Packaging, Distribution and Warehousing; Conservation; Life cycle concept"

2) "Social Values and Ethics: Code of Conduct; Employee welfare; Equity; Public awareness and Ethics"

3) "Economic Stability: Profitability; Strategic collaboration and Information sharing; Logistics optimization"

4) "Operational Performance Assessment: Audit and Assessment; Standardization"

5) "Internal Factors: Organizational culture; Technology; Corporate Strategy and Commitment"

6) "External Factors: Government Rules and Regulations; Customer Pressure; Competition"

Hansen and Schaltegger propose an extended scorecard architecture under the name of Sustainable Balanced Scorecard (SBSC) as an approach (Hansen and Schaltegger, 2012). In (Epstein and Wisner, 2001) the differentiation of the SBSC from the balanced scorecard (BSC) is explained by "recognizing sustainability-related objectives and performance measures and it is an appropriate tool for integrating strategically relevant environmental, social, and ethical goals. The SBSC measures an organization's performance in four to five perspectives, which are: financial, customer, internal business process, learning and growth, as well as environmental perspectives. Integrating social and environmental metrics into the scorecard outcomes group of benefits improves decision-making and corporate responsibility" (Epstein and Wisner, 2001).

2.2 Sustainable Development in the Arctic

The following paragraphs will give a brief overview over the literature in regard to Arctic supply chains with a focus on sustainability. (Gunnarsson, 2013) gives an outlook of marine operations in the Arctic in the future. (Trump, Kadenic and Linkov, 2018) use a multicriteria decision analysis to help identify policies that minimize the potential for adverse environmental impacts and at the same time maximize economic and industrial objectives. (Franklin, 1983) showed in a paper the adverse obstacles Arctic supply chains face in Canada. During the last years a decline in Arctic sea ice lead to the possibility of new routes in the Arctic. (Pizzolato et al., 2014) conducted a study of vessel voyages by using a large dataset based on the level of sea ice. Between 1992 and 2012 increased traffic was observed in connection with declining levels of sea ice (Pizzolato et al., 2014).

Melting Arctic sea ice make new shipping routes feasible, for example the Northwest Passage (NWP) and the Arctic Bridge. The former can be used as an substitute route for the Panama Canal and the latter can be used to connect e.g. the port of Murmansk with Canada (Pizzolato et al., 2014). This will lead to a need in investments in a better port infrastructure, the use of natural resources and higher tourism without leading to adverse effects for environment, people, and wildlife (Rompkey and Cochcrane, 2008). (Buixadé Farré et al., 2014) state that research on Arctic shipping routes was focused on the Northeast Passage (NEP) along the Arctic coasts of Norway and Russia and the Northwest Passage (NWP) around the Arctic coasts of the US and Canada. The Northern Sea Route (NSR) is another name for the NEP. However according to (Solski, 2012) the NSR is in Russia defined "as extending from the Novaya Zhelaniya straits (at the Novaya Zemlya archipelago,

connecting the Barents Sea to the West and the Kara Sea to the East), to Cape Dezhnev by the Bering Strait".
(Wang and Overland, 2012) predict summers with no ice in the Arctic by 2030. (Hinzman et al., 2005) write about the climate changes in the Alaskan part of the Arctic. (Prowse et al., 2009) did a study on the influence of climate change for the Canadian Arctic. They took a look into additional business and the establishment of new routes for mining and oil companies. The following routes were identified in the Arctic area of Canada: "to the port of Churchill and via Hudson Strait, to the Beaufort Sea via Bering Strait or the Mackenzie River, and through the Arctic Archipelago via the Northwest Passage (NWP). The NWP extends from Baffin Bay through Lancaster Sound to the Beaufort Sea via a number of different waterways". Whereas (Walsh, 2008) shows different scenarios till 2050 for the Arctic climate. (Buixadé Farré et al., 2014) are describing the chances the Northeast Passage can bring as a maritime route for the connection of the Atlantic and the Pacific but they also state the limitations of the NEP in comparison to the Suez Canal, e.g. "jurisdictional disputes create political uncertainties; shallow waters limit ship size; lack of modern deepwater ports and search and rescue (SAR) capabilities requires ships to have higher standards of autonomy and safety; harsh weather conditions and free-floating ice make navigation more difficult". The Northeast Passage has a big economical potential for transports between Europe and China, South Korea and Japan. The distance using the NWP instead of the Suez Canal can shorten the distance between Yokohama and Rotterdam by 37% or between Busan and Rotterdam by 29% (Buixadé Farré et al., 2014). (Ng et al., 2018) did a paper on the opportunities of new routes in the Arctic.

The Arctic is also a place where large natural resources are. Crude Oil and liquefied natural gas (LNG) projects are realized for example in the Pechora, Kara, White and Barents Sea (Bambulyak, Rautio and Grigoriev, 2012).

3 Method

Sustainable supply chain development in the Arctic is primarily connected with maritime transportations. “The Review of Maritime Transport 2019” defines maritime transport as "a complex area of activity, owing to the inherently international nature of shipping and its multi-stakeholder dimension. These characteristics create an analytical challenge that is compounded by the role of the sector as an input production factor supporting other economic sectors and areas of activity, such as trade, fishing, tourism and energy". (UNCTAD, 2019)

For this paper performance indicators developed by the United Nations Conference on Trade and Development (UNCTAD) were used. Indicators for maritime transport support monitoring, measuring, reporting and evaluation and thus could provide a guidance in sustainable development goals achievement. One of the tools, the UNCTAD Framework for sustainable freight transport, supports the development of sustainable freight transport strategies with the help of set of 250 indicators, 152 of them can be applied to maritime transport. (United Nations, 2015). Another tool is “The Review of Maritime Transport 2019” (UNCTAD, 2019) which considers different performance indicators related to the maritime transport sector. There are also goals and performance indicators of Russian legislation and public institutions, related to Arctic region development.

As result, there were the reference models of the Northern Sea Route Sustainable Chain Management Framework and the Northern Sea Route Sustainable Balanced Scorecard were elaborated, which are able to bring together and systematize goals and dimensions of sustainable development of the Arctic Maritime Supply Chains.

According to (United Nations, 2019), the most valuable sustainability parameters of the Maritime Transport are "efficiency, access to markets, infrastructure endowment, supply-side capacity, trade facilitation" and their available proxy measures are shipping connectivity and port turnaround times. A country's shipping connectivity depend on geography, trade volumes and port efficiency. Based on the Trade Port Management Program results there has been a port performance scorecard developed, "26 indicators were identified, collected and classified into six main categories: finance, human resources, gender, vessel operations, cargo operations and environment". Another factor of the shipping connectivity is the shipping fleet, characterized by vessel operations efficiency.

It also has a substantial impact on the environment, which could be measured by three vessel indicators: fitted with a ballast water treatment system, scrubber to reduce Sulphur emissions, and to adhere to regulations to reduce nitrogen-oxide pollution. (United Nations, 2019).

The Decree on the Foundations of State Policy of the RF in the Arctic up to the year 2035 established 15 performance indicators which characterize the efficiency of the provided policy in the Arctic including the life expectancy of people born in the Arctic, migrant population rate, unemployment rate, average salary, share of regional gross product, value-added share of high-technology production, NSR cargo shipping volume including transit cargo and environmental spending (Russian Federation, 2020).

In addition, there are a number of institutions which activity is connected to the sustainable development of the Arctic and who contribute substantial inputs in this field. There is the Centre of Expertise “Project office of the Arctic development” (PORA). Among their initiatives, they have developed the Polar Index, which is assigned to the Arctic sub region or companies operating in the Arctic (Bobylev et al., 2018). Methodological basis of the Polar Index (PORA, 2020) is a concept of the sustainable development. The Polar Index includes sets of performance indicators, including socio-economic, socio-ecological, environmental-economic for regions and economic, social, environmental – for companies.

Socio-economic indicators for regions are average salary and living wage ratio; migration rate; regional gross product per capita; transport infrastructure availability; respect for the rights of indigenous peoples; housing provision per inhabitant; proportion of population using the Internet to total population; employment and unemployment as a percentage of the total population. Socio-ecological indicators for regions are the number of people with access to quality fresh water; the increase of life expectancy of indigenous peoples; existence of regional and municipal programs to adapt people and management systems to climate change. Environmental-economic indicators for regions are share of environmental spending in the regional budget; growth rate ratio of stocks and production of critical mineral resources; percentage of recultivated land area; percentage of GDP per emission fees; percentage of hazardous waste.

Economic indicators of the Polar Index for companies, working in the Arctic zone, settled as asset profitability, income trends, and capital expenditure. Social indicators are working conditions of the company employees, level of their skills, charity activities, infrastructure development, policies for indigenous populations. Environmental indicators are pollution rates, accidents, investments in environmental protection activities, resource-saving technologies availability, recycling of raw materials (Bobylev et al., 2018).

Another public institution, which realizes sustainable development principles in the Arctic Zone is project “Arctic 18-24-35: view of youth”. Developed by this institution is the strategic document “Strategy of the Arctic 18-24-35” which represents the vision of a young Arctic Zone future across a range of priorities(Dolgova, Ruzakova and Siluanova, 2018):

1) ensure comprehensive human development as a key engine and object of regional development;

2) increase the multiplier effect of large Arctic projects on the basis of integrated innovations;

3) create conditions to improve the quality of life and social standards in the Arctic Zone;

4) develop regional entrepreneurship, with a focus on youth projects, small and medium-sized businesses;

5) improve the competitiveness of Arctic transport systems on the basis of multimodal transport and logistics infrastructure;

6) ensure a balance in the society and nature development;

7) promote the discovery of the innovative potential of the Arctic through related targeted high-tech projects development.

Public institutions in the Arctic Zone are important to reach the sustainable development goals proposed by the performance indicators, but they almost have no influence on the decision making by the government, regional or federal. The role of public institutions will probably increase after the new project digital platform “Arctic 2035” will be launched. This project was initiated as the opportunity to generate interest of experts and the public to a government strategy development and has different types of participant's relationship, including expert round-tables discussions, mobile discussion clubs, online offers submitting and feedback. This project is supposed to increase the influence on government policy in the Arctic Zone and the involvement of citizens into decision making.

4 Results

The authors propose the model of the Northern Sea Route Sustainable Supply Chain Framework (Fig. 1). This model reflects factors influencing maritime supply chain sustainability under six dimensions of WCSSCM: environmental, social value and ethics, economic stability, operational performance assessment, internal and external factors.

The environmental dimension of maritime supply chains depends on pollution rates, accidents, resource-saving technology availability, and investments in environmental projects. Social value and ethics dimension need to be supported with a code of conduct, which ensures comprehensive human development, creates conditions for improving the quality of life and social standards in the Arctic Zone; grants employee welfare and equity, and guarantees public awareness and ethics. The economic stability dimension needs to ensure profitability of NSR operations, logistic optimization and strategic collaboration and information sharing within all stakeholders. The operational performance needs to ensure shipping connectivity, port waiting times, as well as vessel and cargo operations optimization. The internal factors dimension are corporate strategy and commitment, organizational culture and technology. As along the NSR different companies will operate, this dimension needs to enable their interoperability and communications based on mutual principles of collaboration, by a support business ecosystem activity. The external factor dimension requires alignment with local and international rules and regulations, public institution assessment, customer pressure and competition realities.

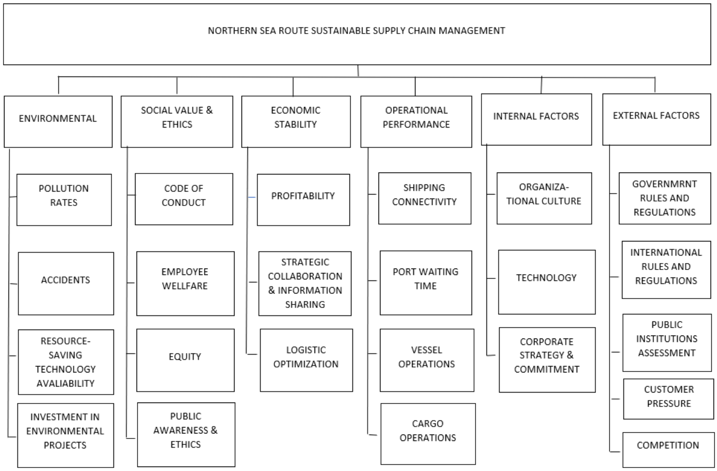

Figure 1: Northern Sea Route Sustainable Chain Management Framework

Furthermore, there is the Northern Sea Route Sustainable Balanced Scorecard model developed which as logical extension of the NSR SCM Framework represents goals which should be accomplished for a sustainable supply chain development (Fig. 2). The NSR SBSC model contains six perspectives: economic performance, external stakeholders, environmental performance, social performance, operational performance, and skills and capabilities and evaluate the NSR as business ecosystem, which contains of a number of different agents.

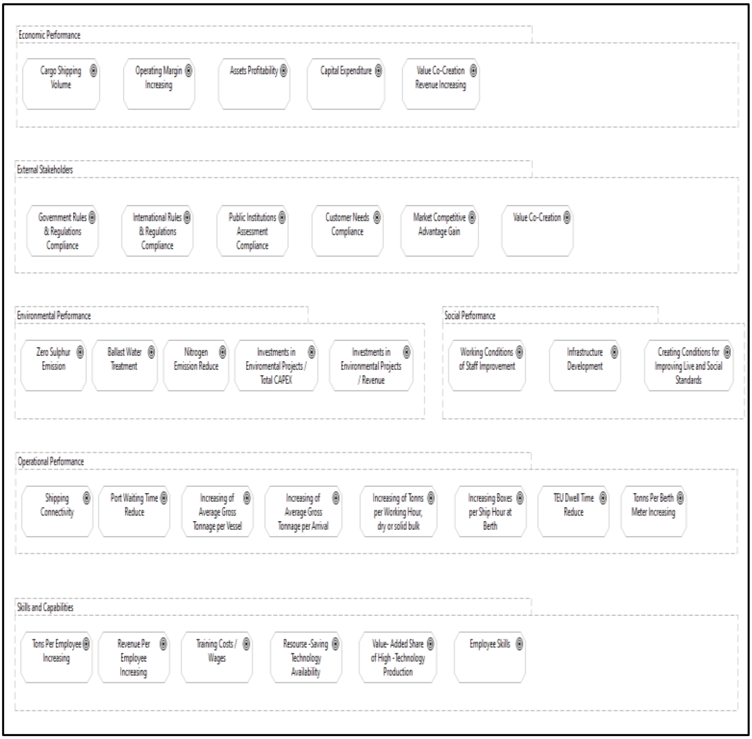

Figure 2: Northern Sea Route Sustainable Balanced Scorecard

The Economic Performance perspective set a number of goals such as cargo shipping volume and operating margin increasing, assets profitability, capital expenditure, increasing of value co-creation revenue.

The External Stakeholders perspective controls government and international rules and regulations compliance, relationship with public institutions, customer needs compliance, market competitive advantage gain and value co-creation.
The Environmental Performance perspective set such goals as zero Sulphur emission, ballast water treatment, nitrogen emission reduction, correlation between investments in environmental projects and total Capital Expenditure (CAPEX) and revenue.
The Social Performance perspective consists of such goals as improvement of staff working conditions, infrastructure development, creating conditions for live and social standards improvement.
The Operational Performance perspective has goals of shipping connectivity, port waiting time reduce, increasing of average gross tonnage per vessel / arrival, increasing quantity of tons per working hours for dry or solid bulk cargoes, increasing quantity of containers per ship hour at berth as well as quantity of tons per berth meter, reducing of Twenty-foot Equivalent Unit (TEU) dwell time.
The Skills and Capabilities perspective evaluate succeeding such goals as tons or revenue per employee increasing, resource-saving technology availability, value-added share of high-technology production, correlation between training costs and wages and employee skills improvement.
The Models of the Northern Sea Route Sustainable Supply Chain Framework and the Northern Sea Route Sustainable Balanced Scorecard are useful to provide substantial support for a sustainable development assessment of the NSR as international transport corridor and modern transport communication of the RF.

5 Discussion of Results

The Russian Arctic is an extremely complex facility for public administration. Its complexity consists not only in climate, environmental or logistic features that provide an impact on development but the main difficulty is the critically high cost of human error. The price of development mistakes in the Arctic does not lend itself to neither economic nor social calculation. The Arctic is deservedly considered the most dangerous region on the planet. The Arctic is the northern belt of Russia, a special regional dimension of the country, in which huge territories extending from the extreme points of the Russian borders in Europe to the limits of Russia in Asia, are merged by the unity of harsh natural and climate conditions, the wealth of natural resources, and a huge potential for the development of maritime transport (Dolgova, Ruzakova and Siluanova, 2018).

In December 2019, the Russian Security Council has approved "The Foundations of State Policy in the Arctic zone until 2035". This document shall combine the activities of national projects and state programs, investment plans of infrastructure companies, and development programs of Arctic regions and cities. The State policy of the RF in the Arctic is based on national priorities of the RF. The national interests of the Russian Federation in regard to the Arctic are (Decree of the President of the RF N164, 2020):

a) "to ensure the territorial integrity and sovereignty of the RF";

b) "preservation of the Arctic as a territory of a peaceful, stable and mutually beneficial partnership";

c) "ensuring high quality of life and good living conditions of people in the Arctic area of the RF";

d) "development of the Arctic areas of the RF as a resource base and its rational use to accelerate the economic growth of the RF";

e) "development of the NSR as competitive in the world market";

f) "protection of the Arctic environment, to protect the traditional way of life of indigenous peoples living in the Arctic zone of the RF".

Above mentioned policy has established a very high level economic, social and environmental dimensions of the Arctic region development as well as internal and external state policy at this region, but more precise goals were conducted by another document. The Government of the RF has approved the development plan of the NSR infrastructure until the year 2035, the first policy document defining the development of the largest maritime transport highway of the Russian north. The plan is intended to specify the activities of the Northern Sea Route federal project, it includes construction of nuclear ice breakers, emergency and hydrographic vessels, a dredging fleet, using ice-class container ships powered by nuclear fuel or liquefied natural gas, construction of container hub terminals, port infrastructure development, global maritime disaster communication and safety facilities construction, objects automatic identification system and remote sensing system in NSR areas development, continuity of satellite communications securing for NSR users, centralized operational and tactical management system development, creation of a Russian container operator for international transportation on the NSR, analysis the need for a national maritime dredging company, establishment of a single control center for navigation control and the year-round navigation with organization of transportation on a regular basis (Russian Federation, 2019).

The development plan of the NSR infrastructure has determined a number of measures for shipping connectivity and other operational aspects improvement, but the document hardly identifies social issues in the Arctic regions dependent on the NSR work. Without this it will be difficult to attract staff to the Arctic. Another risk was announced by the Accounting Chamber of the Russian Federation. According to auditors, the shortage of transport vessels may call into question the expected growth of cargo traffic to 80 million tons (RG.RU, 2020). Economic, environmental dimensions as well as internal and external environment are not revealed at the document.

Despite the fact that today exploration and development is one of the domestic policy priorities of the RF, the Arctic still does not have a centralized system of management and a single vector of development. At present, the Arctic zone of the RF is a conglomerate of separate administrative entities with different status, including entire regions, as well as individual municipal districts and cities. The Arctic territory does not have a single management administration and thus no tool for centralized planning and control over the implementation of the taken decisions. Although possible models exist for integrating the Arctic into a single administrative framework, it is necessary to create a common basis for further development and a single vector of further growth by using the principles of sustainable development (Bobylev et al., 2018). The NSR Sustainable Chain Management Framework and External Stakeholders Perspective of the NSR Sustainable Balanced Scorecard can serve as a foundation for such process of developing.

Moreover, the Northern Sea Route development is regulated by different government authorities. Thus, the infrastructure development is under control of the state corporation "Rosatom", and for cargo turnover are responsibility lies with the Ministry of Nature of the RF, the Ministry of Transport of RF, the Ministry of Far East Development and "Rosatom" as well. These authorities have different forecasts for the NSR cargo turnover development and even try to accomplish the goal of cargo turnover increase by 2024 with the extension of the NSR borders. Such aspects of the NSR Sustainable Chain Management Framework as technology, organizational culture, strategy and commitment are intendent to contribute to coordination and efforts concentration of all stakeholders.

The ecological dimension of the NSR development is still under great pressure as the dominant part of the planned cargo turnover increase represents crude oil from greenfield site mining. Setting of clear goals and dimensions for the control as they mentioned in this paper reference models will play a role in ensuring sustainable environment.

The Northern Sea Route could become a driver of the Arctic zone progress, but it needs to satisfy sustainable supply chain management requirements, and with this regard key performance indicators elaboration based on the international and Russian institutions experience can provide considerable support.

6 Conclusion

The issues of Arctic Zone sustainable development as well as Arctic maritime supply chains are in themselves extremely relevant and therefore actively discussed by different stakeholders. The Arctic is deservedly considered the most dangerous region on the planet as the price of development mistakes in the Arctic does not lend itself to neither economic nor social calculation. Melting Arctic sea ice make new shipping routes feasible; this will lead to a need in investments in a better port infrastructure, the use of natural resources and higher tourism without leading to adverse effects for environment, people, and wildlife.

Considering Arctic maritime supply chains from its sustainability point of view may lead to both productive and balanced development of shipping in the region. Sustainable supply chain management (SSCM) became one of the most prolific research areas over the last years. Taking into account such goals of sustainable development, as environmental issues, good working conditions and economic growth, fair actions and production when designing maritime supply chains is very important for its overall success and effectiveness. In this point the interaction of business, society and government involved in Arctic supply chain management is strongly needed and developed in this paper the NSR Sustainable Chain Management Framework and the NSR Sustainable Balanced Scorecard might contribute to Arctic maritime supply chain sustainability.

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Artificial Intelligence and Operations Research in Maritime Logistics

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Purpose: The application of artificial intelligence (AI) has the potential to lead to huge progress in combination with Operations Research methods. In our study, we explore current approaches for the usage of AI methods in solving optimization problems. The aim is to give an overview of recent advances and to investigate how they are adapted to maritime logistics.

Methodology: A structured literature review is conducted and presented. The identified papers and contributions are categorized and classified, and the content and results of some especially relevant contributions are summarized. Moreover, an evaluation, identifying existing research gaps and giving an outlook on future research directions, is given.

Findings: Besides an inflationary use of AI keywords in the area of optimization, there has been growing interest in using machine learning to automatically learn heuristics for optimization problems. Our research shows that those approaches mostly have not yet been adapted to maritime logistics problems. The gaps identified provide the basis for developing learning models for maritime logistics in future research.

Originality: Using methods of machine learning in the area of operations research is a promising and active research field with a wide range of applications. To review these recent advances from a maritime logistics' point of view is a novel approach which could lead to advantages in developing solutions for large-scale optimization problems in maritime logistics in future research and practice.

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1 Introduction

Artificial Intelligence (AI) is currently one of the major topics in research as well as in practice. It can be used to gain information from analyzing huge datasets, for example for anomaly detection or picture recognition. Simultaneously, Operations Research (OR) is a well-known field and its methods are commonly applied to use given information for developing optimal decisions, e.g. regarding production or scheduling. Especially the Logistics sector uses OR regularly for optimizing their processes, e.g. for optimizing the routing of trucks (Hillier and Lieberman, 2010, p. 4).

In the Logistics sector, Maritime Logistics is of particular importance. More than 11 million tons of containers and dry bulk were shipped across the oceans in 2018. Consequently, maritime transport is described as “the backbone of globalized trade” (UNCTAD, 2019). As a result, fast, efficient, and reliable transportation is necessary. Meanwhile, the advancing digitalization of the sector and the ever-increasing amount of available data are opening up new opportunities. Data collected on ships can be made usable by intelligent methods to extract information. A combination with well-known OR methods offers the possibility to use synergies and advantages of both methods.

In this work, we examine how the combination of OR and AI is discussed, evaluated, and applied in the scientific community. The objective of this paper is to identify opportunities for the combined application of OR and AI in Maritime Logistics, to generate an overview as well as to detect research gaps. This includes questions regarding application areas which are (probably) most suitable for utilizing OR and AI, as well as the discussion where the two methods overlap.

The paper is structured as follows: In Section 2 we give some theoretical background on OR and AI/Machine Learning, respectively. This is followed in Section 3 by describing our methodical approach to the literature review. After this we will present our findings and highlight some important publications in Section 4. In Section 5 we then identify some research gaps before we conclude and give an outlook on future research perspectives.

2 Theoretical Background

2.1 Planning problems in maritime logistics

There are many different planning problems in Maritime Logistics, which can be categorized by their area of application.

Planning problems at sea are, for example, the strategic design of a container liner network, i.e. on the selection of ports and routes as well as the operative decision about the vessel speed (e.g. Meng, et al., 2014).

Various planning problems exist with regard to terminals and ports, since this is where Logistics at sea and Logistics on land meet. The planning of the positioning and the scheduling of a vessel at the berth, called Berth Allocating Problem (BAP), is a relevant planning problem. At the terminal, several planning problems regarding intralogistics and storage yard optimization have to be addressed (Anwar, Henesey and Casalicchio, 2019). In particular, the routing of trucks, straddle carriers or AGVs (automated guided vehicles) and the efficient storage of containers to reduce movements of cranes and reshuffling are analyzed in research (Stahlbock and Voß, 2007; Speer and Fischer, 2017; Böse, 2020).

The connection of ports and terminals with the so-called Hinterland can be enabled through different modes of transport like truck, rail or inland vessel. For all modes of transport different planning problems exist, like the decision which mode of transport to use or the routing of the vehicle. Furthermore, repositioning of empty containers is an important aspect of planning problems in practice as well research (Braekers, Caris and Janssens, 2013, e.g.). Also, methods of revenue management can be applied to Maritime Logistics, for example for container shipping companies (Zurheide and Fischer, 2012).

Generally speaking, all these problems are optimization problems and hence can be tackled with OR methods, while to use AI a large amount of data is necessary. These data can be supplied by public organizations or can be obtained from and stored by private organizations. For research, open data platforms are necessary to utilize AI. Automated identification systems (AIS), which record and store vessel positions and details like ships' headings, is a popular data source for the scientific community (e.g. Nguyen, et al., 2018). Furthermore, weather data can be used as well for routing optimization. In practice, most companies can theoretically utilize their own data, e.g. regarding customer inquiries.

The use of AI is suitable for forecasting travel times (for vessels and trucks) and ship arrivals (Hill and Böse, 2017). Image recognition for identifying of number plates or container numbers can also be applied (e.g. LeCun, Bengio and Hinton, 2015).

2.2 Operations Research

OR is used to coordinate operations, processes, and activities in organizations, such as companies and military institutions (Hillier and Lieberman, 2010, pp. 3–4). It can be defined as the development and application of quantitative models and methods for decision support (Kandiller, 2007; Eiselt and Sandblom, 2010). The aim is to find the optimal solution for a planning problem. These problems come, for example, from the field of

transport planning or personnel deployment planning (Hillier and Lieberman, 2010, p. 4).
Mathematical models in OR can be distinguished into (amongst others) linear programming (LP), mixed integer programming (MIP) and non-linear programs (NLP) (Suhl and Mellouli, 2013, p. 12). Furthermore, also simulations, Markov chains and game theory are methods and concepts of OR amongst others (Hillier and Lieberman, 2010).
There are two categories of solution procedures. On the one hand, a model can be solved to optimality. This involves algorithms such as the Simplex procedure or the Branch and Bound method. These methods in most cases require a lot of time to compute the optimal solution for large realistic problems (Rothlauf, 2011, p. 68). On the other hand, there are heuristics. Their goal is not to find the optimal solution, but to achieve a good solution fast. However, it usually cannot be guaranteed that a heuristic solution is close to the optimal one (Rothlauf, 2011, p. 85). Often heuristics are developed specifically for a given problem. As a consequence, a wide range of different heuristics for different problems exists, e.g. the savings procedure for the VRP. Heuristics that can be applied to different problems are called metaheuristics. Examples are Tabu Search or Simulated Annealing (Suhl and Mellouli, 2013, p. 13).

2.3 Artificial intelligence

AI is concerned with making computers capable of emulating intelligent behavior (Holsapple and Jacob, 1994, p. 3). The overall goal is to make machines mimic “cognitive“ functions, such as “learning“ and “problem solving“ (Russell and Norvig, 2009, p. 2). Approaches include statistical methods, computational intelligence, and traditional symbolic AI. Many different tools are used in AI, and besides versions of search and mathematical optimization there are also methods based on logic, probability, and economics.

AI also includes evolutionary techniques, which use biologically inspired mechanisms leading to the evolution of new solutions, thus solving global optimization problems. Common approaches are the “Ant Colony Optimization” (Dorigo, 1992) or the “Particle Swarm Optimization” (Kennedy and Eberhart, 1995), where swarm intelligence is mimicked in a setting where different agents interact with one another while moving through the solution space based on simple mathematical formulae over the particle’s position and velocity to find local and global optima.

Another approach are genetic algorithms, which use biologically inspired operators to generate high-quality solutions (Mitchell, 1997, p. 249). These algorithms are probabilistic methods based on a population-based process which relies on operators such as mutation, crossover and selection used to vary the individuals of that population. These individuals represent encoded solutions to the problem (Homberger, Bauer and Preissler, 2019, p. 143). Genetic algorithms have been successfully applied to solve learning and optimization problems.

While there is no clear cut between AI and heuristic approaches from the field of OR, genetic algorithms as well as evolutionary algorithms use techniques to emulate AI and are therefore regarded as a subfield of AI (Homberger, Bauer and Preissler, 2019, p. 136).

As a theoretical concept, AI has been around for some time, but just recently AI has broken away from being just a theoretical concept to being applied to business problems. This is because of the wide availability of GPUs (graphics processing units), which allow to use parallel processing in a faster, cheaper and more powerful way. Their highly parallel structure makes them more efficient than general-purpose CPUs for algorithms where the processing of large blocks of data is done in parallel. Furthermore, the ascent of AI has to do with a deluge of any kind of data such as videos, images and geospatial data combined with practically infinite storage available (Ongsulee, 2017).

According to Arthur Samuel in 1959, Machine Learning (ML) as a subset of AI is the subfield of computer science that gives "computers the ability to learn without being explicitly programmed" (Muñoz Medina, 2014). It is particularly interesting in the area of optimization, as it addresses the study of algorithms that improve automatically through experience (Mitchell, 1997, p. 2). Machine learning is employed in a range of computing tasks where designing and programming explicit algorithms with good performance is difficult or infeasible. ML focuses on performing a task given some finite (and usually noisy) data, called „training data" (Bengio, Lodi and Prouvost, 2018, p. 2). It applies algorithms that analyze data, learn from it and make informed decisions based on the learned insights. ML can serve two purposes. Firstly, instead of using extensive computations to find a solution, the expert uses ML to achieve a fast approximation. In this case, learning is used to build such approximations in a generic way, i.e. without deriving explicit algorithms. This method assumes expert knowledge of the problem. For the second purpose, this expert knowledge might not be sufficient and known methods and algorithms may be dissatisfying. In that case ML is applied to learn from the decisions algorithms made and to learn out of this experience to find the best performing behavior (Bengio, Lodi and Prouvost, 2018, p. 3).

In machine learning, one differentiates between different learning methods. In supervised learning, training data consisting of input and target pairs is used to find a function that for every input has an output which is as close to the target as possible. Finding such a function is called learning and is solved via optimization problems, where the measure of discrepancy between the output and the target can be chosen depending on the task (Bengio, Lodi and Prouvost, 2018, p. 6). The case where only the input is provided is called unsupervised learning. For example, the aim is to discover groups of similar examples in the data, called clusters, or to determine the distribution of the data within the input space, called density estimation (Bishop, 2006, p. 3). Another learning method is reinforcement learning, in which case an agent interacts with an environment through a Markov decision process. The problem is to find suitable actions to take in a given situation in order to maximize a reward, but, in contrast to supervised learning, here the learning algorithm is not given examples of optimal outputs. Instead it must find them through trial and error (Bishop, 2006, p. 3). A popular tool in ML is the decision tree, which is a decision support tool that uses a tree-like structure to create a model for decisions and their possible consequences. A decision tree consists of nodes and branches. The crucial part in building a decision tree is deciding which features to choose and what conditions to use for splitting (branching). ML can be used to learn these features from data by recursively partitioning the source set into subsets

(Quinlan, 1987), which constitute the successor children of that node, following splitting rules based on classification features (Shalev-Shwartz and Ben-David, 2014, p. 255).

One particularly interesting subfield of ML is Deep Learning (DL) (LeCun, Bengio and Hinton, 2015), a very young field of AI based on artificial neural networks. DL focuses on building large parametric approximators using deep neural networks (DNN), which are neural networks with a high number of layers. With these high dimensional networks one can achieve an unprecedented flexibility to model highly complex, non-linear relationships between variables (Kraus, Feuerriegel and Oztekin, 2020, p. 628). It has only recently started to gather more attention, as the methods are dependent on the availability of both computational power as well as large datasets. But since nowadays large datasets are common in most businesses, Deep Learning is on the way to becoming the industry standard for predictive analytics in OR (Kraus, Feuerriegel and Oztekin, 2020). Figure 1 illustrates the embedding of the discussed subfields of AI and the relation to OR.

In summary, in a broader sense AI does not only include algorithms from machine learning and deep learning, but one can also include intelligent algorithms and heuristics such as genetic algorithms or evolutionary algorithms such as particle swarm optimization.

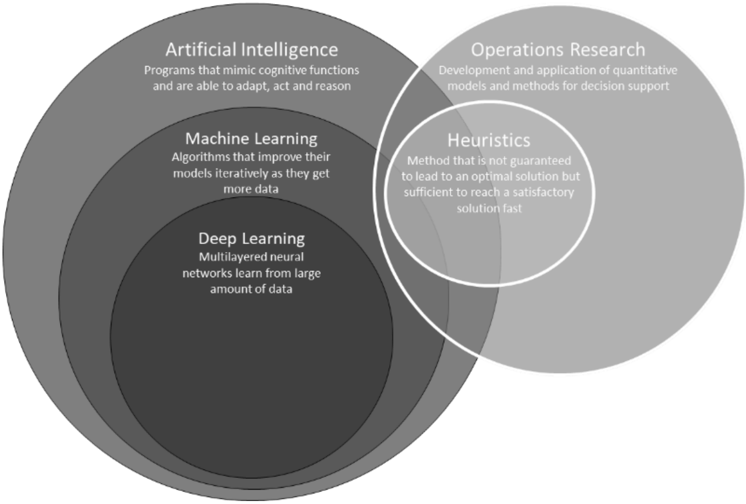

Figure 1: Subfields of AI and OR

2.4 Differentiation

To understand how AI, and ML in particular, can be used to complement OR techniques to tackle optimization problems, one has to understand the differences, but also the similarities between OR and ML.

Machine Learning and OR both use iterative methods to solve problems of a practical nature. Optimization problems in OR can be formulated as a constrained maximization or minimization program, where the objective function defines the measure of solution quality (Bengio, Lodi and Prouvost, 2018, p. 4). Many learning problems are also formulated as minimization of a loss function, which generally is the measure of discrepancy between the output, meaning the predictions of the model being trained, and the target (Le Roux, Bengio and Fitzgibbon, 2011, p. 404).

But even though they are closely related, especially through optimization, there are also aspects which separate these two areas, namely the methods used to tackle these problems. In general, while AI is used to extract information out of a (big) dataset to gain knowledge, OR is used to support decision making by using this knowledge. OR mainly focuses on solving optimization problems through knowledge of the structure of the problem. It requires some insight into solving that kind of problem, which is then passed to the machine, but it is not based on a model obtained by training on a data set and does not adapt itself iteratively over time. An ML algorithm on the other hand is an algorithm which adapts itself to data (Bishop, 2006, p. 2). The core objective is to generalize from its experience, which means the ability to perform accurately on new examples after having experienced a training data set (Mohri, Rostamizadeh and Talwalkar, 2012, p. 7).

While optimization algorithms can minimize the loss on a training set, machine learning is concerned with minimizing the loss on unseen samples, called test data. Because of this, alternative techniques have to be used in order to prevent the model from overfitting on the training data (Le Roux, Bengio and Fitzgibbon, 2011, p. 403). This is not to say that an OR solution method is in general worse than an ML method. In fact, OR methods might be faster than an ML method, because they are perfectly suited for this exact problem. But an ML method can be more flexible and generalize to a wider range of problems without the need for expert knowledge of structural properties.

There are different possibilities to connect OR and AI methods to exploit their synergies. For example, Bengio, Lodi and Prouvost (2018) differentiate between three possible algorithmic structures and categorize approaches accordingly. In the category end-to-end learning, an AI is trained to develop a solution directly from the problem input. In our work, also heuristic solution methods like Genetic Algorithms are counted towards this category. The category Learning meaningful properties of optimization problems includes methods where AI is used to generate further information for the parametrization before the actual optimization. The third category Machine learning alongside optimization algorithms uses a structure in which the OR method repeatedly requests machine learning methods for further optimization. So, the two methods alternate in an iterative process, and this process ends when a good solution is found (Le Roux, Bengio and Fitzgibbon, 2011, p. 422).

As seen above, because of the similarities of both areas as well as the differences in the methods applied, both areas can profit from each other by combining their knowledge to learn how to solve problems in an efficient way.

3 Methodology of Literature Review

The structure of this literature review is based on the methodology of Tranfield, Denyer and Smart (2003).

For the selection of the studies it is necessary to define the time horizon, keywords and to select databases. Considering the objective of the paper and the currentness of the topic, the time horizon is set from 2010 to today (March 2020). To find also most recent research results, the database arxiv (with not yet reviewed papers) was included in the search. Furthermore, the databases Scopus, Web of Science and IEEE are used, aiming at finding all relevant publications from different disciplines like management, Logistics and engineering.

The following table describes the structure of the search strings used consisting of four 'and' pillars with each of them having different terms combined with 'or'.

Table 1: Search terms

	AND	AND	AND	AND
OR	Operations research	Artificial intelligence	Logistics	Maritime
OR	Optimization	Deep learning	Transport	Port
OR		Machine learning	Traffic	Container
OR			Routing	Ship
OR			Scheduling	Hinterland

The combinations of these terms in the query are searched in title, abstract and keywords of publications in the databases. In the next step, the publications were screened by analyzing title and abstract. It turned out that when using this precise search string, many articles were listed that focus on other topics. These papers either do not fit because of the method (not AI and OR) or of the research field (not Maritime Logistics). For example, some papers utilize AI and OR for software engineering using containers in the programming language Java, which is not related to containers in the maritime definition. Furthermore, many papers list AI in their keywords, but do not make clear what AI is used for.

In total, more than 200 publications were found in the four databases (199 Scopus + 55 IEEE + 49 Web of Science + 15 Arxiv). The above-mentioned screening and selection results in 40 publications, excluding duplicates (22 Scopus + 5 IEEE + 15 Web of Science + 3 Arxiv). Furthermore, some snowballing was done to find additional publications. In the snowballing procedure, the reference list of already found and selected papers is analyzed with regard to suitable further papers (backward snowballing). Furthermore, the papers citing a paper can also be analyzed (forward snowballing). These further papers are then evaluated and, if appropriate, are added to the literature review (Wohlin, 2014) Ten new publications were found through snowballing techniques.

4 Results of Literature Review

4.1 Overview

Most of the publications were published in the second half of the decade, which shows that the relevance of the topic has recently been increasing. Figure 2 shows the number of relevant publications.

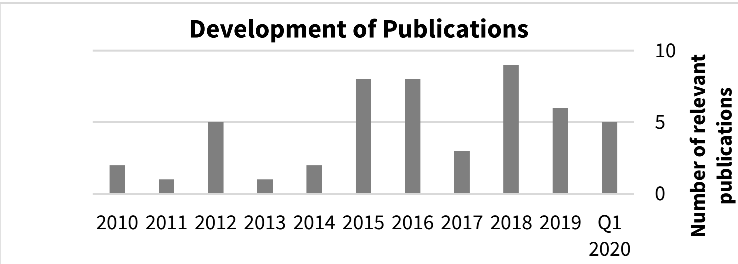

Figure 2: Development of Publications

The application areas range across all fields of Maritime Logistics. Many publications use AI and/or OR for oversea routing. Authors utilize, for example, Automatic Identification System (AIS) data for trajectory predictions to avoid ship collision or weather data to avoid heavy storms (e.g. Lee, et al., 2018; Li, Liu and Yang, 2018; Virjonen, et al., 2018). Furthermore, some papers deal with Berth Allocation Problems (BAP) and related issues like quay crane scheduling or BAP for bulk terminals (Pratap, et al., 2015; e.g. Castilla Rodríguez, et al., 2020). The distribution of the application areas is shown in Figure 3.

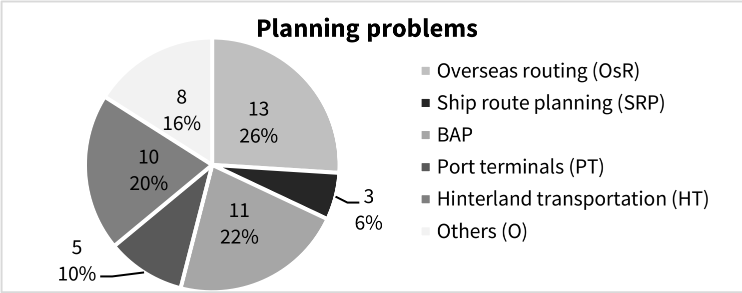

Figure 3: Planning problems (plan. prob.) of AI in Maritime Logistics

As described in Section 2, there are different possibilities to combine the strengths of OR and AI. Following our categorization based on Bengio, Lodi and Prouvost (2018), there are three categories. For a better overview, end-to-end learning is split into those papers using heuristics like genetic algorithms or ant colony algorithms, and those that do not use evolutionary methods. End-to-end learning is used in most papers as can be seen in Figure 4.

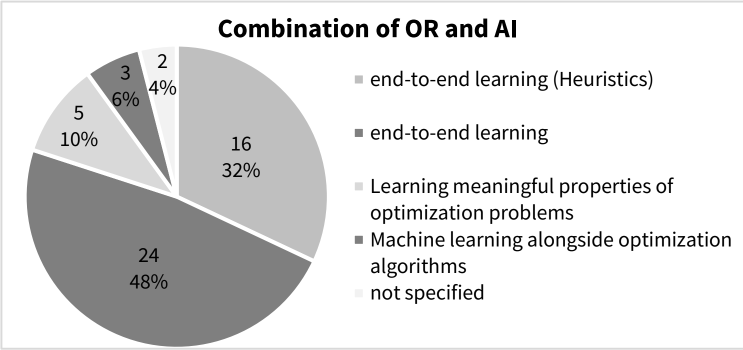

Figure 4: Combination of OR and AI in Maritime Logistics

Regarding the different AI methods and algorithms, ant colony algorithms and genetic algorithms make up a large part of the methods used for problems in Maritime Logistics (see Figure 5). Deep learning is used in twelve publications. In the papers, different approaches of machine learning like k-nearest-neighbor or support vector machines are used (Zhang, et al., 2016; e.g. Virjonen, et al., 2018). In addition, in some of the papers several methods are applied simultaneously or are compared. In this case, the dominant method is considered only once in Figure 5. All in all, it can be stated that intelligent heuristics dominate the usage of AI. For this reason, most publications use unsupervised algorithms.

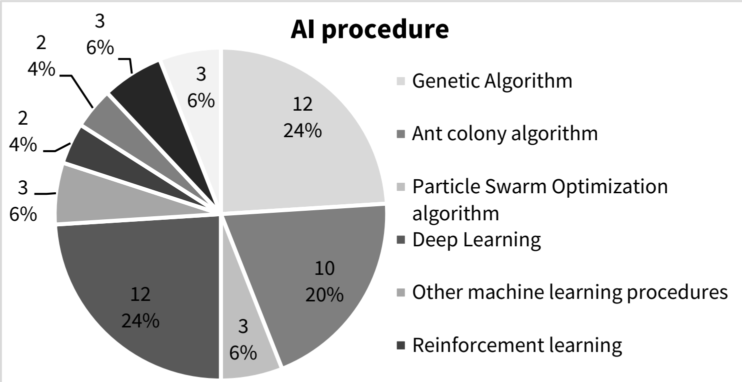

Figure 5: AI procedure

The following table gives an overview of the 50 papers that we analyzed. Moreover, it describes the categories Combination of AI & OR, AI methods used and the respective planning problem in more detail.

Table 2: Papers analyzed

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Tsou, et al.	2010a	end-to-end learning	Ant Colony Algorithm	Collision Avoidance Path Planning (OsR)
Tsou, et al.	2010b	end-to-end learning	Genetic Algo-rithm	Collision Avoidance Path Planning (OsR)
Xu, et al.	2011	end-to-end learning	Back Propa-gation Neu-ral Network	Vessel Trajectory Predictor (OsR)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Escario, et al.	2012	end-to-end learning	Ant Colony Algorithm	Optimal Trajectories of Autonomous Surface Vessels (OsR)
Kaveshgar, et al.	2012	end-to-end learning	Genetic Algorithm	Quay Crane Scheduling Problem (BAP)
Lalla-Ruiz, et al.	2012	Machine learning alongside optimization algorithms	Path Relinking	Berth Allcoation Problem (BAP)
Rodriguez-Molins, et al.	2012	end-to-end learning	Genetic Algorithm	Berth Allcoation Problem (BAP)
Wojtusiak, et al.	2012	Machine learning alongside optimization algorithms	Learnable Evolution Model (LEM)	Variant of Vehicle Routing Problem (HT)
Expósito-Izquierdo, et al.	2013	end-to-end learning	Estimation of Distribution Algorithm	Quay Crane Scheduling Problem (BAP)
Lajjam, et al.	2014	end-to-end learning	Ant Colony Algorithm	Quay Crane Scheduling Problem (BAP)
Ting, et al.	2014	end-to-end learning	Particle Swarm Optimization	Berth Allcoation Problem (BAP)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Dobrkovic, et al.	2015	end-to-end learning	DBSCAN, Genetic Algorithm, Ant Colony Algorithm	Estimating Ship Arrival with AIS (O)
Gue, et al.	2015	end-to-end learning	Ant Colony Algorithm	Ship Routing (SRP)
Kambey, et al.	2015	end-to-end learning	Ant Colony Algorithm	Container Truck Hinterland (HT)
Lazarowska	2015	end-to-end learning	Ant Colony Algorithm	Oversea Routing (OsR)
Orgaz, et al.	2015	end-to-end learning	Genetic Algorithm, Data Mining Case Based Reasoning	Route Planning (HT)
Pratap, et al.	2015	end-to-end learning	Genetic Algorithm	Robust Berth Allocation for Bulk Terminals (BAP)
Supeno, et al.	2015	end-to-end learning	Genetic Algorithm	Container Terminal Truck Scheduling (PT)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Xue, et al.	2015	end-to-end learning	Ant Colony Algorithm	Container Drayage with Truck (HT)
Daranda	2016	end-to-end learning	Neural Network	Maritime Traffic Prediction (O)
Gómez, et al.	2016	end-to-end learning	Neural Network	Operational Parameter Forecasts in Automated Container Terminals (PT)
Hottung, et al.	2016	end-to-end learning	Biased Random-Key Genetic Algorithm	Container Pre Marshalling Problem (HT)
Lisowski	2016	end-to-end learning	Neural Network	Ship Trajectory Optimisation (OsR)
Liu, et al.	2016	end-to-end learning	Particle Swarm Optimization, Artificial Fish Swarm Algorithm	Quay Crane Scheduling Problem (BAP)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
van Riessen, et al.	2016	Machine learning alongside optimization algorithms	Decision Tree	Hinterland Transport Mode Decision (HT)
Yan, et al.	2016	end-to-end learning	Unsupervised Data Mining	Vessel Movement Analysis and Pattern Discovery (O)
Zhang, et al.	2016	Learning meaningful properties of optimization problems	Neural Network, Support Vector Machine	Service Maintenance, Short-term-traffic Forecast Ferry Terminal (PT)
Garcia-Flores, et al.	2017	Learning meaningful properties of optimization problems	Not specified	Demand Forecasting Rail Scheduling at Container Port (HT)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Margain, et al.	2017	end-to-end learning	Ant Colony Algorithm	Capacitated Vehicle Routing Problem (HT)
Protopapadakis, et al.	2017	end-to-end learning	Deep Learning, Deep Stacked Autoencoders	Anomaly Detection (O)
Gao, et al.	2018	end-to-end learning	Recurrent Neural Network, Deep Learning	Vessel Trajectory Predictor (OsR)
Hoseini, et al.	2018	end-to-end learning	Hybrid Imperialist Competitive and Genetic Algorithm	Berth Allcoation problem (BAP)
Lee, et al.	2018	Learning meaningful properties of optimization problems	Data Mining Techniques	Vessel Speed Decision with Wind Data (OsR)
Li, et al.	2018	end-to-end learning	Ant Colony Algorithm	Ship Weather Routing (Oversea) (OsR)
Li, et al.	2018	end-to-end learning	Ant Colony Algorithm	Ship Weather Routing (Oversea) (OsR)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Liu	2018	end-to-end learning	Genetic Algorithm, Particle Swarm Optimization	Shipping Route Planning (SRP)
Müller	2018	end-to-end learning	Biased Random-Key Genetic Algorithm	Liner Ship Fleet Repositioning Problem (SRP)
Nguyen, et al.	2018	end-to-end learning	Deep Learning, Recurrent Neural Network	Trajectory Reconstruction, Anomaly Detection and Vessel Type Identification (O)
Virjonen, et al.	2018	end-to-end learning	K-Nearest Neighbour Algorithm	Ship Trajectory Prediction (OsR)
Kanović, et al.	2019	end-to-end learning	Particle Swarm Optimization, Genetic Algorithm	Ship Lock Zone Controlling (O)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Larsen, et al.	2019	end-to-end learning	Feedforward Neural Network, Deep Learning	Load Planning Problem (O)
Nguyen, et al.	2019	end-to-end learning	Deep Learning, Recurrent Neural Network	Anomaly Detection (O)
Tang	2019	Not specified	Bee Colony Evolutionary Algorithm	Scheduling of Transport Paths (PT)
Verma, et al.	2019	end-to-end learning	Reinforcement Learning	Ship Load Sequencing in Ports (PT)
Zhao and Shi	2019	end-to-end learning	Recurrent Neural Network, Deep Learning	Vessel Trajectory Predictor (OsR)
Castilla Rodríguez, et al.	2020	Learning meaningful properties of optimization problems	Estimation of Distribution Algorithm	Quay Crane Scheduling Problem, Decision Support (BAP)

Author	Year	Combination of AI & OR	AI procedure	Application area (Abbr. of plan. prob.)
Ham-mouti, et al.	2020	end-to-end learning	Genetic Algo-rithm	Berth Allcoation problem (BAP)
Gkerekos, et al.	2020	Not specified	Not specified	Oversea Routing (OsR)
Hottung, et al.	2020	Learning meaningful properties of optimization problems	Deep Neural Network	Container Pre-Mar-shalling Problem (HT)
Iran-nezhad, et al.	2020	end-to-end learning	Reinforcement Learning	Container Hinter-land Transport (HT)

4.2 In depth-analysis of selected papers

In the following, we highlight some approaches where Machine Learning is used in combination with OR to solve optimization problems in Maritime Logistics. We follow the distinction in Bengio, Lodi and Prouvost (2018) to survey how these techniques are applied. Note that the different sections are not necessarily disjoint.

4.2.1 End-to-End Learning

The first and most obvious approach is to tackle a given combinatorial optimization problem solely with ML techniques. The ML model acts alone and is trained to find solutions to the problem directly from the input.
This is done in Nguyen, et al. (2018). The huge amount of AIS data, namely hundreds of millions of messages every day, provides a huge potential to extract, detect and analyze relevant information. The authors develop a deep learning model to provide an automatic system which can process and extract useful information in an unsupervised way. They train a variational recurrent neural network (RNN), which converts the noisy, irregular-sampled AIS data to consistent and regularly-sampled hidden states that may correspond to specific activities such as “under way using engine”, “at anchor” or “fishing”. Higher levels, meaning task-specific layers of the RNN, correspond to task-specific layers, which are able to address different tasks such as trajectory reconstruction, anomaly detection or vessel type identification. In contrast to state-of-the-art methods, the model is able to jointly address multi-tasking issues (Nguyen, et al., 2018).

Another example is Müller (2018), where AI methods are applied to solve the liner shipping fleet repositioning problem (LSFRP). Liner shipping companies have large networks of connected ports to transport containers by operating several services. These services are modified on a regular basis due to economic and seasonal trends. In that context, vessels are reassigned to other services and have to be repositioned. Repositioning vessels considering the costs for moving the vessels is defined as the LSFRP. For this problem, a biased random-key genetic algorithm (BRKGA) is developed. In contrast to other genetic algorithms, the random-key genetic algorithm aims at encoding the chromosomes with floating point values in the range of [0,1] instead of using integers to eliminate the offspring feasibility problem. This concept was extended to the BRKGA [Gonçalves et al, 2011] by applying a different crossover strategy to generate the new population. While the proposed method is able to find good solutions for smaller instances, it is not able to compete with the current state-of-the-art heuristic for larger instances of the LSFRP. Note that in an attempt to improve the algorithm, the author combines BRKGA with a local search heuristic, which improved the performance. This attempt therefore also fits in the section „Machine Learning alongside OR“, which highlights the fact that these categories should not be seen as mutually exclusive (Müller, 2018).
Larsen, et al. (2019) believe that ML is useful to solve combinatorial optimization problems with incomplete information, because the application has to be able to make decisions on a tactical level, and the ML model is able to use the stochasticity of the problem to quickly predict tactical solutions under uncertainty. They tackle the load planning problem (LPP). The problem is to decide how many of a given set of containers of different types can be

loaded on a given set of railcars of different types and how many of the railcars of each type are needed. The decisions must be made without knowledge of the container weights since this information is not available at the time of assigning the containers. Furthermore, the problem requires solutions in real time, which cannot be generated for the stochastic nor the deterministic version of the problem using commercial solvers. In the training stage, the authors use solutions to the deterministic version of the problem, which can be formulated as a MILP, to train a neural network to predict the solution of the stochastic LPP. It is shown that the ML model is able to quickly find accurate solutions online, because some of the complexity of the problem is outsourced to the training stage (Larsen, et al., 2019).

4.2.2 Learning meaningful properties of Optimization Problems & Machine Learning alongside OR

In many applications, using only ML to find solutions is not the most suitable approach. Rather, ML can be used to provide the optimization algorithm with valuable information to help solve the problem. This can be done in different ways. ML can either be applied to provide additional information to the optimization algorithm, which can be called „Learning meaningful properties of OR problems“, or ML is used alongside optimization algorithms. The difference to the previous approach is that the same ML method is frequently called from a master algorithm to support lower level decisions (Bengio, Lodi and Prouvost, 2018).
The first approach is chosen in Lee, et al. (2018), where a speed optimization problem is considered. The aim is to find a Pareto optimal solution by

considering the trade-off between minimizing fuel cost and maximizing service level. Instead of using theoretical fuel consumption functions, data mining techniques are applied to weather archive data to estimate the real fuel consumption considering the variabilities in weather conditions. A Particle Swarm Optimization technique based solver which uses the weather impact data is applied to generate Pareto optimal solutions. A decision support system is developed for Liner operators to decide about sailing speeds of vessels for each leg considering customer requirements, showing the trade-off analysis between fuel consumption and service level. Numerical experiments then show that especially for long voyage legs where weather conditions are highly variable the improvement on fuel estimation is significant, which offers considerable cost improvements (Lee, et al., 2018).
An example for the second approach is Hottung, Tanaka and Tierney (2020). They adopt the method of frequently calling an ML model for solving the Container Pre-marshalling Problem (CPMP). This problem is concerned with the re-ordering of containers in container terminals during off-peak times so that containers can be quickly retrieved when the port is busy. The goal is to find a minimal sequence of container movements that sort a set of container stacks according to the time each container is expected to exit the yard. While there are a number of exact methods to solve this problem, their computation time is too long to be used in a decision support system. This is why there is a large number of heuristics, which are highly specialized, costly and time-intensive to design. Hottung, Tanaka and Tierney therefore develop a so called Deep Learning Heuristic Tree Search (DLTS), which merges the heuristic approach of a tree search with DNNs for the CPMP to generate heuristics for branching and bounding in the search tree

without a deep understanding of the structures of the CPMP. The DNNs are trained offline via supervised learning on existing (near-)optimal solutions for the CPMP to learn solution strategies and lower bounds to the CPMP. In the tree search procedure the DNNs are then integrated to decide which branch to choose next and to prune the search tree. While DLTS does this with extraordinarily little expertise input from the user regarding the problem, it is able to outperform state-of-the-art heuristic solutions to the CPMP. This shows the huge potential in solving optimization problems with the help of ML (Hottung, Tanaka and Tierney, 2020).

A similar approach is chosen in van Riessen, Negenborn and Dekker (2016). Their motivation is to derive real-time decision rules for suitable allocations of containers to inland services. To obtain this, first optimal solutions to problem instances are generated by an exact solving method, which is not suitable for real-time decisions because of the computation time as well as incomplete information. Then a decision tree is created using a supervised learning method, which learns decision rules for the allocation of a container to a suitable service based on the container and order properties, such as the time of availability, the transportation lead time, and container mass. This set of rules can be used in real-time as a decision tool to provide a set of suitable services to a human planner. A case study shows that the developed decision support system is able to reduce inefficiency and therefore transportation costs without extensive IT development (van Riessen, Negenborn and Dekker, 2016).

Another application of ML alongside optimization algorithms is done in Expósito-Izquierdo, et al. (2013). They apply an evolutionary algorithm, the

Estimation of Distribution (EDA) algorithm, to solve the Quay Crane Scheduling Problem (QCSP), where the goal is to minimize the handling times when performing the tasks of loading and unloading containers onto/from a container vessel. While EDAs are well suited for exploring the solution space and locating promising regions, they have certain shortcomings in finding local optimal solutions. To overcome these limitations, the authors combine their EDA with a local search algorithm, which is used to carry out the intensification of the schedules found. But since local search is a time-consuming algorithm, it is only applied to a subset of solutions with the best objective function value. Their computational results show that this is a promising method to obtain high quality solutions in a competitive time frame (Expósito-Izquierdo, et al., 2013).

This approach is continued in Castilla Rodríguez, et al. (2020). Their motivation is to overcome the limitations of the previously developed algorithm, namely the limitation to deterministic data and the assumption that there are no constraints with respect to internal delivery vehicles. They combine the previously developed intelligent evolutionary algorithm, which generates high quality schedules for the cranes, with a simulation model that incorporates uncertainty and the impact of internal delivery vehicles. The proposed method allows to combine the strengths of mathematical optimization algorithms which implement ML with real scenarios where non-deterministic scenarios may rule out highest quality solutions in theory, as these theoretically optimal solutions may be limited by other factors such as the availability of internal delivery vehicles. This again shows that applying ML techniques to operational research problems provides more flexibility in real life scenarios, where decisions have to be made in real time and under uncertainty (Castilla Rodríguez, et al., 2020).

5 Conclusion and outlook

A literature review of reports and journal papers on the combination of AI and OR in Maritime Logistics of the last ten years was conducted. The findings are categorized by the different applications of AI in Maritime Logistics as well as the different techniques, and an overview on the current state of research is provided. This section recaps and presents future research directions.

The problems that occur when searching for new developments in the usage of Machine Learning for optimization problems are two-fold. On the one hand there is an inflationary use of AI keywords in the area of optimization publications as this area gains more and more attention. On the other hand, even if AI methods are used, the descriptions of these methods are often condensed in a way that makes it difficult to understand the chosen models.

Besides, it was shown that ML can be applied in different ways to tackle optimization problems. On the one hand, there is the setting of end-to-end learning, where ML models are trained to find solutions directly from the input. On the other hand, ML is also used alongside OR methods. AI methods are used to help with the branching and bounding decisions as well as with modelling uncertainty in decision making in a better way than standalone OR models are able to. There are many publications in the area of OR which are concerned with modelling uncertainty, but which do not use ML methods. To adapt these models and apply ML techniques to better model uncertainty is a promising research gap for future research.

Standard ML methods, especially evolutionary algorithms, are still the most common approach. But there is a rising interest in using deep learning methods as a new technique to tackle optimization problems, which is due to the new possibilities that the wide availability of GPUs offers in terms of computation power. It is noteworthy that most of the approaches which use ML methods to tackle optimization problems in Logistics choose end-to-end methods to get the solution directly from the input, rather than implementing ML techniques in existing OR algorithms. But with the increasing interest in deep learning, new approaches of combining these two areas become popular. Especially the approach chosen by e.g. Hottung et al. (2020) to implement deep neural networks into search trees appears to be promising. These deep learning techniques which allow to model highly complex non-linear relationships between variables offer a great perspective to support existing OR solution methods and will be an important factor in future research.

Most of the applications of ML in Maritime Logistics rely on AIS data as their main input, which is due to the broad availability of these large datasets. This is also the reason why applications in other areas of Maritime Logistics apart from routing vessels are underrepresented. To use ML also at the intersection of Logistics at sea and Logistics on land (terminals and hinterland), more data needs to be provided in order to create more possibilities for the application of models which rely on large datasets. There has also been a growing interest in combining ML and OR to let programs automatically learn heuristics for optimization problems to avoid the costly and time-intensive development of highly specialized heuristics by humans. But our research also has shown that there are only a few attempts to transfer these methods to problems in Maritime Logistics. This research gap may be due to the lack of IT infrastructure compared to other areas of Logistics, but it also offers a great perspective for future research to apply these new ML approaches with the help of the ever-increasing amount of data available to problems of Maritime Logistics.

Although most of the approaches presented in this literature review are just the first steps in trying to apply ML to enhance the performance of solution methods for optimization problems, it has a huge potential to produce efficient solution strategies for optimization problems in the future. Hence, there are many opportunities for future research to exploit the possibilities of applying AI to optimization problems in Maritime Logistics.

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State of Research in Arctic Maritime Logistics

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Purpose: The Arctic is of interest for many states and commercial organizations as it has a large undiscovered potential but very challenging climate and logistical conditions. Arctic maritime logistics need significant investments in infrastructure and is supposed to cause a minimal impact on the environment during port operations and cargo transit by creating efficient and safe supply chains. At the same time, ensuring the most efficient, reliable and safe functioning of supply chains is required.
Methodology: The methodological basis of the paper is the analysis and structuring of existing publications on Arctic maritime logistics, a systematic review and formulation an applied system of relevant performance indicators related to Arctic supply chains (e.g. ice conditions, vessels and their parameters, the safe operation of floating production facilities and properties of ports).
Findings: The result of this paper is a systematic overview of the current state of research on Arctic maritime logistics challenges and the influencing key performance indicators as well as approaches to assess the performance at all stages of the Arctic supply chain to facility and improve Arctic supply chains in the future.
Originality: The originality of the study is defined by the scope of the review conducted. It is the first comprehensive overview over Arctic supply chains covering all relevant countries from a maritime logistics standpoint. The results of this paper create a solid foundation for further research in the area of developments of Arctic maritime logistics.

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1 Introduction

The exploration of the Arctic has become the object of close attention of governmental bodies, the scientific community, and individual researchers. Characteristics of the Arctic that determine the need for special approaches to its development are the “extreme climatic conditions, focal (cluster) nature of the territories development, […] remoteness from major industrial centers, high resource intensity” (Didenko, Skripnuk and Rudenko, 2015 cited in Yakovlev et al., 2019, p. 1), lack of labor force, outflow of the population, inaccessibility of regional facilities, dependence on the supply of resources from other regions, low sustainability of ecosystems, and the presence of waste and pollution from human activities. Globally, the Arctic is the region with the highest undiscovered hydrocarbon potential. The Arctic exploration of offshore hydrocarbon deposits (the so-called offshore zone) entails not only economic benefits from the production and sale of hydrocarbons, but also has significant social effects associated with job creation and increasing the region’s attractiveness for the inhabitants, as well as environmental effects associated with violation of the ecosystem of the region and the need for removal and disposal of waste from the activities of mining enterprises (Katysheva and Tsvetkova, 2017). The evolution of the Arctic shelf deposits within the sustainable development concept requires consideration of various economic, social, natural, environmental, and institutional factors, each of which determines certain limitations and sets decision criteria for the development and operation of individual deposits and the exploration and development of the shelf zone and the entire region as a whole. Thus, the sustainable development of the

Arctic suggests an effective balance between economic growth, environmental protection, and social relations. Existing Arctic shelf development projects are often distinguished by a single-criterion decision making - economic growth to the detriment of other components (social and ecological ones) (Tsyganov, 2019; Infrastructure Development Plan for the Northern Sea Route until 2035). The transport and logistics infrastructure of the shelf zone and the region is one of the key factors for the economic, social and environmental efficiency of shelf field development since it determines the possibility of developing and operating the field, as well as the availability, terms of provision and cost of the resources necessary for the development and operation of fields (personnel, material and technical resources) and, as a result, profitability of hydrocarbon production.

2 Methodology

As a research methodology, qualitative methods were used in the form of an analysis of the results of materials published in scientific literature on the Arctic shelf zone development. Interpretative methods to analyze the results are used. The study used a systematic approach to conducting a literature review. It consisted of a wide-ranging review of the available scientific literature, its assessment, and the formation of the research result.

In relation of the development of the Arctic region and the Russian fuel and energy sector, the authors conducted a study to develop an effective model for offshore field development in the Arctic zone of the Russian Federation (Balashova and Gromova, 2017). For the development of offshore fields the model of creating consortia was considered and analyzed, considering the specifies of the Arctic region (Balashova and Gromova, 2017). In this model, from two large companies onwards, companies are temporarily merged to carry out a specific project under agreed conditions. At the same time, the state provisionally selects potential candidates (Balashova and Gromova, 2017).

The authors also conducted a study to develop proposals for the Artic region's selection of work organization technology, considering social aspects (Kozlov et al., 2017). The advantages of long-distance commuting strategy (shift work) for the mining industry and for remote regions such as the Arctic, where skilled labor is not available, are revealed. At the same time, this technology also has drawbacks, and therefore further research is planned to select an effective technology for the Arctic (Kozlov et al., 2017).

Also, this group conducted a study to develop a concept of enterprise architecture and a methodology to develop and implement an Integrated

Management System (IMS) for mining companies (Ilin et al., 2017). It is recommended that the implementation of the IMS Project takes place in synchronization with the master plan of the project in corporate construction (Ilin et al., 2017). This allows to improve the development and integration of automated systems, build "a business model for an effective enterprise management system, and reduce future costs for the modernization of production and services". Further studies are supposed to build the most efficient architecture for the mining industry and the Arctic region (Zaychenko, Ilin and Lyovina, 2018; Ilin, Levina and Iliashenko, 2017). In addition, models for creating effective value chains in relation to the Arctic region were considered (Afonichkina, Afonichkin and Didenko, 2019). Also, the decision-making support methodology may be the methodological basis for planning the development of the Arctic region, which allows assessing future risks and compensating for them in advance. This methodology predicts economic and financial indicators and financial risks, evaluates various development options. The relationship between risk and return is also calculated (Bril et al., 2017).

3 Results

To collect and analyze information on the state of research in development of the Arctic shelf zone under the logistic approach, the relevant scientific literature in this area has been studied. Information on basic research studies are presented below.

As part of the study of the problems of the Arctic, including areas of innovation and technological development, world scientific researchers include research universities and scientific organizations of the Arctic countries (Rachold, Hik and Barr, 2015). All countries conduct research on various problems relating to the Arctic, including universities and scientific organizations of Russia, studying, and implementing projects for the constituent entities of the Russian Federation included in the Arctic zone.

The organizations listed below are the main global researchers on Arctic research:

The United States Arctic Research Commission (USARC, 2020) focuses on a wide range of problems under the slogan "The USA is an Arctic power with borders and fundamental interests in the Arctic zone". The United States Artic Research Commission publishes a wide array of studies and reports regarding topics of interest in the Artic like oil exploration but also on social issues of the people living in the Artic (USARC, 2020).

The University of the Arctic (UArctic, 2020) representing an international network of colleges, research institutes, universities, as well as organizations working in the field of higher education and research in the circumpolar North. The research results are published in the Arctic Yearbook, an international peer-reviewed publication that addresses current topics of “regional geopolitics, circumpolar relations, and security” (UArctic, 2014) in a broad sense. A review of research issues shows that they affect: strategic, political, and technological aspects; problems of increasing human resources potential in the Arctic; higher education and vocational training; workforce development; emergency preparedness and response; tourism; transport infrastructure; military / state security infrastructure; increased local participation in resource development and research; regional management capacity; migration regional innovation and human capital; healthcare and social security (UArctic, 2014).

An approach has been developed that divides the Arctic space into target subspaces (Didenko, Skripnuk and Krasulina, 2016; Didenko, Skripnuk and Rudenko, 2015; Rudenko and Didenko, 2015). The Arctic zone of the Russian Federation is composed of the possible types of target subspaces, which will be named and partly be explained below (Didenko and Skripnuk, 2018; Didenko, Skripnuk and Krasulina, 2016; Didenko, Rudenko and Skipnuk 2015):

- Base cities are medium-sized to large settlements and factories, on which area “industrial organizations, construction sites, railway terminals and other industrial infrastructure facilities, as well as commercial, domestic, medical, cultural, educational and administrative facilities” (Didenko and Skripnuk, 2018, p. 4) can be found.
- Normally mobile shift camps are located close to mineral deposits or in areas where infrastructure facilities are built and maintained. Permanent infrastructure is difficult and economically disadvantageous (Didenko and Skripnuk, 2018).
- Territories for the extraction of mineral resources (Didenko and Skripnuk, 2018).

- Recreational areas are mainly reserves, national parks and tourism (Didenko and Skripnuk, 2018).
- Arctic fisheries include facilities and infrastructure for industrial fishing and require an approach that is extremely cautious due to the Arctic ecosystem's fragility and its vulnerability to climate change (Didenko and Skripnuk, 2018; McBride et al., 2014).
- The infrastructure for protecting a safe existence, includes "various defense establishments and facilities, threat detection and prevention services, means for security of communications and information, customs, ecology, reconnaissance satellites, etc." (Didenko and Skripnuk, 2018, p. 5).

Northern Sea Route (NSR) differs from the target subspaces mentioned above in its size, complexity, and numerous combinations with other subspaces (Didenko and Skripnuk, 2018). The Northern Sea Route is listed to be a single target subspace, mainly because of its geo-economic significance (Didenko and Skripnuk, 2018; Smith and Stephenson, 2013, Rothwell, 2012). In addition to a possible shipping route, the Northern Sea Route also consist of port and service facilities that form its subspace (Didenko and Skripnuk, 2018; Stenson and Hammill, 2014). The key ports of the Northern Sea Route are Murmansk, Dudinka, Bilibino, Pevek, Anyuysk, Chersky, the ports of Chukotka, several fields, and Providence Bay (Didenko and Skripnuk, 2018). The Northern Sea Route's role is growing with global warming and is to become an important trade route between Asia and Europe. At present, ship passes have been implemented on the Murmansk - Dudinka - Busan (South Korea) - Shanghai (China) route, from Norway to Japan and other countries (Miheeva, 2019). Advantages of the Northern Sea

Route are also related to the relocation of production centers and consumer markets in Europe across the north to the northeast in Asia (Verny and Grigentin, 2009). Moreover, the Northern Sea Route development is associated with the solution of problems linked to the geographical features of the territories (uninhabited, undeveloped, insufficient port infrastructure), extreme climate conditions, and increased service risks. The warmer temperatures and thus the receding of ice leads to other further shipping routes, e.g. the Northwest Passage (NWP). The NWP could be used instead of the Panama Canal (Pizzolato et al., 2014). This will shorten the route between Shanghai and Rotterdam by 27% (Buixadé Farré et al., 2014). Ng et al. (2018) also state the potential for new shipping routes in the Artic. Authors like Wang and Overland (2012) assume that the Artic will be without ice during summer season by 2030. Melia, Haines and Hawkins (2016) predict that by 2050 moderately ice-strengthened vessels are likely to be able to operate on trans Artic routes 10-12 months per year. They also indicate that transit times form Asia to Europe will be 10 days faster than alternative routes. Browse et al. (2013) state that the shorter distances will lead to a positive effect by reducing shipping emissions globally but only lead to a negligible increase of black carbon in the Artic. Schøyen and Bråthen (2011) compared the NSR with the Suez Canal for bulk shipping and came to the conclusion that the small adverse effects / external costs in the Arctic (e.g. increased air pollution or possible oil spills in environmentally sensible areas) are offset by a global reduction in CO2 emissions when the NSR is used instead of the Suez Canal.

Lasserre (2014) did a case study examining the profitability of Artic shipping looking at 27 different models proposed between 1991 and 2013. Lasserre

(2014) deemed the use of Artic shipping not profitable but his paper was challenged by Wang et al. (2016) which on the contrary stated that shipping lines using the Arctic routes have indeed a high commercial value compared to the use of the Suez Canal. Cariou et al. (2019) investigate why the NSR is not used as commercial route (except for some trials by shipping companies) even though it is ice free for three months per year and come to the conclusion that the NSR is currently only 1.5 months per year a competitive alternative to the Suez Canal. Yuan, Hsieh and Su (2019) examine the effects of new shipping lines on the resilience of operational container routes by using a fuzzy cognitive map. Afenyo et al. (2017) did an analysis for shipping accidents in the Arctic using Bayesian networks. Rahman et al. (2020) developed a Bayesian marine logistics risk model for operations in the Flemish Pass Basin (Newfoundland and Labrador, Canada).

The target subspaces for this article are considered as objects participating in supply chains. The integration into the chain of Arctic subspaces, considering environmental, social requirements, and risks, gives a synergistic effect in the developing Arctic regions. Particularly, general transport as well as logistics infrastructure ensures a reduction in transportation costs and revenue growth.

Baydukova et al. (2019) in their work consider issues of a promising resource base for the protection of the Russian Arctic region, based on capabilities of modern supply chain management (SCM) systems in logistics. Katysheva and Tsvetkova (2017) considers the organization of a logistic scheme for oil transportation in Arctic fields, which allows increasing production and the efficiency exploitation of oil fields. Dudin et al. (2016) consider methodological approaches to organize the logistics of facilities located in the Arctic territories using an approach that integrates “green” logistics technologies and methods of economic and mathematical modeling. The article by Kozlov et al. (2019) explores the issues of optimizing the management system of "transport and logistics services of companies operating in the Arctic zone" (Kozlov et al., 2019). The article of Veretennikov, Mikulenok and Bogachev (2018) explores the problem of creating and developing an Artic logistical system based on the implementation of key performance indicators related to provide secure key processes. In the following studies by Tsyganov (2019), Radushinsky et al. (2017), Akimova (2018), Petrov et al. (2019), the conditions for an organized development of infrastructure in transport, energy, information, and telecommunications in the Arctic region based on transport and logistics corridors of the Northern Sea Route are considered.

The study of researchers from the Kola Science Center of the Russian Academy of Sciences (Tsukerman, Fadeev and Kozlov, 2019) analyzes the actions to formulate a strategy for the development of oil and gas areas on the Arctic shelf, covering the problems of justifying science, regulatory framework, consistency, adaptation, development of innovation, effectiveness, quality of products, informatization and efficient use of labor, and environmental protection. A research group from Finland conducted an analysis of promising technologies for using the natural resources of the Arctic region (Myllylä, Kaivo-oja and Juga, 2016). Zhura et al. (2019) state in their paper that the NSR "has turned into the most important transport and logistics network, having its major impact on the economic development of the northern territories and logistics network, having its major impact on the economic development of the northern territories and overall transportation support of the industrial, social and defense structure of the Artic Region as a whole and the northern coastal areas of Russia specifically".

Work in the Artic contains the following potential risks - natural, technical, infrastructural, environmental. Carayannis, Cherepovitsyn and Ilinova (2017) also considered additional features, risks, and difficulties in developing shelf fields in the Arctic region. Researchers from Canada, for example, are considering pollution risks from oil spills, governance, and sovereignty between Arctic states (Gulas et al., 2017). Statoil (Utvik and Jahre-Nilsen, 2016) considers the safety and sustainability of the Arctic region as part of an assessment of objectives and production possibilities. This is pursued by “planning of exploration and development operations where safety and sustainability related risks are addressed early to ensure appropriate mitigating actions” (Utvik and Jahre-Nilsen 2016, p. 1). This improves the quality and reliability of risk management and allows to identify needs in the field of development of science and technology. The company creates risk assessment instruments for environmental management and decision assistance, as well as methods for effective monitoring of the environment (Utvik and Jahre-Nilsen 2016). Examples of mitigating technology-related risks are ice management and the developing of a numerical model for icing and snowfall (Utvik and Jahre-Nilsen 2016). Under the aspect of operational safety, risk reduction is mainly associated with actions to protect the working environment in the Arctic and logistics planning. Among other things, in scientific articles, attention is paid to raising the internal rate of return (IRR) of such projects.

The risk groups indicated underline the high level of difficulty in the Artic shelf development and thus demonstrating the need of developing an effective decision support system (DSS) in this area, which will take into account all the required factors (Balashova and Gromova, 2017). Simultaneously, the concept of sustainable development of the territory is required. Issues of the DSS development were considered in the research of Ilin et al. (2017) and Bril et al. (2017). Issues of using DSS in manufacturing companies are considered in articles by Kasie, Bright and Walker (2017) and Felsberger, Oberegger and Reiner (2016). There are studies on the possible application of DSS by drilling crews by using the available resources for the prevention of accidents at on- and offshore industrial facilities (especially oil and gas) (Asad et al., 2018). At the same time, the issues of using DSS in mining companies, their functionality, capabilities, and the effects achieved are not widely considered in scientific literature, while being very relevant. In this context, it is planned to implement a study aimed at developing effective DSS in mining enterprises, including considering the peculiarities of the region of the Arctic. In this case, attention is paid to the solution of the problem by developing the infrastructure of transport and logistics of the region.

The study by Keil (2017) comprehensively examines the outlook for the Arctic shelf oil and gas industry, including global markets, international relations, issues of resource choice and the use of international energy companies. All these issues are important for understanding the importance of the Arctic in global energy supply. The same issues were considered in the study of McCauley et al. (2016), which analyzes the evolution of necessary energy infrastructure and principles of energy policy in the Arctic region in the context of global relations. The study by Henderson and Loe (2016) considers the environmental risks in the Arctic region from hydrocarbon exploration and production, as well as issues of the necessary infrastructure and economic development indicators, including from the perspective of other energy sources. This article gives an overview of oil and gas development on the Arctic shelf and outlines the development potential of the region. The oil, gas and business opportunities of the Arctic region are considered in the article (Motomura, 2018). In particular, the analysis of this issue considers the complex and expensive operating conditions of fields, as well as the parameters of the worldwide hydrocarbon market.

The development of Arctic maritime logistics should be considered comprehensively, considering the development of the Northern Sea Route, accelerating the socio-economic developing of the Arctic zone, and implementing investment projects for mining. To accomplish these tasks, it is important to create port and coastal infrastructure, to expand the Northern Sea Route's icebreaker to reduce the risks of navigation along the Northern Sea Route, and combine the sea routes with freight traffic within the framework of the general transport infrastructure (Northern latitudinal passage) (Didenko and Cherenkov, 2018; Infrastructure Development Plan for the Northern Sea Route until 2035). It also requires a common set of measures for navigational and hydrographic support and navigation safety, and the creation of a unified global system of maritime communications along the northern sea route. An important task is to ensure year-round navigation (Gurlev, Yemelyanova and Klimashkina, 2019).

4 Interpretation of the results

The literature research showed that this topic is very relevant and there are a lot of different opinions in the scientific community. The literature research also showed that most research was done in Russia and Canada about Arctic supply chains and to a lesser degree in other countries. This paper also showed that the interest in this topic increased over the last years with changes in temperature in the Artic and thus new opportunities. Another key finding is that not only the approaches to the topic vary widely but also the findings.

Based on the information obtained as a result of the analysis of existing thematic scientific literature, it is relevant to establish the foundations of sustainable development for the Arctic shelf development system and the DSS model, which allows to process and analyze heterogeneous data on the decision-making situation, as well as create potential scenarios for the development of the situation. Such DSS should consider all the above-mentioned groups of risks associated with the provision of Arctic maritime logistics.

The implementation of such a fundamental task requires the involvement of researchers and practitioners with competencies in the fields of socio-economic systems management, logistics, IT, expertise in the field of hydrocarbon production, transport and business modeling, design of information systems and applications, and the formation of requirements for IT services. To solve the problem of an effective sustainable development of shelf fields and the development of the corresponding regions of the Arctic zone in a multifactorial and multicriterial way, it is necessary to provide an appropriate theoretical and methodological approach of such a development. A complete analysis of the decision-making situation for each individual project (field), a description of all possible scenarios for the development and operation of individual fields from a sustainable development perspective, as well as scenarios for the development of the shelf zone and the region as a whole are required.

It is important to establish a theoretical and methodological foundation for the development of the Artic shelf. On this, a decision model support system is modelled. This allows processing and analyzing heterogeneous data about the decision-making situation and thus working out possible scenarios.

It is also recommended to introduce a key performance indicator system that covers all parameters of the supply chain (ice conditions, vehicles used and their parameters, safe operation of floating production facilities, port characteristics, etc.). A constant analysis of the system of such indicators will be required to identify ways to improve the efficiency of supply chains and weaknesses.

A promising way to develop Arctic marine logistics is to expand the Northern Sea Route. This should address the above unsolved problems associated with it and the existing risks. Accordingly, several proposals are required to effectively address the identified problems.

5 Conclusion

A significant complication of the development of marine logistics in the Arctic are problems in the Northern Sea Route with operations. In connection with this, further studies are needed that can offer ways to solve these problems. Especially with warmer temperatures in the Artic and thus less / thinner ice new routes will become economically feasible and be a competition for established routes, e.g. the Northern Sea Route could be an option for transports from East Asia to Northern Europe. This will lead to lower costs and also to less CO2 emissions in the shipping sector. Further studies are also planned to develop an optimal system of indicators of the efficiency of the functioning of supply chains.

Thus, the focus of research on marine logistics in the Arctic is on the topics of integrated development of the region, calculation and accounting of risks, optimization of the population, optimal integration of the Arctic subspaces, use of digital technologies in the developing of the Northern Sea Route.

Previous studies have shown significant problems that should be addressed. These problems are mainly associated with the climatic features of the region, the small number and uneven distribution of the population, settlements, ports, as well as with the identified risks. They also require solving the problems of the operation of the Northern Sea Route. The Northern Sea Route is investigated as an option to the Suez Canal (Skripnuk et al., 2020). Currently this is further a theoretical issue since the route is only three months ice free. In the coming years however with melting ice in the Artic these routes can be economically feasible and by the smaller distances can also lead to lower environmental pollutions worldwide. The issues of calculating the logistics chain, considering the minimum possible costs and effective international cooperation on the Northern sea route, remain open.

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Financing investments in a landlord port

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Purpose: Given of a landlord port model, private operating companies have to invest in superstructure, equipment and labor to maintain and improve the physical and non-physical flow of goods. The purpose of this paper is to examine interdependencies as well as existing collaborative strategies between operators in ports and to develop a collaborative concept for financing such investments.
Methodology: A literature review on supply chain management, port and collaboration is applied with a focus on vertical inter-organizational integration and collaborative strategies of financing investments. Based on the idea of cooperative game theory, a new collaborative concept for financing investments in ports is developed.
Findings: In literature, collaboration and the supply chain perspective are gaining in importance. However, collaborative approaches for financing investments that are necessary for the improvement of the value chain are almost completely left out of consideration.
Originality: Academic literature on network structures in ports as well as vertical inter-organizational integration is limited. This paper emphasizes the importance of collaboration in port structures and in a first attempt, discusses how joint financing provides added value for the logistics chain.

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1 Introduction

Since the 1980s, the port administration model changed due to the changing shipper practices resulting from technology advances and the need for cost-efficiency and improved service networks (Juhel, 2001; Munim, Saeed and Larsen, 2019). Private participation in port financing plays a major role in port development. One of the most applied models for large and medium-sized container ports is the landlord port (Zhang, 2016). The Port Authority is the owner of the land and infrastructure, which is leased to private operating companies. The Port Authority is responsible for the maintenance and the long-term improvement of the land and infrastructure, e.g. accessibility to roads, quay facilities, and berths. The private companies own and maintain the superstructure and equipment necessary for the port operation and employ dock labor (Brooks, 2004). In the last decade, the supply chain management (SCM) approach as a source of competitive advantage has gained in importance for ports (De Martino and Morvillo, 2008). A port, together with its terminals and logistics service providers, is offering a service to its customers such as cargo handling, transportation, storing, distribution, and information exchange (Dekker and Verhaeghe, 2012). These port functions are part of a chain system which is characterized by intra- and inter-organizational business processes and are carried out by port terminals (Robinson, 2002). Thus, terminal operations representing a part of the logistic chain are central to the competitive strategy rather than the whole port (Heaver, 1996). Improved integration and collaboration between port actors involved in the logistic chain lead to competitive advantage since business processes needs to be connected. Further, it is not just important to have a good location of a port, but also to offer a good service and a good logistic network. To provide fast and efficient services to customers, investments in specialized handling equipment, information and communication technology (ICT), and human capital are needed. Investments may create value for the logistic chain, for example through increased productivity, increased capacity, or reduced cost. Private investments in the previous mentioned areas are mainly financed with revenues from handling fees. A major challenge concerning necessary investments are the associated investment and finance risk. Most investments are capital intensive, have a long-term character (Dekker and Verhaeghe, 2012; Notteboom, 2004), which leads to a growing cost of superstructure. With the financial crisis in 2008, banks increased their lending rates and became more selective in approvals leading to a lack of finance or high cost of finance. The worse the financial condition of a company the higher the capital lending rate. The cost of capital rate reflects the risk of a financial default. A financial default or even bankruptcy of a partner in a chain may result in a disruption of the physical and non-physical flow. Cases of filling companies or a hostile relationship between port actors from the recent past have shown what consequences it may have for a port or a logistic chain. In 2016, the South Korea Shipping liner Hanjin have gone bankrupt due to financial difficulties. Ports refused the handling of loaded cargo due to the fear of non-payment (The Guardian, 2016). With the loss of a customer, ports had less volume of cargo to work with, which can be seen as a loss of business (Margaronis, 2016). In 2020, the International Longshore and Warehouse Union (ILWU) faces bankruptcy after the loss of a dispute with the International Container Terminal Services Inc. (ICTSI). The ILWU, a labor union complaining about safety conditions and urged jurisdiction for the handling of refrigerated containers, slowed down coordination and called for strikes at the Port of Portland (Read, 2020; Randles, 2020). The dispute caused the Port a loss of major customers like the Hanjin and the Westwood Shipping Line. Further, exporters of goods had additional costs of about $15 million a year due to the transport of goods to other ports (Njus, 2017). Moreover, downward pricing pressure caused Premium Transportation Services Inc. (TTSI), one of the largest port trucking companies of South California, to file for bankruptcy in 2016. On the one hand, major clients demanded lower prices and on the other hand, cost of litigation with independent drivers of the company who felt they are being treated unfairly and claimed to be treated as full-time employee led to financial difficulties (Phillips, 2016). Due to the implementation of the clean-truck program in 2006, independent drivers had to buy new trucks for at least $100,000, compared to former costs of $20,000 for used trucks. TTSI offered a lease-purchase contract to drivers who could not afford the costs of a new truck, which were now dependent on TTSI (Mongelluzo, 2016).

However, the return of investments depends on the future economic situation and the competitiveness of the port and terminals. Therefore, the creation of relationships between port actors and the improvement of the offered service by collaboration, which means the sharing of risk, cost and benefit, is mandatory for the competitiveness of the logistic chain and the port as well as the return on investment, which is discussed in the following.

2 Supply chain management applied to ports

2.1 Supply chain management

The supply chain management strikes for the coordination of business functions and business activities within and across organizations (Mentzer et al., 2001; Werner, 2017; Stentoft, Stegmann Mikkelsen and Rajkumar, 2018). Since the supply chain consists of more than one interdependent organization an inter-organizational integration needs to be achieved improving the flow of goods, information and finance (Mentzer et al., 2001; Fandel, Giese and Raubenheimer, 2009, p.4; Werner, 2017; Stentoft, Stegmann Mikkelsen and Rajkumar, 2018, p.28). The objective of a supply chain is to maximize the total value, which is the difference between customer value and supply chain costs, as well as to improve the profit of each organization and the supply chain as a whole (Chopra and Meindl, 2014, p.4; Stentoft, Stegmann Mikkelsen and Rajkumar, 2018, p.28). Customer value can be increased by increasing the service or quality of a product or service and decreasing the cost and time of delivery. In a supply chain, the value chain of an organization is part of a value system and is represented in Figure 1.

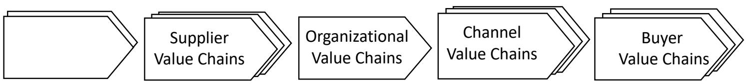

Figure 1: The value system (Porter, 1985)

The value system consists of the value chains of all organizations involved in the creation of a product or service. The output of the supplier is the input of the organizational value chain. Thus, the supplier influences the value chain of the organization. In reality, an organization is rather connected to multiple organizations upwards and downwards the supply chain corresponding to a network structure (Coyle et al., 2017).

For the inter-organizational coordination and integration, the relationship between the operators of a supply chain is important. The relationship between supply chain operators is concerned with commitment, trust building, sharing of know-how and information, and increasing transparency referring to a cooperative or collaborative behavior (Mentzer et al., 2001; Clott and Hartman, 2016; Werner, 2017, p.21). Characteristics of such a relationship are the sharing of risks, costs, rewards and information, the synchronization of decisions as well as joint actions and process integration with the aim of long-term partnerships (Mentzer et al., 2001; Christopher, 2016, p.125). Due to the synonymous use of the terms "cooperation" and "collaboration" in context of SCM in literature, this paper uses the terms synonymously as well and refers to a collaborative behavior.

The following section provides an overview about inter-organizational relationships in a container port.

2.2 Inter-organizational relationships in a port

In a supply chain, the terminal operator and the logistics service provider can be considered as some kind of third party logistic provider (3PL), which is a market-focused organization managing all activities in order to satisfy customer needs (Robinson, 2002; De Martino and Morvillo, 2008). It represents a business system competing against other ports (Musso, Ferrari and Benacchio, 2006). Since several organizations are involved in the handling of cargo and thus, in the creation of the service, the port can be seen as a network of port operators co-producing value. Operators in a container port are for example the terminal operator, shipping company, shippers, feeder operator, freight forwarder, road haulers and rail operator (De Martino and Morvillo, 2008; Martin and Thomas, 2001; Vitsounis and Pallis, 2012; Carbone and Martino, 2003). For better understanding how port operators are producing value it is important to understand the interdependencies between them.

Interdependencies between port operators can be distinguished between sequential, pooled, and reciprocal interdependencies (Thompson, 1967; Borys and Jemison, 1989; De Martino and Morvillo, 2008; Vitsounis and Pallis, 2012). In sequential interdependencies the output of an activity is the input of the activity of another actor. It is related to Porter's firm value chain system and it is the basis for the supply chain concept, which is the achievement of economies of integration (De Martino and Morvillo, 2008). Figure 2 represents an example of sequential interdependencies between port operators. A shipping company is carrying out an activity such as the transportation of containers to a port, which represents the input of the terminal operator's activity, e.g. the handling of the containers within the port area. In turn, the output of the activity of the terminal operator is the input of the activity of the freight forwarder, who transports the containers from the port area to another destination. These interdependencies work the other way around as well (Vitsounis and Pallis, 2012).

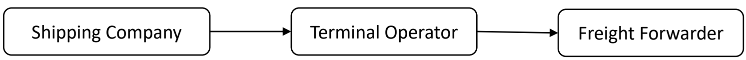

Figure 2: Sequential interdependencies in a port

In case an activity uses two resources, or two activities use the same resource it represents a pooled interdependency. This certain interdependency can be investigated in supply networks and lead to economy of scope or scale, when the two activities are identical or similar (Thompson, 1967; Borys and Jemison, 1989; De Martino and Morvillo, 2008; Vitsounis and Pallis, 2012) as shown in Figure 3.

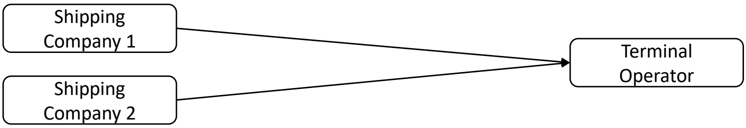

Figure 3 : Pooled interdependencies in ports

For example, a terminal operator is handling more than one ship to reach a certain throughput of containers. Also, to fill the capacity of a ship of a shipping company a certain amount of containers is necessary (Vitsounis and Pallis, 2012), which are delivered from several freight forwarders and works in the other direction, from the freight forwarder over the terminal operator to the shipping company.

The third type of inter-organizational interdependency is the reciprocal interdependency. It refers to the mutual exchange of input and output between two operators and is represented in Figure 4. The activity of one actor is dependent on the activity of another actor and it corresponds to economies of innovation, agility, and reactivity to changes. A change in activity of an actor can just be made if the other actor changes its activity as well

(Thompson, 1967; Borys and Jemison, 1989; De Martino and Morvillo, 2008; Vitsounis and Pallis, 2012).

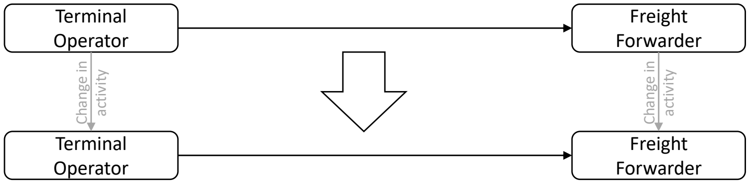

Figure 4: Reciprocal interdependencies in ports

By investigating the relationships between port operators, it is possible to determine a supply network for a port. For simplicity reasons the network considered in these papers consists of the main port operators: the shipping company (SC), the terminal operator (TO), and the freight forwarder (FF) and is presented in Figure 5.

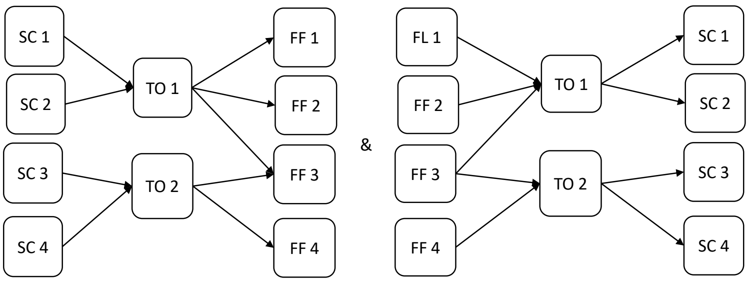

Figure 5: Supply network of a port

In case the activities are not well coordinated, e.g. containers to be loaded on the ship are not arriving on time or it takes too long to unload the ship, it might happen that the shipping company is looking for another port even though the location of the port might be beneficial for the shipping company. Further, storage space in a port is limited which is why the transportation of the containers through the freight forwarder or the shipping company is essential (Musso, Ferrari and Benacchio, 2006). The dwell time, the time cargo spends in a port, needs to be reduced, because the longer it takes, the higher the costs for all parties. But cost-effective port operations is the basis for low freight rates, which lead to competitive advantage (Martin and Thomas, 2001; Juhel, 2001). Thus, it is important to improve the activities continuously and work collaboratively from time to time, which can be achieved through investments in ports that have to be financed.

3 Financing investments in ports

According to Musso, Ferrari and Bernachio (2006), the profitability and the financing of investments are seen as one of the most critical factors in the chain of a port. Promising investments (Inv) in port assets have the potential to increase the level of service (s.l.) and the level of throughput Th (per unit and total of time) and is shown in Figure 6.

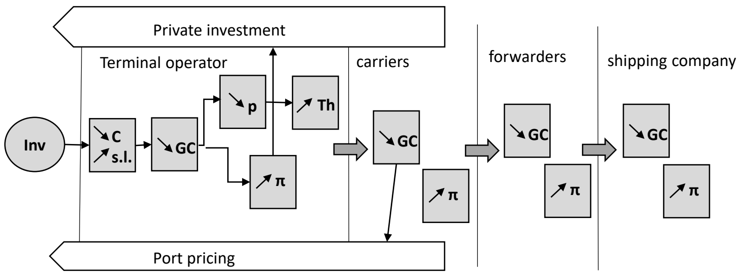

Figure 6: Port Investments and its microeconomic consequences following (Musso, Ferrari and Benacchio, 2006)

The increase of the service level is directly related to the investment (Inv). Further, investments in assets improving the activities in a port result in a reduction of cost C which reduces the generalized cost GC. In case of high competition, the price p will be reduced which will cause higher throughput and an increase in profit π resulting from increasing return of scales. The lower the competition, the higher the profit. In addition, all operators involved in the port activities of a chain will benefit from a reduction in generalized cost or price. Lower prices will cause higher throughput which results in higher profits. Thus, it can help to improve the competitive position of a port (Juhel, 2001; Meersman, 2005; Musso, Ferrari and Benacchio, 2006; Dekker and Verhaeghe, 2012).

Due to a restriction of public finance in numerous countries and the growing cost of infra- and superstructure by reasons of an increasing size of ships and rapid development of goods handling and processing technologies, investments in port projects with private participation have been encouraged in the need to find cost-effective solutions (Juhel, 2001; Musso, Ferrari and Benacchio, 2006). Considering terminals as commercial entities and therefore, emphasizing the importance of profitable prices for the offered services, the private sector has become more involved in investing in ports since 1990 (Meersman, 2005; Musso, Ferrari and Benacchio, 2006) and is shown in Figure 7.

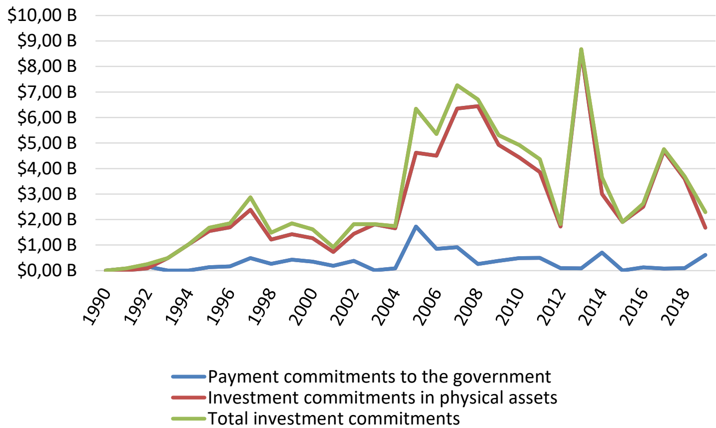

Figure 7: Investments with private participation in ports in billions of US dollars according to the World Bank's Private Participation in Infrastructure (PPI) Project Database

Especially, the increased competition and the traffic volatility in the port market in combination with the fast development of goods handling technologies support the financial significance of superstructure over infrastructure (Musso, Ferrari and Benacchio, 2006).

However, a major challenge for the implementation of investments in ports is the financing. Not uncommonly, port investments are capital intensive, have a long lead time, often have to be adapted and therefore, are considered to be risky (Notteboom, 2004; Dekker and Verhaeghe, 2012). Also, after the financial crisis in 2008 banks become more selective in approvals and increased the lending rates resulting in difficulties to obtain loans or high cost for financing for port operators (Cruz and Marques, 2012). Thus, there is a lack of investments leading to a deterioration in competitiveness of the port which in turn enhances the risk of a default of a port operator. A default or even a bankruptcy results in a supply chain disruption which causes a further deterioration in competitiveness (Vázquez, Sartal and Lozano-Lozano, 2016).

A relatively young research field dealing with the improvement of the financial flows in a chain system is supply chain finance (SCF). The objective is to maximize the profit of a single or several organizations by lowering costs, avoid bankruptcy, share risk and rewards and reach financial stability along the chain. SCF emphasizes a collaborative approach since supply chain operators are connected and thus, are dependent from each other. Non-collaborative financial practices, e.g. pushing costs up- or downstream the supply chain, just lead to financial instability and increases the risk of a disruption (Vázquez, Sartal and Lozano-Lozano, 2016; Somorowsky and Haasis, 2018).

4 Literature review

In this research, a literature review according to (Fink, 2014) is applied. The review examines articles dealing with collaborative approaches in ports on the microeconomic level. Due to the characteristic that more than one port operator is involved in the carrying out of port activities, the search will include supply chain management as well. It should be noted that articles dealing with cooperative behavior in context of SCM and ports are included as well since there is no significant difference in the use of the terms *collaboration* and *cooperation*. The papers were examined based on its content according to the following questions:

Which port operators are involved in existing collaborative approaches applied in ports?

What flows of the supply chain, e.g. flow of goods, flow of information or financial flow, are at the heart of collaborative approaches?

What are the qualities of collaborative approaches?

An emphasis will be on collaborative approaches and on financial practices to implement investments in ports. It will be interesting to see whether financial practices are seen to be value generating activities in the context of ports.

4.1 Selection process

A systematic literature search was conducted in the library databases Scopus and Web of Science looking for strings (e.g. port AND "supply chain management", "value chain" AND collaboration, cooperation). The search criteria used were language (English), source type (article, conference review), and year (1960-2020). From 1960 to 2020, 76 articles could be identified, and 39 articles were eliminated due to duplication or no accessibility. From this basis, the 37 identified articles were read carefully. Papers focusing just on governmental investment decisions were excluded as this paper focuses on private investments on a microeconomic level. In a landlord port, private companies are responsible for investments in superstructure. The financing of such investments is of interest, since they are required for activity improvements and thus, value generating. Papers discussing financial flows and especially the exchange of financial flows between port or supply chain operator are selected. Also, papers focusing on investment decisions on a company level, ignoring the links between other port operators or operators of the supply chain, were excluded. Since supply chain management and supply chain finance supporting the collaborative approach where supply chain operators are interdependent, looking at the enterprise level in isolation is not supporting the management approach needed. In the end, the following 5 papers were selected for a closer examination due to a focus on investments in superstructure, financial flows, the supply chain management on a microeconomic level excluding articles dealing with a governmental perspective, and the discussion of collaborative approaches.

Table 1: Paper selection

Author, Year	Title
(Dong et al., 2010)	Analyzing inland-orientation of port supply chain based on advertising-R&D model
(Ascencio et al., 2014)	A Collaborative Supply Chain Management System for a Maritime Port Logistics Chain
(Islam and Olsen, 2014)	Truck-sharing challenges for hinterland trucking companies: A case of the empty container truck trips problem
(Robinson, 2015)	Cooperation strategies in port-oriented bulk supply chains: aligning concept and practice
(Liu et al., 2016)	Supply chain cost minimization by collaboration between liner shipping companies and port operators

4.2 Findings from literature

First, the analysis deals with the identification of port operators involved in collaborative approaches applied in a port environment. Afterwards, the flows that are investigated and the qualities that are necessary to create and maintain collaboration are examined.

The approaches discussed in the selected papers are involving port operators such as carrier and shipping lines (Islam and Olsen, 2014), or shipping lines and port operator (Liu et al., 2016). The carrier assumes the function of the onward inland transport. The other papers are considering the port as one entity being part of the global supply chain and focusing on the relationships between port operator and inland port (Dong et al., 2010) as well as between exporter, terminal operator, importer, and government (Ascencio et al., 2014; Robinson, 2015). Table 2 shows the result of the involved port operators identified from the selected papers.

Table 2: Involved port operators

Author, Year	Shipping company	Terminal operator	Freight forwarder	Port as one entity
(Dong et al., 2010)			X	X
(Ascencio et al., 2014)				X
(Islam and Olsen, 2014)	X		X	
(Robinson, 2015)				X
(Liu et al., 2016)	X	X		

In many cases, the port is seen as one entity being part of the value creation process of the supply chain (Ascencio et al., 2014; Robinson, 2015), whereby Dong et al. (2010) distinguish between inland port, e.g. port activities on the land side, and the gateway port, e.g. port activities on the water side. However, as the works of Islam and Olsen (2014) and Liu et al. (2016) emphasize, many different port operators are involved in port activities relevant for the supply chain and for the port as whole to gain competitive advantage. So far, there is no approach available discussing investments and financing

decisions where more than two port operators are involved. Since port activities are interdependent usually involving more than two port operators, an approach going beyond a dyadic relationship is required.
All authors emphasizing the importance of the improvement of the flow of goods and of information and Dong et al. (2010), Islam and Olsen (2014), and Liu et al. (2016) are focusing on the financial flows as well. Robinson (2015) focuses on the stockpiles of coal and the need to minimize the queue length and demurrage costs where the terminal operator is acting as a coordinator to ensure coal availability and achieve shorter queue length. Beside of the optimization of operational efficiency there is a need for long term efficiency and thus, a need for investments eliminating bottlenecks. Necessary investments should be funded from federal government and the collaborating parties could benefit from their own improved business. A similar idea to encourage port operators to work collaboratively in prospect of improved businesses are coming from Ascencio et al. (2014). The authors introduce a framework for an inland coordination of the port logistics. It includes the management of port logistics governance which is responsible for the communication between the different port operators and the improvement of international trade procedures, a port logistics operations model which determines the available infrastructure and the logistics processes, and a logistics management platform system which supports the port activities in terms of conceptualization of the planning, scheduling, and controlling the physical and information flows. The system consists of a demand, orders, and vehicles management. It focuses on a good coordination between terminal operator and carriers picking up or delivering

cargo from and to the port resulting in reduced waiting times for truck drivers and capacity and service level improvements of the terminal operator. The financing of the system is not discussed. Another collaborative approach where the collaborating parties can benefit from shared resources and thus, achieving a better utilization is introduced by Islam and Olsen (2014). The collaboration is taking place between carries having difficulties reducing empty truck trips. In this approach, jobs that are not suitable to be combined with other jobs to enhance high utilization can be offered to other carries. In return for a payment of a fee, another carrier which can combine the offered job overtake the job and benefit from higher utilization. Further, the port benefits from better removal or delivery of cargo. Who and how the system needed to communicate and offer the jobs is financed is not discussed.

A collaborative approach between a shipping line and a terminal operator where the shipping line is compensating the terminal operator for additional cost is introduced by Liu et al. (2016). Additional costs of the terminal operator are resulting from higher port productivity, for example from the operation of additional quay cranes. Thus, the shipping line can save time at the port and reduce the speed on sea resulting in a reduction of demurrage cost and a reduction of fuel cost. The use of cost subsidies and profit allocation arrangements in collaboration is presented by Dong et al. (2010). The inland port and port operator have the opportunity to invest in research and development to achieve higher flexibility and productivity. In the cooperative setting the port operator may provide cost subsidy to the inland port to maximize overall profit of the port chain and its own profit.

The authors could show that there exists a Nash equilibrium of the cooperative strategy compared to a non-cooperative strategy. Thus, a cooperative strategy and the providing of cost subsidies result in better profits for the two ports.

Table 3: Flows of the supply chain between port operators

Author, Year	Flow of goods	Flow of information	Financial flows
(Dong et al., 2010)	X	X	X
(Ascencio et al., 2014)	X	X	
(Islam and Olsen, 2014)	X	X	X
(Robinson, 2015)	X	X	
(Liu et al., 2016)	X	X	X

Approaches that also involve financial flows can be distinguished between financial flows on the operational level (Islam and Olsen, 2014; Liu et al., 2016) and on a strategic level (Dong et al., 2010). Nonetheless, as the work by Dong et al. (2010) emphasizes, financial flows on the strategic and on the operational level are dependent. Especially, when it comes to the question who should finance the investment and who is overtaking the financial risk, the strategic level cannot be left out of consideration. Financial risk is not taken into account by any of the selected papers. The qualities of collaboration mentioned are similar among the presented approaches and are shown in Table 4. First, a systematic perspective needs to be applied considering the interdependencies between different port operators. Thus, the physical and information flow need to be coordinated in terms of available infrastructure, the use of common resources, sharing of information, collaborative decision-making, and continues improvement on the operational and strategical level (Dong et al., 2010; Ascencio et al., 2014; Islam and Olsen, 2014; Robinson, 2015; Liu et al., 2016).

Table 4: Qualities of collaborative approaches

Author, Year	Sharing of			Info. exchange	Joint action	Trust	Decision sync.
	risk	cost	profit				
(Dong et al., 2010)	X	X	X	X	X		X
(Ascencio et al., 2014)				X	X		X
(Islam and Olsen, 2014)			X	X	X	X	X
(Robinson, 2015)			X	X	X		X
(Liu et al., 2016)		(X)		X			X

Dong et al. (2010) were the only ones dealing with risk and the sharing of the investment costs. The risk considered is demand risk, since the freight market demand is elastic, where the port competes with other transport modals such as rail, air, or truck. Due to this, the expected profit of all participants should be large enough to make investments reasonable. Financial risk and its consequences are not investigated. Further, through cost subsidy and a profit allocation arrangement, the collaboration is beneficial in terms of maximizing profit. Liu et al. (2016) suggest to use a higher handling rate to share the investment cost. However, there is a problem to maintain relationship between port operator and shipping company, because the shipping company is free to choose another port and thus, the cost sharing is no longer possible. Since the development and the maintaining of long-term relationships, trust and commitment are essential, there is a need for a provision of incentives for the participating parties (Islam and Olsen, 2014). It is important that the incentives set are fair as collaboration only works if the port operators are willing to work together (Robinson, 2015; Liu et al., 2016). Agreements based on contracts can help to build trust as well as making decisions on the basis of cost-benefit analysis, which can be called *calculative trust* (Islam and Olsen, 2014; Robinson, 2015).

5 Development of a concept for collaborative financing investments in ports

Many approaches provide ideas on how collaboration can be beneficial for port operators, which are based on the need of investments in superstructure, equipment, or labor and thus, based on the need of financing these investments. The idea of compensation or subsidy introduced by Dong et al. (2010) and Liu et al. (2016) are an attempt to determine the financial effort of involved port operators, but the question remains how much everyone should pay and who else is financially advantaged or disadvantaged, e.g. through the emergence of bottlenecks. Financial issues such as the risk of a default or the cost of capital are left out of consideration. The long-term financing of investments still remains on a company level. In the worst case, companies are not investing in value-generating activities or the investment leads to a disruption due to financial distress or opportunistic behavior, e.g. bankruptcy of Hanjin or strikes at the Port of Portland. Due to the inter-dependencies between several port operators, the financing of an investment should take place on a supply chain level following a collaborative approach going beyond a dyadic relationship. There is a need for port operators to maintain the relationship in the long term. Since financial decisions must be made where more than one port operator is involved, game theory can be used to facilitate the decision.

5.1 Cooperative game theory

Game theory is used to analyze the rational decision-making behavior in situations where more than one party is involved. The payoff of one party depends on the behavior or actions of other parties, which refers to strategies and can be of competition or cooperation. It can be divided into cooperative and non-cooperative game theory. The cooperative game theory focuses on the coalition building and the payoff and communicated agreements can be enforced, whereas the non-cooperative game theory is strategy oriented and understands players as self-interested and unable to follow agreements (Prisner, 2014, p.1). A cooperative game, or more precisely transferable utility game (TU game), is defined by a finite set of players and a characteristic function, which measures the benefit or cost of every coalition of players representing subsets of the initial set of players which refers to the grand coalition (Wiese, 2005, p.89). It can be used to examine the problem of profit allocation and the determination of a stable coalition, which is of interest in supply chains. In a stable coalition, there exists an allocation such that no one of the players would like to leave the coalition as they cannot achieve the profit on its own or in smaller groups (Meca and Timmer, 2008). A solution concept of the cooperative game theory that deals with stable coalitions is the *Core*. The core allocates payoff distributions to coalitions. Such a payoff needs to be feasible, individual and coalitional rational. A payoff distribution is feasible if the coalition members receive not more than the grand coalition can generate. Individual and coalitional rational applies if no individual player and the grand coalition oppose the assigned payoffs. No coalition member should find themselves worse off than before and the generated profit of the coalition needs to be fully assigned (Wiese, 2005, pp.143–147).

5.2 Cooperative game theory applied to finance private investments in ports

The collaborative concept for financing investments in ports can be subdivided into network investment appraisal, determination of current financial situation of the port operators, calculation of the financial contribution, and allocation of the total profit and is illustrated in Figure 8.

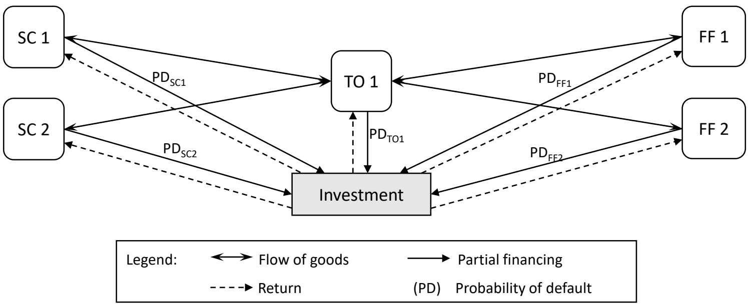

Figure 8: Collaborative approach for financing investments in ports

Taking the example of section 3, where competition is high. The profitability of an investment for all port operators needs to be evaluated. This can be done with the characteristic functions representing the profit functions of all port operators in a network structure, where the output of a port operator is the input of a following port operator. Just profitable investments should be selected, e.g. the sum of the profits of all port operators is positive. For example, an investment located at the terminal operator is increasing its service level, which in turn reduces the costs following a reduction in the generalized costs. The terminal operator will reduce the price in order to increase throughput which increases the profit. The profit of the shipping companies and of the freight forwarder will increase as well, as they benefit from the reduction of the price or generalized costs. Since joint actions will improve trust and the maintenance of the relationship, the financing of the investment should be shared. The sharing of the investment cost, the profit, and the financial risk have to be considered. The determination of the financial situation can be observed by the credit rating of the port operator. On basis of the credit rating, the height of the capital cost can be determined, which is defined by the capital cost rate in combination with volume and duration. Further, the credit rating is an indicator for the risk of default. It is assumed that a default results in a suspend of service, which reduces profit. Given the financial structure, the profitability of the investment, and the cost of investment including capital cost, the partial financing can be calculated for each possible coalition. Members with a poor credit rating are blocked by the coalition members since the risk of a default would increase much faster with additional financial burdens compared to members with a good credit rating. The value generated by the grand coalition is assumed to be best since it contains the profits obtained by all port operators. Now, the payoffs for the port operators depend on their marginal contributions obtained by the financial and operational abilities. Members with higher contributions get more of the total profit compared to members with lower contributions. Members with no financial contribution are likely not to receive anything from the additional profit.

This concept might be a mechanism for financing investments in ports. Further, this concept can be used as an incentive scheme as an improvement of financial stability and an optimization of the operations would lead to higher contributions and higher payoffs.

6 Conclusion

The objective of the port is to gain competitive advantage, which can be achieved through investments. Since several port operators are involved in the creation of the service, the port can be seen as a network of port operators co-producing value, where direct and indirect relationships among the port operators exist. Promising investments in port assets increase the performance of the port actor, where the investment is carried out, and of the other port operators being involved in the activities of the port related supply chain. Usually, the investment is financed by the port actor where the investment is carried out. This might cause problems in terms of high cost of finance, higher risk of default, or the creation of displeasure and stagnation in case of a feeling to be treated unfairly. A collaborative approach, where resources and risk is shared and where a systematic view is applied might help to overcome these problems and improve the performance of each port actor and the whole system. One question in supply chains is to find a setting in which collaboration is working. Everyone is better off with the coalition than on its own or in smaller groups. Cooperative game theory provides a solution concept for this question. It is to be noted that solution concepts of cooperative games are limited to a certain number of players due to computational reasons. Further, there is a need for side payments and agreements based on contracts, which would be suitable for port operators looking for long-term relationships.

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Northern Sea Route e-platforms: tools for competitive development

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Purpose: The current study purpose is preparation of proposals for the creation of digital services platforms, which could be provided on the Northern Sea Route as an international maritime transport corridor, on the basis of an existing maritime container industry e-platforms analysis, as well as on the basis of the transport market participants requirements for the composition and characteristics of services.
Methodology: The problem is considered in terms of the Enterprise Architecture approach. This study uses TOGAF and the Capability Driven Approach (CDA), a modern approach to the information systems development. These approaches help in analyzing the peculiarities of global e-platforms from the perspective of aggregating the enterprise architecture components into a business capability and provide foundation for the suggested tools determination.
Findings: Conducted studies suggest that the digital business ecosystems development is now widespread in the maritime container shipping industry, and e-platforms are an effective tool to ensure their performance. With the help of EA and CDA, it is possible to formulate proposals for e-platforms, based on the synthesis of transport market participants requirements.
Originality: The NSR development as international transport corridor along with benefits at the same time is controversial for carriers for a number of reasons, including the need of the NSR competitiveness increase by providing service at the level usual for carriers. The results of this paper create a foundation for further researches of digital services development in Arctic maritime logistics.

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1 Introduction

Nowadays the existing economic situation and political will of interested parties create steady prerequisites of the Northern Sea Route (NSR) development as international transport (including transit) corridor. In the future, until 2030, it is expected on this direction the cargo flows increase not only for companies, operating in the Arctic, but also maritime container transportation volume growth from China to Europe. Along with benefits such as significantly reducing cargo delivery times, reducing geopolitical risks, providing an alternative to transportation across the Suez Canal, the Northern Sea Route project at the same time is controversial for carriers for a number of reasons.

The first reason is the economic efficiency of transit transportation in difficult Arctic conditions. It is well known that NSR winter navigation is impossible without the participation of an atomic ice-breaker fleet, which significantly increases the transit transportation costs in the Arctic, and modern ships designed for the Arctic year-round operation are very expensive. Despite of the Government of the Russian Federation readiness to subsidize carrier companies on this route, the issue of transit transport organization efficiency, interaction of ice-breakers and transport fleet, terminals and other transport process participants remains open.

The second reason is the lack of multimodal transport infrastructure in the Arctic, the need to develop economic sectors and related modes of transport which provide cargo traffic in the Northern Sea Route.

The third reason is the need of the Northern Sea Route competitiveness increase by providing service at the level usual for carriers. Currently, the maritime container transport industry participants represent increased demands for the cargo transportation process transparency, container processing time reduction due to information exchange efficiency improvement between counterparties, possibility of multimodal transportation electronic processing.

The current study purpose is preparation of proposals for the creation of digital services platforms, which could be provided on the Northern Sea Route, on the basis of an existing maritime container industry electronic platforms analysis, as well as on the basis of the transport market participants requirements for the composition and characteristics of services provided along the Northern Sea Route as an international maritime transport corridor.

2 Method

Digital business ecosystems are currently becoming a modern way of cooperation and development in various sectors of economy. E-platforms are effective means of creating such digital business ecosystems and ensuring their functioning. This term first appeared in EU documents and referred the fact that the convergence of networks and information technologies forms the basis for growth and development of the economy. The rapid development of the Internet and information technology gave way to the creation of many digital business ecosystems, the largest ones being Google, Amazon, Facebook and Apple. There are many different definitions of digital platforms, but most authors define the digital platform as a system of formal and informal rules and algorithms for network user interaction, based on various architectural standards of software and hardware, which are used for storing, analyzing and transmitting data about the participants of the interaction (Styrin et al., 2019)

Today, electronic platforms are actively being introduced in the maritime container shipping industry. They perform various business functions and support the interaction of participants in the business ecosystems. The maritime environment is composed by electronic systems and services that manage various incoming and outgoing information and data through collaborative and automated processes and services (Ducruet and Zaidi, 2012). The platforms used in the industry now can be divided into three large groups by their role in the process of participants interaction in the business ecosystems:

1) E-platforms built by commercial ports. Thus, (Dellios and Polemi, 2012) describe Maritime Community Cloud platforms which support such business processes as ship and cargo management; intra-port communication; provision of information to regulatory authorities, transport services, healthcare organizations and other parties; ground container logistics, security services and information integrity services.
2) E-platforms built by public authorities. In order to facilitate the international trade procedures and coordinate the control carried out by the competent bodies of commercial and technical supervision, the governments introduce Single Window facility in their countries. Managed centrally by a leading agency, the Single Window provides public authorities with the opportunity to access information or actually receive information that is relevant for performing their tasks. Public agencies can coordinate their control actions while importers and exporters can submit standardized electronic data via a single entry point, in order to comply with all the regulatory requirements related to import, export and transit (Maydanova and Ilin, 2018).
3) E-platforms built by largest players of maritime container shipping industry. Keeping in mind the business capability of transparency and flexibility of the supply chain process, industry participants build various e-platforms thus aiming to ensure the functioning of the digital business ecosystem. The largest players that create such platforms are global forwarding companies, digital freight forwarders (that have just emerged on the market) and container shipping lines (Druz et al., 2018; Elbert et al., 2017; Feibert et al., 2017; Fruth and Teuteberg, 2017; Lam and Zhang, 2019; Zaborovsky et al., 2018).

For analysis of an existing maritime container industry electronic platforms and preparation of proposals for the creation of digital services platforms, which could be provided on the Northern Sea Route, the problem is considered in terms of the Enterprise Architecture approach, a concept of enterprise management that has been actively developed over the past 30 years by recognized management institutions and is now widely applied in practice. (Lankhorst, 2017) gave the following definition to this concept: “[EA] is a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise’s organization structure, business processes, information systems, and infrastructure”. Currently, there are several well-known approaches to EA. These approaches rely on different viewpoints on EA and modeling techniques associated with them. According to recent studies (Aldea, 2017), the most commonly used approaches are The Open Group Architecture Framework (TOGAF), Zachman Framework, Gartner Enterprise Architecture Framework, Federal Enterprise Architecture Framework (FEAF), Department of Defense Architecture Framework (DoDAF).

This study uses TOGAF and the Capability Driven Approach (CDA), a modern approach to the information systems development. These approaches help in analyzing the e-platforms from the perspective of aggregating the enterprise architecture components into a business capability and provide foundation for the suggested tools determination.

Business capability is a special ability or power that a business can possess or exchange in order to achieve a specific goal or result. A business capability can be defined by a description of what needs to be done with some details added. A further, detailed definition of the capability requires an understanding of how this can be achieved by combining such supporting components as roles, processes, information, and tools. Business capability is determined with the aim of lasting as long as possible, while the content of the components is subject to frequent changes. The implementation of a business capability also relies on a set of tools, or resources and assets, such as tangible assets (equipment) and intangible assets (available funds, IT systems, intellectual property) (Sandkuhl, 2018). For the analysis of an existing maritime container industry electronic platforms, as well as for the composition and characteristics of services provided along the Northern Sea Route as an international maritime transport corridor approaches and methods that can classify the impact of EA components on business capabilities of companies are required.

3 Results

The NSR as an international maritime transport corridor besides advantages of time saving cargo delivery and carrier companies subsidizing need to comply the ad-vanced competition requirements. Currently, new establishment in management thinking has been the realization that individual enterprises no longer compete as self-contained entities, but rather as supply chains. Christopher states that compa-nies enter “an era of "online competition," where prizes will go to those organizations that can better structure, coordinate and manage relationships with their partners in a network committed to ensuring excellent value in the final market. Supply chain management aims to provide more cost-effective end-customer satisfaction by inte-grating buyer/supplier processes. This integration is generally achieved through greater transparency of client needs through information sharing, as well as through the creation of seamless processes that link the identification of physical replenish-ment needs to a "just-in-time" response” (Christopher, 2005). As mentioned above, the digital business ecosystems development is now wide-spread in the maritime container shipping industry, and e-platforms are an effective tool to ensure their performance. Table 1 presents the TOGAF-based analysis and a classification of the existent e-platforms in maritime container shipping industry. Digital platforms on the basis of such supporting components as roles, processes, information, and tools support different business capabilities of companies - industry participants.

Thus, Maritime Community Cloud e-platforms support business capability of cross-border trustworthy e-services to all commercial ports and their users in a cost-effec-tive way; Single Window e-platforms perform submission of a standardized infor-mation and documents with a single-entry point to fulfill all regulatory requirements; business ecosystem e-platforms ensure supply chain transparency and agility and support e - commerce capability. In accordance with the development plan, the NSR will have at least two hub ports and business capability of cross-border trustworthy e-services to ports and their users need to be supported by digital platforms, devel-oped either port community, either state body. Currently such digital platforms are not introduced in the Russian Federation as all ports of the RF are so named "out-ports", but not hub ports and their cargo handling volume is substantially lower. In case of the NSR hub ports construction, the need of Maritime Community Cloud e-platforms development will increase significantly. Single Window introduction is the world-wide initiative supported by The United Na-tions Network of Experts for Paperless Trade and Transport in Asia and the Pacific (UNNExT) in cooperation with the Economic and Social Commission for Asia and the Pacific, United Nations Economic Commission for Europe, World Customs Or-ganization and national governments and state bodies. With their concerted efforts the experience of Single Window creation was outlined, there were determined stages and foundations of the creation at the national and regional level. There were qualified five main stages of the national Single Window creation. Maydanova and Ilin propose that "they could be used as a basis for the long-term strategic plan for the implementation of a national Single Window and represent at the fourth level an integrated national logistics platform interlinking the administrations, companies and the service sectors to better manage the entire chain of import-export operations and on fifth level-interconnection and integration of national single windows into a bi-lateral or regional cross-border e-information exchange platform" (Maydanova and Ilin, 2018). Currently national Single Window is not introduced in the Russian Federation.

Brandenburg states that "the emerging competitive paradigm of today’s complex global markets is that path to sustainable advantage lies through managing the com-plex web of relationships that connects suppliers and customers in a cost-effective, value-added chain. In connection with these changes, the role of transparency and flexibility of the supply chain is increasing and the continuous interaction of partici-pants in the business ecosystem becomes a must" (Brandenburg, 2013). Keeping in mind the business capability of the supply chain process transparency and flexi-bility, industry participants build various e-platforms thus aiming to ensure the func-tioning of the digital business ecosystem. In case of the Russian container operator creation for international transportation along the NSR, e-platform supporting digital business ecosystem of the NSR should be developed. As was mentioned above, the implementation of a business capability relies on a set of tools: tangible and intangible assets. A variety of modern technologies are used to operate e-platforms in maritime container shipping industry , such as Cloud Computing, Electronic Data Interchange, the Internet of Things, Big Data, Global Positioning System (GPS), robotic-aided systems, cyber-physical systems, block-chain, radio frequency identification (RFID) tags, and sensors. All these technolo-gies need to be introduced for the NSR digital platforms successful development. It is appropriate to devote special attention to such supporting component of busi-ness capability as information : modern digital platforms in maritime container ship-ping industry support Business-To-Business (B2B), Business-To-Government (B2G), Government-To-Government (G2G) data exchange at the local, regional, national and global levels. The NSR e-platforms shall maintain such data exchange with using of various interfaces for interaction.

Table 1: Maritime container shipping industry e-platforms classification

Capability	**Cross-border trustworthy e-services to all commercial ports and their users in a cost-effective way**	**Submission of a standardized information and documents with a single-entry point to fulfill all regulatory requirements**	**Supply chain transparency and agility / E - commerce**
Roles	Maritime Community Cloud	Single Window	Business ecosystem
Business processes	Vessel & Cargo Management Inland Logistics Communication at Port Level Integration Services Security Services	Obtaining necessary permits and clearance related to import, export or transit-related requirements Obtaining international trade-related data and statistics in a comprehensive and timely manner	Booking placement Cargo tracking Rate analytics Procurement Supply- chain control Financing services Marketplace
Information	B2B, B2G Information Exchange on local / national / regional level	G2G, B2G Information Exchange on local / national / regional level	B2B Information Exchange on local / national / global level
Tools	Cloud Computing, EDI, Big Data, Robotics, IoT, RFID, sensors, cyber-physical systems, GPS, Blockchain	Cloud Computing, EDI, Big Data, Robotics	Cloud Computing, EDI, Big Data, Blockchain, IoT, RFID, GPS, sensors, cyber-physical systems, Robotics

4 Discussion and Recommendations

Thus, development of the Northern Sea Route as an international maritime transport corridor requires not only fleet and port construction, infrastructure development and organizational agents appointment, but the development of information and communication technologies as well, including e-platforms implementation. Such e-platforms will bring substantial competitive advantage to the Northern Sea Route and will provide service at the level usual for carriers.

Some discussion points could be determined at this:

1) Digital platforms will not be able provide services of the physical infrastructure, while developed the NSR physical infrastructure could work without any digital platforms. On this reasoning could be the answer that currently digital platforms become a substantial tool in competition between maritime container shipping industry companies allowing direct communication with customers. Such communication will help to increase quantity of shippers and at the end, profitability of the NSR shipments.

2) The NSR shippers will have advantage in timing and cost compensation and will not care about communications and supply chain transparency. This reasoning could be answered that usual logistic scorecard is not only time and cost, but service quality and relationships as well. Digital platforms will provide desired service quality and relationships, and cost compensation to shippers is very expensive approach for the NSR progress. Organizing the NSR services on the level usual for carriers will support to increase economic effect of a new international maritime transport corridor launching.

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The impact of an asymmetric allocation of power on the digitalization strategy of port logistics

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Purpose: The objective of this paper is to investigate the impact of the asymmetric allocation of power on the digitalisation strategy in port logistics. To reach this purpose this paper combines the term of asymmetric power to the concept of bargaining power, supply chain leadership theory, and the trends of digitalisation in port logistics**.**

Methodology: A systematic literature review on the asymmetric allocation of power is used to synthesize the current state of the art in this field of research**,** by selecting journals in supply chain management, logistics and operation research. This review establishes a theoretical framework while combining the concept of digitalisation in port logistics and the research about the allocation of power.

Findings: While this paper provides an overview of the research of marketing channels, bargaining power, supply chain leadership theory, and information asymmetry in SCM, it also develops a definition for the asymmetric of power. Linked to the classification of relations within a port, conclusions are drawn about the influence of power on digitization in that port.

Originality: During the last decades the importance of ports has transformed from traditional regional gateways to key-factors in the supply chain and logistics activities. While the influence of globalisation and digitalisation increases, digitalisation becomes one of the central strategic terms for port logistics. Based on these trends the strategic decisions within the port are getting penetratively influenced by the relationships within the supply chain.

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1 Introduction

For in the last decades the port was regarded as a separate hub in the consideration of international supply chains. However, with the increasing globalisation of markets, the importance of the port in the supply chain continues to grow (Zondag et al., 2010; Tseng and Liao, 2015; Keceli et al., 2008). Companies are increasingly recognizing the dependence of their competitiveness on the flow of goods in the port (Lee, 2006; Gao, 2009; Robinson, 2002; Zondag et al., 2010). In 2018 the global container freight traffic exceeded the 11 billion tone mark. The United Nations Conference on Trade and Development expected growth of up to 3.5 percent in the international maritime trade between 2019-2024 (United Nations, 2019). In the European Union, the maritime sector handles up to 90 percent of the freight trades with third countries and up to 30 percent of the intra European Union trade (Mangan, Lalwani and Fynes, 2008). At the same time, the port and the maritime economy are also influenced by the disruptive technological change in information and communication technologies (Balan, 2020; Moshe and Arie, 1986). The logistic sector, in general, will adopt data-driven technologies faster than most other business sectors (Balan, 2020).
As an essential part of global supply chains, the ports have to manage various actors, networks and coordinate the flow of thousands of cargos, information and financial transactions (Heilig and Voß, 2016). More than ever the port is influenced by all activities and organizations within the boundaries of the port: „cargo handling, storage, clearance, ship servicing, etc. and the organizations involved – ship owners, agents, port management, stevedores, customs, transport firms"(Lee, 2006). The digitalisation will be one

of the central enablers for achieving success in the competitive environment of global markets (Heilig, Voß and Lalla-ruiz, 2017; Balan, 2020; Keceli et al., 2008). To give an example: Maersk and IBM have developed the collaborative blockchain platform TradeLens in 2018, with the objective to create a digital „ecosystem, bringing transparency, visibility and efficiencies to every actor that is part of [the] shipment"(Pradi, 2020).
With the increasing digitalisation of the supply chain, the management is expanding on various levels (Goldsby and Zinn, 2016; Stank et al., 2019; Hofmann et al., 2019). The growing demands and complexity in the supply chain lead to the necessity of making the processes and procedures in the supply chain more efficient (Butner, 2010; Oesterreich and Teuteberg, 2016, p.131). Ports are complex and multipart organizations in which institutions and processes interact at various levels. One of the central tasks of the supply chain management is to coordinate the relationships of the supply chain. This involves assessing the positioning of each supplier in the supply chain and evaluating it in terms of collaborative overall success. Each company, in turn, is striving to maximize individual profit (Monczka et al., 2016, p.22; De Martino and Morvillo, 2008; Londe and Masters, 1994). This paper distinguishes between logistics, trade and supply channels. The interaction among these three functions and the rapid change in information and communication technology justifies the high relevance of examining the relationship and power structures in the port more closely (Bichou and Gray, 2004). Nowadays there is less research that integrates the concepts of supply chain management, supply chain integration, relationships, and power along with the supply chain and the digitalisation in the supply chain. This

paper follows the objective to give a first overview, in the form of a literature review, about the impact of an asymmetric allocation of power along the supply chain on the digitalisation strategies in the port. This literature review is based on the existing research on the impact of disruptive technologies on the port and the research of power structure within the supply chain.

To reach the objective of the paper, it is structured into a theoretical overview, the review and presenting the results of this research in the last chapter. The theoretical implications present the concept of the port supply chain, defines power within the port, and gives a short overview about the digital transformation of port logistics. In the third chapter the research method, as well as the results are presented. The paper ends with a summary of the results, and the conclusion in the last chapter.

2 Theoretical Implications

In the context of globalisation, the notion of freight transport and logistics steadily increases its impact on the competitive environment and becomes one of the central enablers for competitive advantages (Robinson, 2002; Botti et al., 2017). To determine the effects of the allocation of power, in relation to the port's digitalisation strategies, it is necessary to develop a general understanding of the port's integration into the supply chain, but also to identify the individual actors within the port. The first step, therefore, is to consider the allocations and interactions along with the resources and infrastructure in the context of the port. Besides this, a general understanding of power will be developed and a short overview of port digitalisation will be given.

2.1 Concept of Port Supply Chains

Following the concept introduced by Heaver et.al. this chapter is structured along with the terminal operation model and port cross-sectoral mergers. Generally, there are three types of freight handling actors in maritime logistics; “port authorities, shipping lines with terminal operations, and independent container terminal management companies”, whose actions depend on the global supply chains (Heaver, Meersman and Voorde, 2001). The structures of port administration/port authority could be illustrated by the landlord model, in terms of its ownership and the operating structures of the port. The port could be separated into infrastructure and superstructure, whereby the infrastructure is administrated by the governance and the superstructure is operated by private companies (van der Lugt, de

Langen and Hagdorn, 2015; Chen, 2009). Further approaches incorporate terms of ownership and operating structures into the models of tool port and service port. The tool port is based on a port authority, which provides the infrastructure and superstructure, and operates some port services as well, all other services are provided by private investors. Service ports are based on the approach that the port authority provides all necessary services (Chen, 2009; Brooks, 2004).
The operation of the terminal can be divided into terminal operating shippers, terminal operator shipping companies, terminal operator port authorities, and terminal operating companies. Further structures and actors will be directly influenced by this operation model (Bichou and Bell, 2007).

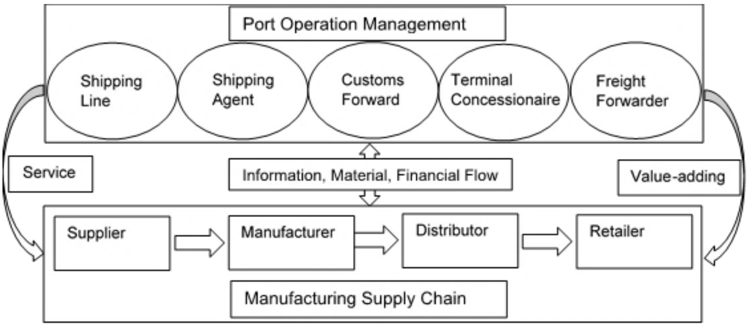

Figure 1: Port Supply Chain, in addition to (Gao, 2009, Vaio and Verriale, 2020, Robinson, 2002)

Besides the organization of the terminal, the upstream and further flow of goods via the shipping lines, the coordination and other logistics service providers plays a central role in the port's relations. As shown in Figure the port has become the convergent point of the transactions and business interactions between different supply chains. For example, material and information flow between enterprises are handled through the port (Gao, 2009). The example in Figure elaborates a short overview of a manufacturing and third-party logistic distribution supply chain while including the port. The supply chain of the port is illustrated, based on (Robinson, 2002). The supply chain of the port can be separated in addition to their spatial allocation. The shipping line bypasses this allocation, other actors like the shipping agent, customs forwarder, terminal concessionaire, or the freight forwarder operate from the land segment.

2.2 Definition of Power in the Concept of Supply Chain

The importance of power took on a central role in early research to examine sales channels (Reve and Stern, 1979; Gaski, 1984; Lusch and Brown, 1985). Frazier shows the balance of power in the cooperation between two companies, with a corresponding potential of influence in each dyad (Frazier, 1983). The concept of power within a marketing channel is defined by the ability to establish a binding guideline for the participants of the channel regarding products or brands (Lusch and Brown, 1985). However, this definition only includes a focus on the end customer and as such is not fully applicable to the supply chain. Following the approaches of marketing, the concept of power within a supply chain can be defined by assuming that there is a relationship between the actors of the supply chain (Johnsen and Ford, 2008). This relationship is shaped by reciprocal influence and also acceptance (Kouzes and Posner, 2005; Defee, Stank and Esper, 2010). Johnsen and Ford summarize the characteristics of the supply chain relationship (Johnsen and Ford, 2008). The concept of power is defined as the ability of an actor to exert influence on customers, competitors, and suppliers against the achieving of its own goals (Cox et al., 2003; Johnsen and Ford, 2008). Johnsen and Ford distinguish three possible variants of cooperation in the customer-supplier relationship: an asymmetry on the customer side, an asymmetry on the supplier side and a symmetrical distribution of power (Johnsen and Ford, 2008; Michalski, Yurov and Botella, 2014). A corresponding power position can be based on the financial strength or size of the company (Johnsen and Ford, 2008). The structures of this approach can be further extended to relationships with, for example, logistics service providers or shipping companies. Porter provides a further approach to defining the concept of power in his model of the Five Forces, in which he shows the bargaining power of customers and suppliers over business decisions (Porter, 1980, p.4). The execution of this power can be seen, for example, in the possibilities of influencing price or product quality and thus exerting influence on the further supply chain. The power of influence increases with the dependence of the actors on each other (Porter, 1980, p.27). Furthermore, the trend of globalisation is influencing the power structures within the port. Besides this trend, three strategy patterns are evident: Merges, Regional Coverage, and Internationalisation. The increase in customers power and the need for investments to meet transhipment requirements urge many companies to merge. The merge of companies enables them to attain a stronger position in negotiations and to create the opportunity to use synergic effects vis-à-vis the port authority and shipping companies. Other ways to increase market power are regional coverages or global expansion. Companies increase their span of service in the current region or provide a similar service in adjacent locations. Several of the regional companies increase their market power by extending internationally. (Heaver, Meersman and Voorde, 2001).

Following the concept of Johnson and Ford an asymmetric power allocation, will be defined in this paper, as the ability to influence the participants of the supply chain, to lead them to your own goals. The influence can be exerted by the supply chain leader, as well as the supplier or customer. The extent of possible influence depends on the direct or indirect bargaining power of the participants to the supply chain, which, for example, is based on the financial strength or the company size.

2.3 Digital Transformation of Port Logistics

Over the last 30 years, the increased competitive pressure and the pressure to innovate has led ports and port supply chain to optimize their processes and transform their system landscape. Related to the evolution of international trade the port has to manage an enormous quantity of cargos, by various customers in addition to the international commodity flow. A possible drive to maintain competitive pressure is the use of information and communication technology in their physical and decision-making processes (Keceli et al., 2008; Tseng and Liao, 2015). Due to an increasing digitalisation of processes, the proximity of the individual actors within the supply chain increases, and the integration of all processes into each other grows accordingly, up to a collaborative supply chain. In addition to the increasing integration of information and communication technology, the terminology of this term evolved from telematics provided for road transport to contemporary smart/intelligent solutions, like cloud computing, Internet of things, or Big Data solutions. There are several reasons for the investments in information and communication technologies: cost reductions, an increase in the service level, the enhancement of transport and logistic processes, and lastly an improvement of safety and security. (Carlan et al., 2017). The increasing integration is based on the use of appropriate port communication systems, which enable a consistent sharing of information along with global supply chain (Vaio and Varriale, 2020; Martino et al., 2013; Carlan et al., 2017) and so the gain of market force (Lee, Padmanabhan and Whang, 2004).

In principle, different categorization can be defined to emphasize how the use of information systems changes the process landscape of the supply chain. In the literature, the standardization or the creation of a uniform database is mentioned as an example, as well as the creation of cross-organizational databases, the change in control systems through the creation of contactless control options, or the automation of transactions (Vaio and Varriale, 2020).

3 Literature Review about the allocation of Power in Supply Chain

The objective of a literature review is the structured and scientifically qualifiable analysis and presentation of the literature of a certain topic or subject area (Denyer and Tranfield, 2009, p.671; Fink, 2014, p.3 f.). This paper aims to investigate the impact of the asymmetric allocation of power on the digitalisation strategy in port logistics. For this literature review, the review methodology according to Fink is used. To comply with the quality criteria, he recommends a step-by-step procedure in the preparation of the review.

3.1 Methodic Framework of the Review

In the first step, he recommends formulating the research question, which guides the screening of literature and helps to reach the objective of the paper (Fink, 2014, p.3). Based on the theoretical framework the following question can be deduced:

- *To what extent does existing research take up the impact of the allocation of power on port strategy, especially ports digitalisation strategy?*

Based on this question, it is necessary to locate and select the relevant literature (Fink, 2014, p.3 ff.). Denyer and Tranfield recommend to define the search term based on the theoretical background, pick the relevant databases and the period of the review. As mentioned in chapter 2.2 the term of power is currently used in different research fields. To reach a general overview this research is going to extend the term of power to "*braining power*" or "*relationship*" or "*market force*" or "*marketing channel*" and at last "*relationship*". In the combination with port and supply chain, it results in the following research term: “*supply chain*” or “*supply chain management*” and “*port*” and "*marketing channel*" or "*market force*" or "*bargaining power*" or “*leadership*" or "*relationship*". To carry further screening these research terms were submitted to the Scopus database in March 2020, which results in 204 publications.

For the fourth step, they suggest to select and evaluate the literature. For this purpose, it is required to develop transparent evaluation criteria. In addition to the search term, this review is limited to journal publications and conference papers/proceedings, which were published in the English language between 2000 and 2020. The research excludes the papers of a first search result, which are published under the subject of Earth and Planetary Sciences, Energy, Arts and Humanities, Chemical Engineering, Medicine, Agricultural and Biological Sciences and Biochemistry, Genetics, and Molecular Biology, because these subjects are not appropriate for the topic of the research. Under these restrictions, the search result was limited to 107 papers, which were published in the last 20 years. This search result needed to be screened and synthesized in the sixth step by reading the titles and abstracts of the papers and excluding the content which did not fit the topic of the research. Especially papers were selected, which included the topic of digitalisation, so after excluding every irrelevant content, 39 papers with a corresponding relevance remain for further analyses.

3.2 Descriptive Screening of the Literature

After the selection of the relevant content, the literature must be analysed (Fink, 2014, p.5; Denyer and Tranfield, 2009; Wallace and Wray, 2011, p.143 ff.). The results of this screening will be illustrated in the following chapters.

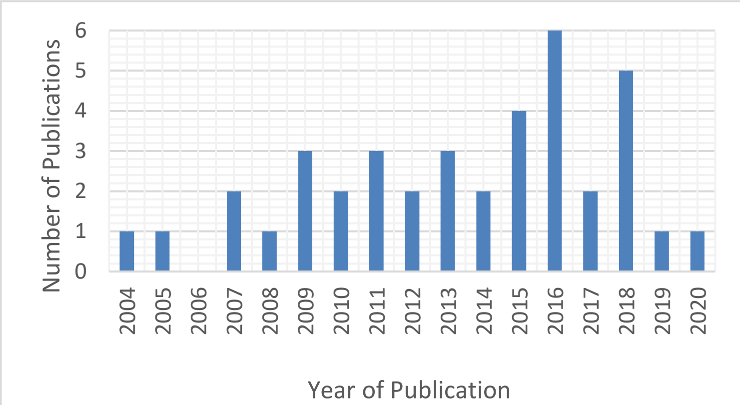

Figure 2: Analysis of papers according to the year of publication

As shown in Figure 2, the first literature on the deduced search term was published by Rodrigue in 2004. The most recent literature is based on Di Vaio and Varriale in 2020. Most of the publications on this topic were published in 2015, 2016 and 2018. A trend towards a growing or decreasing number of publications is not noticeable during the last 20 years. On average, about 2.3 publications were published in the years 2004-2020, which fit into the topic of this review.

Figure 3: Overview of the Sources

Figure 3 displays the sources in addition to the references. The most frequently publishing journals, in this research field, are Maritime Policy (5 publications), Management and Maritime Economics and Logistics (3 publications), and Research in Transportation Business and Management (3 publications). Every other journal has published a maximum of one or two papers.

As shown in Figure 4 most of the papers, up to 27 %, are published to the subject of social science. Further research areas are business and accounting (16%), engineering (14%), decision science (11%), finance (10%), environmental science (9%), and computer science (6%). This allocation to the different topics of research shows the high interdisciplinary significance of the port and its development of strategies.

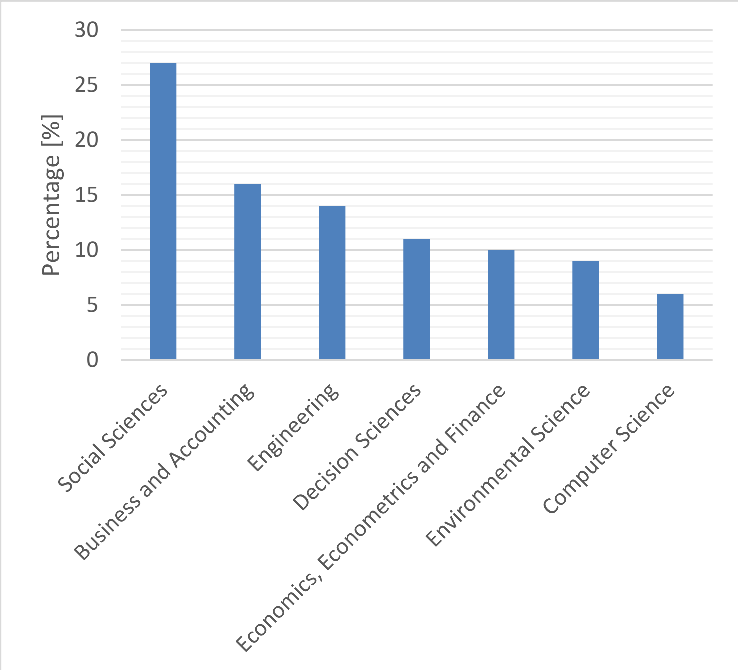

Figure 4: Percentage depending on the subject area of publication

3.3 Meta-Analysis of the Literature

In the previous chapters, the selection and descriptive analysis of the relevant literature was carried out using formally derived, mostly quantitative criteria. Based on this previous analysis, the research question is answered by screening the content.

Basic structures of power allocation in the port can already be found in research on the position of the port in global supply chains or on the structural design of the terminal. This positioning of the port is, among other things, due to the emergence of the possible bottleneck, which a port can represent in the global supply chain. Furthermore, the research focuses on the structures within the port, the role of the government, or terminal operators (Rodrigue and Notteboom, 2009; Hall and Jacobs, 2010; Lam and Yap, 2011; Jacobs and Hall, 2007). Port strategy must be developed dependent on ports role in the global supply chain. With the positioning of the port/terminal as part of a multimodal platform, its importance in global supply chains is growing further. Especially about concerning the availability of information, the port is of crucial importance (Veenstra, Zuidwijk and Van Asperen, 2012). This research thus addresses the central role of the port in the supply chain, the power that the port can exert on the supply chain, but at the same time, it does not explain how power structures affect strategy formation in the port and digitization strategies.

Tongzon, Chang, and Lee point out the importance of building long-term relationships and collaboration to increase supply chains profitability (Tongzon, Chang and Lee, 2009). Collaboration enables the port to gain competitive advantage and increase "port performance such as connectivity, value-added service, safety and security, efficient operation, cost efficiency, reliability and convenience of port users" (Seo, Dinwoodie and Roe, 2016). Liu et al. amplify these advantages by the example of the short time scheduler and decreasing port times. A consistent sharing of information between the shipping lines and the terminal operator enables them to decrease port time, by, for example, optimize the use of quay cranes (Liu et al., 2016). Seo et al. highlighted five key factors of collaboration among maritime logistics, "information sharing, knowledge creation, goal similarity, decision harmonisation and joint supply chain performance measurement". They suggest the development of collaborative information and trading platforms for the maritime sector (Seo, Dinwoodie and Roe, 2015), which should include governance, terminal operators and shipping companies (Ascencio et al., 2014). As mentioned in the preceding literature the concept of collaboration demands an equal allocation of power along to the supply chain.

Vaio and Varriale show the positive impact of digitalisation on the inter- and intraorganizational relationships of the port. Port communication systems enable the port authority to redesign the inter-organizational relationships and supply chain processes within the port. Digital platforms change the interaction between the players through automation and simplification (Vaio and Varriale, 2020). This positive impact of the digitalization to the inter-organizational relationships can be deducted by the optimization of the hinterland connection. The container barging will be more efficient, while using the digitalization to optimize the coordination between shipping companies, terminal operators and freight forwarder (van der Horst et al., 2019).

The development of deeper intra-organizational relations positively influences the extra organizational relations and helps to increase supply chain integration. Nowadays a competitive environment leads companies to cooperate more closely with their partners and meet their requirements for lower costs and higher quality. Especially in maritime logistics, the knowledge of these impacts could help to develop a strategy to compete in this fast-changing environment (Yang, Yeo and Vinh, 2015).

4 Conclusion

Depending on the structure of the port supply chains a specific allocation of power is created, and thus leads to a corresponding level of influence. In the complex global environment, collaboration enables the economic activity of the port. Finally, the relationships between the individual actors create a network, which influences the strategic formation. The objective of this research was to determine the current state of research on the effects of an asymmetrical allocation of power on strategy development in the port, in particular the development of digitalisation strategies. Based on this literature review, the poor level of the present research, about the impacts of asymmetries in power allocation on strategy development in the port, can be deducted. The main results of today's research, are about relationship management and the impacts of collaboration to ports supply chain strategy or the positive impacts of the digitalisation in general. Despite these poor results, some implications can be concluded.

The central role of the port as a collaborative link in global supply chains is emphasized. Especially about concerning the availability of information, the port plays a central role. The objectives of a digitalisation strategy should, therefore, be based on the creation of a consistent exchange of information along with the supply chain. A reference to the impact of power allocations on digitalisation strategies can only be identified in its basic features based on this review. The collaborative approach provides the supply chain with balanced power, which leads to the necessity of the strategy development to reduce barriers of equal power and support supply chain collaboration.

Following the advantages of a collaborative port strategy, further research focuses on the benefits of closer cooperation with corporate partners. In this regard, the focus is primarily on the possibilities opened up by the digitalisation of processes in the port. Port communication systems enable every participant to share necessary information along with the supply chain and could optimise the processes within the port. Due to the effect of an asymmetry of power, and an inconsistent share of information by individual users, it will decrease the effort of digitalisation for the whole chain. Closer cooperation along with the supply chain thus also increases competitiveness and strategy development has to support cooperation by the implementation of the right IT infrastructure. The focus on customer centricity enables the shipping line and logistic provider, based on the growing negotiating power of the customers, to influence the digitalisation strategy of the port. In addition to the strategy development, this focus on the customer can lead to an asymmetric allocation of power. While the terminal operator provides the infrastructure, they influence the port strategy to a particular extent. With the providing of the infrastructure, they occupy one of the most powerful positions to influence the strategy of the other participants and construct guidelines for the digitalisation.

Our research offers a first qualitative overview of the state of research on the effects of power on strategy formation in the port. The research is limited, in the first instance, by the limited number of specialist data banks on which the review was based on, as well as the subjective selection processes of the search term and literature by the researchers. For further research, it is advisable to expand this understanding of power. Approaches on this matter can be found in qualitative research, for example in the conduct of further reviews or interviews, but also by quantitative research. To develop deeper insights into the influence of power on strategy development, it will be necessary to provide a framework, which enables the researcher to measure these impacts.

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Equipment Selection and Layout Planning – Literature Overview and Research Directions

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Purpose: When container terminals are planned or converted, among others the most suitable container handling system needs to be selected and the appropriate terminal layout needs to be designed. These two planning activities are mutually dependent and affect the costs and future operational performance. This leads to the question of how to arrive at a (near-)optimal solution for given criteria.
Methodology: A mapping review is conducted to investigate how the container handling system is selected and how the terminal layout is designed. Literature is examined regarding the employed methodology, the performance indicator(s) to optimize, and the way terminal layout and equipment selection have been jointly considered.
Findings: Various methods have been used to assess a suitable container handling system and the appropriate layout. Commonly, mathematical optimization is used to arrive at a suggestion and simulation is the tool to evaluate proposed decisions. Aspects such as handling costs, travel distances, or ecological factors are sought to be optimized.
Originality: Several literature reviews in the past years investigated approaches to the plethora of scheduling problems at container terminals. Here, the two strategic planning activities equipment selection and layout planning are presented in detail. This publication focuses on how the dependency of the two activities has been handled in literature.

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1 Introduction

Over the last twenty years, global containerized trade has tripled to approximately 150 million 20-foot equivalent units (TEU) with trade relationships growing and ceasing between countries (UNCTAD, 2020). These unpreceded trade volumes supposedly challenge container terminals, especially since nowadays ultra large container vessels reach up to approximately 24,000 TEU (MDS Transmodal, 2018; Marine Insight News Network, 2020). According to UNCTAD, this leads to fewer but intense workload peaks at container terminals compared to the previous comparably steady stream of smaller ocean-going vessels. Furthermore, carriers plan to deepen their involvement in hinterland transportation (UNCTAD, 2020), which ultimately shifts power from the container terminal operators to the carriers. Therefore, container terminal operators need to improve their position in the maritime supply chain.

One opportunity to enhance the competitiveness of a container terminal is to automate container handling processes. Wang, Mileski and Zeng (2019) stress that the market position is elementary when choosing the automation strategy fitting to the individual requirements. The authors classify container terminals either as international gates (import and export) or as transshipment terminals. If markets are relatively stable and the throughput is certain, automation enables the operator to improve the service. At international gates, operators use automation to obtain low prices whereas at transshipment terminals automation helps reducing berthing times of the vessels and fulfilling the promised schedules reliably. Some container terminals continue to use manned equipment because of the greater flexibility. Altogether, there is no one-fits-all strategy - depending on the role the container terminal plays in the supply chain, individual solutions need to be found. At the same time, a general trend to automation persists.

The construction of an automated container terminal requires careful planning. Kaptein, et al. (2019) emphasize that later structural changes are very expensive. Inter alia, during construction the terminal planners place the rails of the yard cranes determining the later yard block layout. They also decide the thickness of the pavement determining the feasible pathways of heavy equipment. Only in the latest stage of construction, often the future container terminal operator is chosen and included (Kaptein, et al., 2019). This means that the terminal planners determine the role of the future container terminal in the maritime supply chain. Considering the analysis of Wang, Mileski and Zeng (2019), this approach is rather counterintuitive since the operator might want to pursue a different business strategy. Therefore, it is beneficial to leave the selection of the equipment and the layout to the later container terminal operator (cf. Böse, 2011).

The container handling processes from the time the container enters the container terminal by vessel, barge, train, or truck until it leaves the facility again display a great complexity. Hence, the container terminal is often divided into suitable subsystems (Voß, Stahlbock and Steenken, 2004; Stahlbock and Voß, 2007; Gharehgozli, Roy and Koster, 2016). For the presented publication, such a division into spatial subsystems is shown in Figure 1. The separation is based on Böse (2011), only that the horizontal transport from the quay cranes to the yard is considered as the separate subsystem "*(Waterside) Traffic Area"* following the perspective of Ranau (2011). Previously, Kemme (2013, p. 41) has suggested a similar spatial segmentation of a container terminal under a different naming. This publication uses the names prevailing in the literature cited herein. In this figure, the segmentation of the different terminal areas of concern are defined.

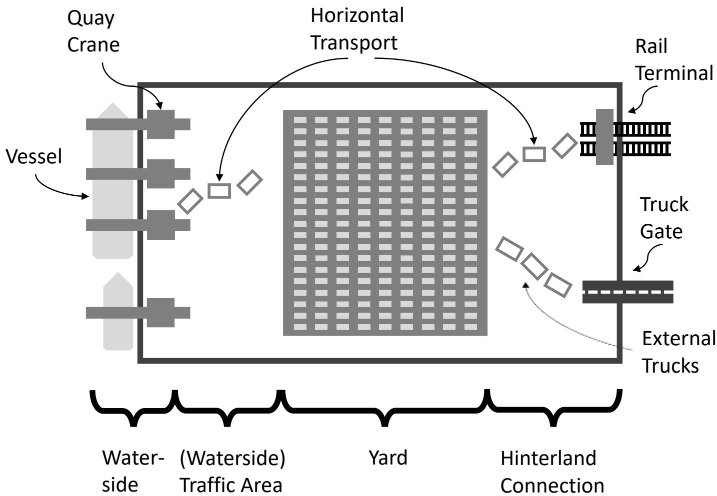

Figure 1: A schematic layout of a container terminal

At a container terminal, usually two container flows prevail: Import/export and/or transshipment. For brevity, in the following only the import flow is sketched out. At the waterside, major container terminals use quay cranes to load and unload the vessels. From there, the containers are transported to the yard. By means of stacking equipment, the container is stored there until sent to the hinterland (alternatively: transshipped). Depending on the mode of transportation, either internal horizontal equipment delivers the containers to the rail terminal or the external truck picks up the container from the stacking equipment in the yard. This schema lacks specific container handling equipment and layout. These are examined in the following two subsections.

1.1 Equipment Selection

First, a quay crane model needs to be chosen that satisfies the requirements of the container terminal. This includes the required size to serve the vessels as well as the moves per hour. After the quay crane has picked up a container, different types of equipment can horizontally transport the box to the yard. The main differentiation lies between self-lifting and non-lifting vehicles: Automated Guided Vehicles (AGVs) or yard trucks are considered non-lifting vehicles whereas Automated Lifting Vehicles (ALVs) and Straddle Carrier (SC) are described as self-lifting vehicles (Carlo, Vis and Roodbergen, 2014a). The authors indicate three common decision problems in transport operations: (a) choose the vehicle type, (b) determine the fleet size, and (c) determine according to which algorithms and rules each vehicle will operate. The first two decision problems are considered to be in the scope of this paper following the 3-Level-Model of Böse (2011). In the yard, commonly found stacking equipment are Rubber-Tired Gantry (RTG) cranes, SCs, and automated Rail Mounted Gantry (RMG) cranes (Wiese, Kliewer and Suhl, 2009). RMGs and RTGs can be summarized as yard cranes. The set of used equipment types is summarized as the container handling system of a container terminal (cf. Böse, 2011).

The wide range of possible container handling system raises the question how to arrive at the best solution for a given container terminal. Brinkmann (2011) presents a rule of thumb for which desired yard capacity (expressed in TEU per hectare) which container handling system including the fleet size is suitable. Johnson (2010) argues that with technological advances, one needs to be careful not to copy outdated solutions from other container terminals but instead to stay innovative.

1.2 Layout Planning

In this publication, layout planning covers the planning of berths, designing the traffic area, the yard including the orientation and dimensions of yard blocks, and the facilities needed for the hinterland connection. The scope is reduced to the aspects of the layout which directly affect the simplified flow of containers through the terminal. Other necessary aspects of planning such as positioning maintenance buildings, staff buildings, or planning the supply & disposal networks are neglected.

Kastner, Lange and Jahn (2020) examine a range of expansion projects at container terminals. In industry, simulation has been most often reported as the quantitative tool to examine a suggested expansion plan. A structured comparison of different layout options considering the same equipment have not been presented. At the same time, linking layout planning and an automated evaluation has been worked on in different projects. Gajjar and Ward (2016) propose a Microsoft-Visio-based tool that derives terminal characteristics such as throughput capacity from a 2d layout. In the project TRAPIST, a terminal planning board is designed that can enter a simulation mode to answer questions regarding operational, equipment, and layout problems (Yang, et al., 2008). Sun, et al. (2013) propose an integrated simulation framework that couples a geographic information system and a multi-agent system. In all instances, the terminal layout is created first and either static formula or simulation models inform the planner about estimated operational characteristics.

1.3 Related Work

Regarding seaport container terminals, frequently literature reviews are compiled (Voß, Stahlbock and Steenken, 2004; Stahlbock and Voß, 2007; Gharehgozli, Roy and Koster, 2016), some with a specific focus, such as scheduling problems in seaside operations (Bierwirth and Meisel, 2010; 2015; Carlo, Vis and Roodbergen, 2015), operations in the yard (Carlo, Vis and Roodbergen, 2014a), or horizontal transport operations (Carlo, Vis and Roodbergen, 2014b). The time horizon of the various problems differ, as well as the area of focus on the container terminal. Long-term planning problems such as layout design have been previously summarized (see e.g. Gharehgozli, Roy and Koster, 2016). The wide scope of such literature reviews has prohibited deeper insights into the matter.

The research question at hand is how to arrive at a (near-)optimal plan covering the container handling system including the fleet sizes and the corresponding layout. Three approaches are theoretically feasible: (1) Given a fixed layout, the container handling system is chosen, (2) Given a fixed container handling system, the layout is chosen, or (3) both container handling system and layout are jointly arrived on (cf. Welgama and Gibson, 1996). Wiese, Suhl and Kliewer (2011) argue that the required terminal capacity both influences the layout and the equipment selection but in practice a prevailing sequence of planning activities exists: The equipment is chosen according to the required capacity for the respective area and the available space. In the aftermath, the layout is planned accordingly - considering equipment-dependent details such as driving lanes and maneuvering areas. The authors' narrative compilation of publications focus on terminal layout planning neglecting the variety of factors that influence the equipment selection process.

Gharehgozli, Zaerpour and Koster (2019) review different container terminal layouts and point out different possible future developments, such as expanding by adding or reclaiming land, collaborating with inland terminals, constructing offshore container terminals, or moving empty containers to external depots. In addition, several innovative solutions such as container racks or overhead grid rail systems are presented. According to their three-step framework, simulation and queueing models are used to estimate throughput performance during the first two steps *layout analysis* and *design optimization*, whereas mathematical optimization is said to be more suitable for scheduling problems within the last step.

2 Literature Review

The research question at hand is how equipment selection and layout planning depend on each other. This targets at finding existing approaches and shortcomings of the research undertaken so far. A suitable review type for this is a mapping review (see Grant and Booth, 2009). Scopus and Web of Science served as databases for the research with each estimated 75 million records (Clarivative Analytics, 2020; Elsevier, 2020). The search is restricted to scientific publications in English. The year 2020 is excluded for repeatability. The search terms are selected in accordance with the wording in (Böse, 2011): For each publication the term "container terminal" is obligatory. Then the publication are filtered to either contain the term "equipment choice", "equipment selection", "container handling system" or both the terms "planning" and "layout". This resulted in a total amount of 129 results. Here, first the abstract and if deemed suitable the full texts have been analyzed.

First, only seaport container terminals are considered. This is deemed necessary for a fair comparison of the publications regarding the different functional areas on the terminal, e.g. at inland container terminals no quay cranes are used. Second, the main topic of the publication needs to cover the choice of an equipment type and/or the terminal layout. This is only a subset of what is typically referred to as terminal superstructure planning (Böse, 2011). Hence, only long-term decisions are considered which require some structural change at the container terminal. Third, only a publication with a comparison of at least two different presented alternatives are considered. This shifts the focus to publications which explain why under given circumstances one solution is preferred. This selection process reduced the number of publications to 28 which are presented in Table.

2.1 Considered Terminal Areas

The literature retrieved by the previously presented search process covers the container terminal including all terminal areas as they have been depicted in Table 1. To analyze which terminal areas are of specific concern, in Table for each publication the covered terminal areas are marked. Three shades of gray convey the degree these areas (or more precise: the container handling operations occurring there) have been considered. The lightest shade of gray expresses that either a single operational scenario is considered or the area is completely excluded from consideration. The intermediate gray reflects that alternative operational scenarios are considered. This could be e.g. an analysis to see how a container handling system or a layout would perform for specific traffic schedules or during peak utilization. The strongest shade of gray indicates that for that specific terminal area alternative container handling systems or layout options are compared. This can be either a manually constructed solution as it is common for simulation models or a solution created by an algorithm, e.g. from the domain of mathematical optimization. Furthermore, for each publication the dominating method(s) are considered. These are presented and explained in Table. A publication is only assigned a specific method, if the work related to the method including the results is presented to the reader in a comprehensible way. This includes that the reader is informed about the scope of the model (including its limitations) and that the results are presented in a way that makes it clear how the results from the model have influenced the later recommendation or decision.

Table 1: Identified Methods for Equipment Selection and Layout Planning

Acronym	Method	Description
CAP	Capacity calculation	Based on yard size and yard equipment, the annual container handling capacity is estimated
CON	Conceptual evaluation	Pro and contra arguments are weighed up and justify the preferred option If MUL present: This applies to at least one criterion
FIN	Financial cost model	A calculation that at least covers initial investment and costs during operation
MO	Mathematical optimization	A selection of a (near-)optimal solution from a given set of feasible solution.
MUL	Multi criteria optimization	Several criteria are summarized in one common score to determine the best solution
QT	Queueing Theory	As part of probability theory, it is used to predict waiting times for systems
SIM	Simulation	The terminal processes in focus are modelled, e.g. with discrete-event or agent-based simulation

Table 2: Publications presented by covered terminal area and methods

Publication	Terminal Area: Quay Side	Terminal Area: Traffic Area	Terminal Area: Yard	Terminal Area: Hinter-land Con.	Methods
Asef-Vaziri, Khoshnevis and Rahimi (2008)					SIM
Basallo-Triana, et al. (2019)					MO
Bardi and Ingram (2010)					CON
Chu and Huang (2005)					CAP
Crawford-Condie and Peet (2017)					MUL CON
Edmond and Maggs (1978)					QT
Golbabaie, Seyedalizadeh Ganji and Arabshahi (2012)					MUL CON
Gosasang, Yip and Chan-draprakaikul (2018)					FIN
Huang and Chu (2004)					FIN
Hubler (2010)					MUL SIM FIN CON
Kemme (2013)					SIM

Publication	Terminal Area				Methods
	Quay Side	Traffic Area	Yard	Hinter-land Con.	
Kim and Kim (1998)					MO
Kim, Park and Jin (2008)					MO
Ludema (2002)					FIN
Meisel and Bierwirth (2011)					MO
Pachakis, Libardo and Menegazzo (2017) (offshore)					CON SIM
Pachakis, Libardo and Menegazzo (2017) (onshore)					CON SIM
Sauri, et al. (2014)					SIM FIN
Vis and Harika (2004)					SIM
Vis (2006)					SIM
Veshosky and Mazzuchelli (1984)					CON FIN
Wiese (2009)					MO

Publication	Terminal Area				Methods
	Quay Side	Traffic Area	Yard	Hinter-land Con.	
Wiese, Kliewer and Suhl (2008)					MO SIM
Wiese, Suhl and Kliewer (2009)					MO SIM
Wiese, Suhl and Kliewer (2010)					MO
Wiese, Suhl and Kliewer (2011)					MO
Yavary, et al. (2010)					SIM
Yan, Fang and Lu (2013)					MUL FIN
Yuan (2011)					MO

From the total 28 publications in Table 2, 16 cover equipment and/or layout alternatives in the yard, 11 in the traffic area, 4 at the quay side, and three at the hinterland connection. Of those, one publication describes an off-shore container terminal which is connected to an onshore container terminal via barges. Hence, for the offshore container terminal the hinterland connection is that barge system. Only 7 publications considered different operational scenarios.

The most commonly used methods are mathematical optimization and simulation with each 10 occurrences. In 7 cases, a financial model is formulated. When considering several criteria, in 6 publications by means of argumentation one option is chosen and 4 publications created an aggregated score by weighting different aspects, e.g. the environmental impact, the duration of construction, or the safety for workers. One publication covered how the annual capacity can be estimated a priori and one uses queueing theory.

2.2 Estimating the Impact of Decision on Operations

When container terminal operators need to decide between different types of equipment and corresponding layouts, they need to estimate the impact of such choices: Will they be able to cope with the traffic demands both on average and during peak workload? Is there an alternative that could save them time and that would smoothen the operation, e.g. by shorter transportation distances? In Table, two different quantitative tools clearly dominate, i.e. mathematical optimization and simulation. In addition, both the waterside traffic area and the yard are covered best. To get an insightful comparison, in the following the literature using mathematical optimization and simulation are presented separately. For each group, the literature is restricted to publications covering the traffic area and the yard.

2.2.1 Mathematical Optimization

Mathematical optimization is the selection of the optimal solution from a set of given alternatives. It is therefore advantageous to use a mathematical optimization technique in the strategic planning phase of logistic systems such as container terminals. However, the problem has to be simplified in order to express the container handling processes into mathematical formulas.

As visualized in Table, it can be observed that mathematical optimization techniques are mostly considered for the layout planning of container terminals. The book chapter of Meisel and Bierwirth (2011) is a pure exception as the equipment section is focused. The authors propose an optimization model for crane capacity dimensioning at the quay of a maritime container terminal. Beside the number of quay cranes, the model decides on the berthing position of the container vessels. A greedy heuristic is used to solve the formulated formulation.

Besides the equipment selection, there is a series of publications about mathematical optimization regarding the layout configurations of a container terminal. This starts with the analytical method of Kim and Kim (1998) which simultaneously determines the amount of space and the amount of yard cranes.

Kim, Park and Jin (2008) present formulas in order to determine the expected number of relocations caused by picking a container which is stored under other containers as well as the expected traveling distances of yard trucks. Given this measurement, the authors come to the result that parallel yard layouts with respect to the quay are more efficient that perpendicular layouts.

Wiese, Kliewer and Suhl (2008) and Wiese, Suhl and Kliewer (2009) adapt a mixed integer programming formulation (MIP) of a facility location problem in order to examine different layout configurations of container terminals. This does include the placement of terminal gates and tracks as well as the oriented yard blocks. The MIP formulation is solved by an optimization software. Further, discrete event simulation is used to evaluate the performance of the suggested terminal configurations.

Wiese (2009) and Wiese, Suhl and Kliewer (2010) consider the yard performance and costs of a container terminal under different possible block widths. This is in contrast to Wiese, Kliewer and Suhl (2008) and Wiese, Suhl and Kliewer (2009), where fixed block lengths are assumed and to Kim, Park and Jin (2008), where only the orientation of the blocks is considered. Wiese, Suhl and Kliewer (2010) propose a mixed-integer model in order to find optimal positions of driving lanes in a rectangular container yard. The MIP model is reformulated to a network flow model. This allows to identify efficiently optimal solutions. Further, a local search heuristic is proposed for non-rectangular instances.

In the book chapter of Wiese, Suhl and Kliewer (2011), the impact of different block configurations on the yard performance and costs is analyzed. A multi-objective optimization model is proposed. With the help of an enumeration strategy, a non-dominated solution is identified.

Basallo-Triana, et al. (2019) propose a non-linear mathematical model for the transshipment process in a container terminal. The objective is to minimize the investment and operating cost such that the terminal has enough capacity and all operations are performed within a given time window. An exhaustive enumeration procedure is implemented in order to solve this problem. The authors draw the conclusion that the container dwell time has a high impact of the performance of the terminal.

2.2.2 Simulation

Simulation can be defined as "a representation of a system with its dynamic processes in an experimentable model to reach findings which are transferable to reality" (Verein Deutscher Ingenieure, 2014, p. 3) and is therefore a suitable tool to predict the operational behavior of a system that is not yet realized. Twrdy and Beskovnik (2008) discuss that simulation is a central method to predict the productivity parameters of a planned container terminal before its realization. The simulation model is based on the considered layout, a chosen container handling system, and the related container handling processes. Since investments into an improved layout or container handling system are long-term decisions, the simulation depends on forecasting such as trends in vessel sizes, transportation demands, and container flows through the terminal. Depending on the type of the current design decision, different kinds of simulation models are used. Angeloudis and Bell (2011) differentiate in their review, among others, between simulation models that are microscopic (detailed) and macroscopic (simplified) as well as generic or focused on a small subset of operations. Dragović, Tzannatos and Park (2017) classify simulation models, among other, on whether alternative container handling systems have been evaluated, analytical models have been tried out (e.g. for scheduling), or storage policies have been tested. This indicates the wide range of questions simulation can help to answer, even though not all questions can be answered with a single simulation model. Therefore, in the following the role of simulation in the retrieved literature has been examined.

Asef-Vaziri, Khoshnevis and Rahimi (2008) present the integration of an Automated Storage and Retrieval System (ASRS) and an ALV System. The

ASRS is used as an alternative to traditional storage yards. The simulation model covers a detailed representation of the ASRS racks including the velocity profile of the storage and retrieval machine. By altering the rack structure and employing varying ALV fleet sizes and different dispatching strategies, the operational characteristics of an ASRS at a container terminal are presented.

Hubler (2010) compares several different types of conventional stacking equipment for the yard. Depending on the equipment, different layout options and possible workflows are compared. In addition, a cost comparison and a qualitative rating is conducted. The rating covers environmental impact, safety, suitability for future automation, and cost risk for construction.

Kemme (2013) sets up a large simulation study to examine the operational differences between RMG systems, i.e. Single RMG, Twin RMG, Double RMG, and Triple RMG. Depending on the system, one to three RMGs are used in one yard block which differ in their crossing abilities. These systems are tested in different environments, e.g. different yard block layouts, different container dwell times, or different container flows. The simulation study aims to create insights for decision makers.

Pachakis, Libardo and Menegazzo (2017) present the container terminal planning process of an offshore container terminal in detail. Four different storage options are compared offshore and two options onshore. In both cases, the yard layout is determined by the equipment and no alternative layouts are discussed. While simulation is used to predict the productivity, in addition aspects such as the ability to phase the works, the energy consumption and the costs of ownership are considered.

Sauri, et al. (2014) discuss when it is reasonable to invest into automated horizontal transport systems. SCs and AGVs are examined by means of simulation to obtain the required fleet size which in turn is part of the cost model. For container terminals with a high throughput and high labor costs, AGVs pay off.

Vis and Harika (2004) compare the unloading times of the ship when using AGVs and ALVs. ALVs have the advantage that if a reasonably sized buffer area exists, the horizontal transport is decoupled from stacking so that the ALV waits less at transfer point. When only considering the purchase costs and neglecting layout restrictions, the authors conclude that ALVs are cheaper since smaller fleets are sufficient.

Vis (2006) compares SCs and yard cranes for storing and retrieving containers from the storage area. Simulation is used to evaluate different arrival patterns both of vessels and from the landside as well as a varying number of rows of a yard block. Results show that the number of rows of a yard block correlates with higher storage and retrieval times making them eventually inefficient.

Altogether, these publications can be grouped into two classes. In the first group, simulation has been used to digitally experiment with innovative and therefore unpreceded solutions. The second group consists of publications that gain insights into operational characteristics of conventional equipment in order to make an informed acquisition decision between different types of equipment. In both cases, simulation enables the planner to determine the required fleet size for the desired throughput. The chosen equipment determines the yard layout which has not been a major subject of discussion in any of the publications.

3 Discussion

The retrieved literature in Section 2 covered a wide range of different long-term decisions regarding equipment and layout. In Subsection 2.1, the literature was classified according to the considered subsystems, i.e. quay side, traffic area, yard area, and hinterland connection. Furthermore, the retrieved literature has been attributed with different methods. In Subsection 2.2, the literature was presented grouped by the employed quantitative method, either mathematical optimization or simulation. In total, the literature has been looked at from three angles which provides some insights worthwhile discussing.

Regarding the considered subsystem, a great discrepancy between the different terminal areas can be seen. While 21 publications examine different equipment or layout options for the yard and 12 for the traffic area, only 5 publications do this for the quay side and only 2 papers discuss different possibilities for the rail and road interfaces. In these two publications by Wiese, Kliewer and Suhl (2008) and by Wiese, Suhl and Kliewer (2009), the hinterland connection is one of several terminal areas that are part of their model. This difference in coverage in scientific literature indicates that the hinterland is of least concern.

When weighing up different equipment or layout options, mathematical optimization and simulation are most commonly used to estimate the impact on operations each decision would have. At the same time, financial and environmental aspects need to be considered. While e.g. Pachakis, Libardo and Menegazzo (2017) describe each option with its pro and contra arguments (which has been indicated in Table as CON), e.g. Crawford-Condie and Peet (2017) aggregate a set of scores into a single score (which has been indicated with MUL in the same table). Such a score clearly indicates the option to prefer which in turn allows to optimize the decision of layout and equipment selection in a formal sense. As far as mentioned in the respective articles, this optimization process has been executed manually.

As discussed in the introduction, when developing the optimal selection for both equipment and layout, theoretically three approaches are feasible: With a fixed layout the equipment is chosen, with a fixed equipment the layout is improved, or both equipment and layout can be freely chosen. Wiese, Suhl and Kliewer (2011) state that typically the type of equipment is chosen first for the respective terminal area and later the layout is designed. The retrieved literature concurs on this point that the general business requirements determines the equipment which in turn determines the layout. In Figure 2, this process has been visualized. While the process imposes an order, in general planning activities are not truly independently (Böse, 2011). For illustration: When determining the fleet size for horizontal transport with simulation, a layout must be assumed. If, on the other hand, a layout is designed with certain yard block dimensions, this implies that for implementation some stacking equipment exists that can be efficiently used for such a kind of yard block. In summary, this sequential process model reflects the common approach to solve the intertwined problem.

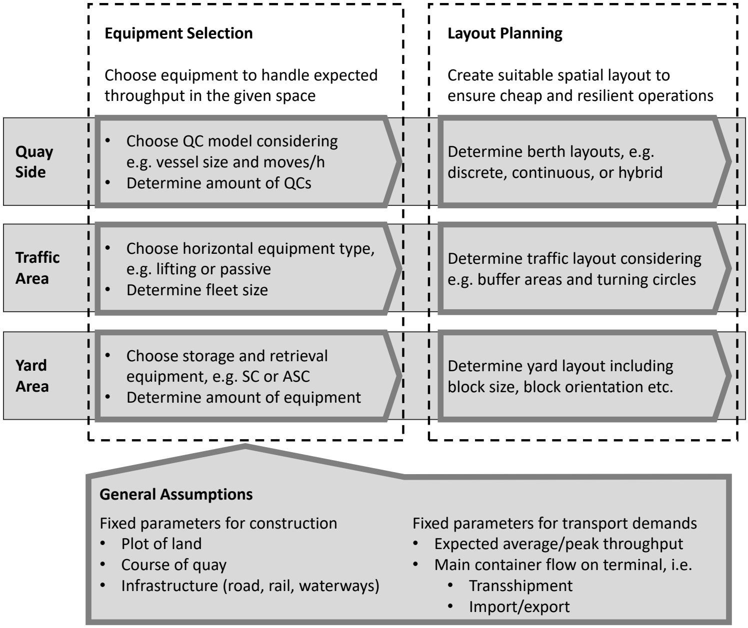

Figure 2: Order of decisions when determining equipment and layout

In Figure 2**,** only the quay side, traffic area and yard area have been considered. Due to low coverage in literature, the hinterland connection has been neglected. Both the equipment selection and layout planning are driven by general assumptions which are determined by the terminal infrastructure and transport demands. The listed assumptions are only exemplary, for further information consult e.g. Böse (2011) and Twrdy and Beskovnik (2008). In the following paragraphs, Figure 2 is discussed and examples from the retrieved literature are given. Especially the difference between mathematical optimization and simulation is worked out.

At the quay side, at modern container terminals ship-to-shore gantry cranes are used as quay cranes. Yavary, et al. (2010) simulate the performance of specific models such as quay cranes with secondary trolleys or tandem lift capability for a given scenario. The results are used as an argument for investment decisions. Meisel and Bierwirth (2011) use mathematical optimization to derive the optimal amount of quay cranes considering both costs and transportation demands.
When selecting the horizontal equipment, costs and operational performance need to be balanced. Sauri, et al. (2014) use simulation to arrive at the required fleet size for SCs and AGVs respectively. The corresponding fleet size is inserted in a cost model that determines the cheaper of the two options. Wiese et al. (2009b) use mathematical optimization for traffic layout planning as placement of terminal gates and tracks is considered in their solution method.
In the yard area, Hubler (2010) uses simulation to determine the productivity and costs of different stacking equipment, i.e. RTGs and RMGs, including different layout options. Considering a variety of further criteria, each option is assigned a combined weighted score that designates the best option. Mathematical optimization is used in a couple of publications (e.g. by Kim et al. (2008) or Wiese et al. (2010)) in order to determine the yard layout. The focus of these papers is mostly on yard block sizes and orientations.
In summary, simulation is employed when a manageable amount of different options is compared. This is especially the case in the equipment selection process. The results of a simulation study can be combined with aspects such as costs, duration of construction, environmental impact, and safety for workers. This shows that the decision for or against an equipment

is not solely an economic decision but it also potentially includes company policies and governmental regulations. On the other hand, mathematical optimization is useful when the amount of options is vast and the score to optimize can be calculated automatically. This especially holds true when comparing different terminal layouts with a fixed container handling system.

4 Conclusions and Future Research Directions

In this paper, we conducted a mapping review on how decisions regarding equipment and layout are connected: Suitable container handling systems have to be selected as well as an appropriate container terminal layout has to be designed. The focus of the literature review is to regard the employed methodology with respect to how these mutually dependent decisions are considered.

The conducted literature review shows that equipment and/or layout in the yard and in the traffic area achieve more attention than at the quay side or in the hinterland. Further, mathematical optimization and simulation are the most commonly used methodologies. It is observed that the equipment selection is mostly tackled with simulation whereas mathematical optimization has its domain in layout planning, particularly in the yard. An interaction of both planning activities as well as of the two methodologies (mathematical optimization and simulation) has been rarely seen in literature. Limitations of this literature review and possible further research directions are discussed in the remainder of this chapter.

4.1 Limitations of This Literature Review

This literature review followed the approach of a mapping review (see Section 2). The details about the search process have been provided for future repeatability. For the same purpose, the analysis has been restricted to the obtained search results ignoring possible leads in the cited literature. Furthermore, in research often several synonyms coexist which makes it challenging to define proper search terms. These search terms need to lead to (close to) all publications that cover the desired topic while at the same time the amount of literature going through the latter manual screening process needs to be of reasonable size. The obtained literature was distilled into a sequential process model in Section 3 and set into context. As a consequence, additional search terms and more scientific databases could have shed a different light on this matter and more details could have been presented.

4.2 Future Research Directions

This publication investigated how the decisions regarding equipment selection and layout planning are integrated. Methodologically speaking these two topics are only loosely coupled. The previously elaborated limitations of this literature review indicate that neither the equipment selection process nor the layout planning could have been examined exhaustively. For both topics, systematic reviews (see Grant and Booth, 2009) that point out the link to the respective other topic could create new insights about how the two decisions are practically and methodologically dealt with.

Furthermore, most of the obtained literature covered design decisions regarding the yard (see Table). While some publications examined the waterside, the decision process regarding the hinterland connection was never the main subject. This leads to two questions: (1) how to best design the hinterland connection (usually truck gate and rail terminal) in terms of equipment and layout, and (2) why this has not been well covered in previous publications.

Last, the herein covered literature was discussing specific types of equipment and specific requirements on a seaport container terminal layout, which restricts the applicability of the proposed solutions to the very same domain. On the other hand, on a methodological level, the decision-making process can be compared with the design of other logistics nodes, such as rail-road container terminals or inland ports. Clausen and Kaffka (2016) have previously demonstrated the parallels between seaport and inland container ports. By pursuing these commonalities and contrasts, a method to jointly cover layout planning and equipment selection at both seaport and inland container terminals can be derived.

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Model Transformation Framework for Scheduling Offshore Logistics

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Purpose: Wind energy is a promising technology to produce sustainable energy. While higher wind speeds at sea result in higher energy production, they also impede the installation of wind farms. Several authors proposed optimization- or simulation-based scheduling models. This article provides a framework to instantiate different models and discusses their advantages and disadvantages using selected models from the literature.

Methodology: Building upon previous research, which deducted a common meta-model by analyzing current literature, the framework realizes this model using the OMG's Essential Meta-Object Facility Standard. Moreover, the framework uses the OMG's Model To Text Transformation Language for transformations to different models found in the literature and from previous work, to evaluate their behavior given the same base-scenario.

Findings: The results show that the proposed framework achieves an instantiation of different model types, i.e., a mathematical optimization, a multi-agent simulation, and a Petri-Nets-based simulation. The discussion highlights the advantages of these types regarding speed, optimality, and flexibility. As the primary advantage, this framework allows investigating the installation on varying levels, focusing on local resources, processes, or the global system.

Originality: This research aims to operationalize a common meta-model and model transformations between different model formulations by applying well-established standards to realize a basis for using these models during the planning and scheduling of offshore activities. To the authors' best knowledge, no comparable work on the integration of different modeling techniques in the area of offshore logistics exists.

1 Introduction

Offshore wind energy has evolved into one of the most promising technologies in producing green and sustainable energy, which has already reached a high level of technological maturity (Dolores, et al., 2010). The last decade shows a close to an exponential increase in the amount of energy generated by wind farms world-wide (REN21, 2018). While higher wind speeds at sea result in higher energy production (Breton and Moe, 2009), they also impede crane operations during the installation of such offshore wind farms. Nevertheless, during the first half of 2019, Germany installed over 1350 new offshore turbines with a total capacity of 6.6 GW. Moreover, Germany plans to construct several additional offshore wind farms over the next decade, with an increasing number of turbines and capacity (Deutsche WindGuard GmbH, 2019). This trend, in combination with upcoming projects for the decommissioning of old wind farms (Beinke, et al., 2020), and a continuous increase in the size and weight of turbine components requires enhanced approaches for the planning and scheduling of such projects to avoid high costs and resource shortages, e.g., at the base-ports (Oelker, et al., 2020). Concurrent literature attributes between 15% and 30% of the lifetime costs of an offshore wind farm to logistics during the construction (Lange, Rinne and Haasis, 2012; Dewan, Asgarpour and Savenije, 2015; Muhabie, et al., 2018). As installation vessels contribute one of the highest cost factors, with charter costs of up to 145.000,00€ per day in 2014 (Meyer, 2014), several authors proposed optimization- or simulation-based scheduling models to increase these vessels' efficiency. Thereby, different types of models, e.g., mathematical optimization models or discrete-event simulation models, focus at different aspects of the planning problem, e.g., determining optimal schedules, fleet mixes or start dates.

This article presents a framework for model transformations that aims to instantiate different models from a common base-scenario. In consequence, process planners can apply different models and use their distinct advantages during the planning, without the need to define their scenario for each model seperately. This article follows the hypothesis that model transformation can achieve interoperability between these models and that different executable models provide distinct advantages in terms of their optimality, speed, and flexibility. After presenting the general process of installing offshore wind farms, this article presents an overview of existing models and approaches in concurrent literature. Afterward, this article provides the framework using methods and standards from the Object Management Group's (OMG) Model Driven Architecture. After defining the framework, this article verifies the above assumption, by instantiating several different models found in the literature and from previous work, i.e., one Petri-Net based simulation model (Peng, Becker and Szczerbicka, 2020), one multi-agent simulation model adapted from (Ait Alla, et al., 2017; Oelker, et al., 2018) and one mathematical optimization model (Rippel, et al., 2019b). Afterward, the article presents the evaluation of these models' behaviors given the same base-scenario to evaluate if the use of different models actually provides the noted advantages. Finally, the article closes with a discussion of the different models and a conclusion on the general framework.

2 Installation of Offshore Wind Farms

The literature differentiates between several concepts for the installation of offshore wind farms. All of these concepts assume the same supply chain but differ in how components are supplied to the construction site. Thereby, all concepts assume that components are manufactured at their respective production ports. In the conventional (Figure 1) concept, heavy-lift vessels then transport the components to a base port, see, e.g., in (Vis and Ursavas, 2016; Quandt, et al., 2017; Rippel, et al., 2019d). Feeder-based concepts assume a direct delivery of components to the installation site using so-called feeder vessels (Ait Alla, et al., 2017; Oelker, et al., 2018). Preassembly concepts additionally assume a partial assembly of components before they are picked up by the installation vessel at the base port. These so-called jack-up vessels perform the actual installation of the turbines in all concepts. These vessels use retractable pillars to mount themselves unto the seabed, raising themselves out of the water. This capability allows mitigating the influence of rough sea conditions, i.e., of wave height restrictions on installation operations.

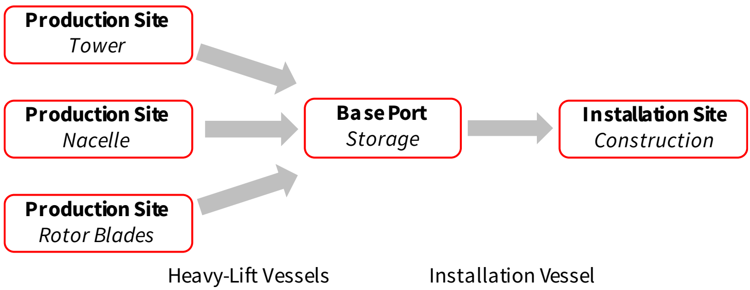

Figure 1: Conventional Installation Concept after (Rippel, et al., 2019b)

The installation of turbines consists of three phases (Vis and Ursavas, 2016; Quandt, et al., 2017). The first and the second phase often take place in different years, as each year only offers some months with reliably stable weather conditions. The first phase comprises the installation of foundations and the infrastructure to connect them to the energy grid. The second phase includes the installation of the turbines. Therefore, installation vessels, equipped with cranes that allow operating in over a hundred-meter height, assemble the tower, nacelle, and blades of each turbine successively. While jacking-up stabilizes the installation vessel and mitigates most of the operations' wave height restrictions, the massive size and weight of the turbines still results in restrictions regarding high wind speeds. Finally, the third phase comprises the commissioning and ramp-up of the wind farm, requiring teams of highly trained and certified technicians.

On the one hand, the installation of wind farms uses highly specialized vessels. In 2014, these vessels had charter costs of up to 145,000€ a day (Meyer, 2014), showing the need to plan and schedule operations efficiently. On the other hand, the process indicates that weather conditions limit the feasibility of offshore operations. While literature shows several different limits (Rippel, et al., 2019a), Table lists the limits used in this article following, e.g., (Oelker, et al., 2018). If, at any time, weather conditions exceed these limits, the installation vessel cannot start an operation or, if it has already started one, it has to abort the operation and restart it later. As a result of these limits and the long duration of operations, the installation process itself highly depends on viable weather forecasts.

Table 1: Duration and limits for offshore operations (Oelker, et al., 2018).

Operation	Base Duration (h)	Max. Wind (m/s)	Max. Wave (m)
Traveling	4	21	2.5
Reposition	1	14	2
Jack-up/-down	2	14	1.8
Load Tower	3	12	5
Load Nacelle	2	12	5
Load Blade	2	10	5
Load Hub	1	12	5
Install Tower	3	12	2.5
Install Nacelle	3	12	2.5
Install Blade	2	10	2.5
Install Hub	2	12	2.5

3 Literature Review - Approaches and Models for the Installation Scheduling

The dependence on weather conditions also reflects in the state of the art in planning and scheduling the installation of offshore wind farms. Vis and Ursavas (2016) state that there exist only a few published research articles on the installation of offshore wind farms compared to other areas like maintenance. Nevertheless, authors have proposed several approaches for the simulation and scheduling of offshore operations. These approaches differ in their modeling technique, aim, and granularity. The remainder of this section presents a short literature review on existing approaches. Thereby, it focusses on the different modeling techniques used to represent the installation process.

Simulation-based models generally focus on the evaluation of specific assumptions or configurations. Muhabie, et al. (2018) present a simulation model to compare the effects of deterministic and stochastic assumptions for weather conditions. Vis and Ursavas (2016) present a simulation study investigating the effects of different preassembly strategies on the overall project efficiency. Ait Alla, et al. (2017) present a multi-agent simulation, implemented in AnyLogic, to compare the efficiency of the conventional and a feeder-based installation concept, further extending the simulation study in Oelker, et al. (2018). Apart from these vessel-centric models, Oelker, et al. (2020) present a simulation study using AnyLogic, which regards available resources inside the base port of Eemshaven in detail. This study highlights that current trends towards an increasing size and weight of components and in the number of concurrent installation projects could lead to shortages in storage space and handling equipment at the base ports. Similarly, Beinke, et al. (2020) present a simulation study that shows a strong increase in the demand for installation vessels over the next years, due to an increasing number of offshore installation and decommissioning projects.

In the literature, two kinds of mathematical models can be found: The majority of models aim at the scheduling of offshore operations at different levels of abstraction. Several other models aim, like the presented simulation models, to assess the efficiency or costs of specific configurations or assumptions. In the context of the later models, for example, Beinke, Ait Alla and Freitag (2017) present a formulation to assess the impact of sharing heavy-lift vessels between several offshore installation projects. Quandt, et al. (2017) present a formulation to evaluate the impact of advanced information sharing between a project’s stakeholders. In a mixed fashion, Kerkhove and Vanhoucke (2017) present a scheduling model to determine when additional installation vessels should be deployed or decommissioned based on the workload and assumed weather conditions. Scholz-Reiter, et al. (2010) presents a multi-periodic scheduling formulation to obtain optimized schedules with a daily resolution. To allow this formulation to handle larger scenarios, the authors extended the approach by an additional solution heuristic in Scholz-Reiter, et al. (2011). Ursavas (2017) lately modified the same model and extended it to handle probabilistic weather assumptions. Ait Alla, Quandt and Lütjen (2013) present a time-indexed job-shop formulation for the planning of offshore installations. This model does not provide a detailed schedule but defines how many foundations or top-structures (turbines) can be constructed within a sequence of 12-hour windows, depending on current weather conditions. Irawan, Wall and Jones

(2017) present another Mixed-Integer formulation for the bi-objective optimization of installation projects, aiming to determine an optimized tradeoff between minimal costs and project durations. In more current literature, they modified their model for the decommissioning of old wind farms (Irawan, Wall and Jones, 2019). All of the presented models include weather conditions on a quite abstract level, i.e., in terms of weather classes (good, medium, bad) that are known to the model in advance. In contrast, Rippel, et al. (2019d) propose an approach, which uses a receding horizon technique and a Mixed-Integer formulation to provide optimal schedules based on short-term weather forecasts using an hourly resolution. The authors later extended this approach to include port-side resources as well (Rippel, et al., 2019b). Comparably, Peng, Becker and Szczerbicka (2020) propose a simulation model using Generalized Stochastic Petri Nets and hourly historical weather records to obtain scheduling decisions.

The presented literature review shows that several authors proposed a variety of models and approaches for the planning, scheduling, or evaluation of offshore installation projects. Each of these models and simulations focuses on different aspects of or provides another level of abstraction from the same baseline installation process. The application of different models provides project planners with highly specialized models and tools to evaluate and plan specific aspects of their project. Unfortunately, planners then need to implement and work with various different formulations. Consequently, the next section presents a framework for model transformations, which, in its current state, is capable of generating instances of the same scenario for different formulations, allowing project planners access to a variety of formulations. Thus, this framework provides a simplified way to use different models for the planning of different aspects, e.g., starting dates, project schedules, or capacity requirements. Moreover, different models apply a variety of ways to estimate the influence of weather dynamics, allowing project planners to evaluate their plans under different assumptions.

4 Framework for Model-Interoperability

The framework presented in this article consists of three main components. First, the underlying domain model. This model aggregates the required information for offshore wind farm installation projects. Second, a set of model transformations to generate executable models and, finally, a user interface to edit and specify the desired installation project. This article presents a prototypical JAVA implementation of this framework, using the Eclipse Rich Client Platform (RCP). This platform allows to implement and deploy code-fragments as plug-ins, which guarantees an easy to extend framework and provides access to a multitude of already available plug-ins under open-source licenses.

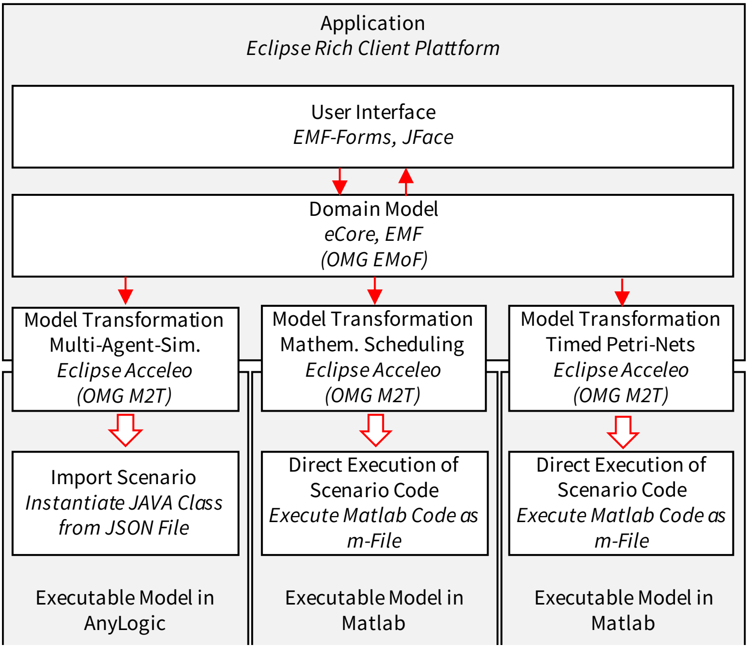

Figure 2: Conceptual design of the framework (top) and the integration with the selected use-cases (bottom)

Figure 2 shows a schematic of the framework's components and its interconnection with selected simulation and scheduling models. Therefore, the gray blocks denote stand-alone applications, i.e., the prototypical implementation of the framework and the respective simulation/optimization tools. The white boxes represent modules, either of the framework (top) or of the respective target model. The figure shows that some of the models need extensions to enable an import of the generated scenarios. For example, the AnyLogic multi-agent model requires an additional class to provide an initial configuration to the scenario, as the original model relied on manual modifications. Besides, Figure 2 indicates the used Plug-ins and Standards in italics for each module.

4.1 Domain Model

The prototype uses a modified version of the domain model proposed by Rippel, et al. (2019c) implemented using Eclipse eCore and the Eclipse Modelling Framework (EMF).eCore thereby represents an implementation of the Object Management Group's Essential Meta-Object Facility (eMoF), while EMF provides capabilities for code generation using an eCore model. The generated code allows managing, loading, and saving of model instances. Additionally, it provides several so-called adapters to simplify the implementation of user interfaces to work with these model instances. Figure 3 presents a simplified overview of the used eCore model. The diagram shows all entities and their interconnections but avoids to show their attributes for the sake of readability. The exported model in Figure 3 also follows the notation of UML Class Diagrams.

The class Scenario constitutes the domain model's central element and acts as a kind of database. Therefore, it contains and manages all other elements, like vessels or operations that project planners could use in specific projects. eCore (Figure 3) shows such containment relations using UML-Compositions. Besides its database of available elements, the Scenario class uses stored BaseOperations to construct process chains for the three main activities: Movement, Loading of Components, and Installation. Depending on the focus of the scenario, e.g., the process chain for installations could include operations required to install foundations or operations required to install top-structures or both. While this article only focusses on the installation of top-structures, this definition of process chains allows more flexibility.

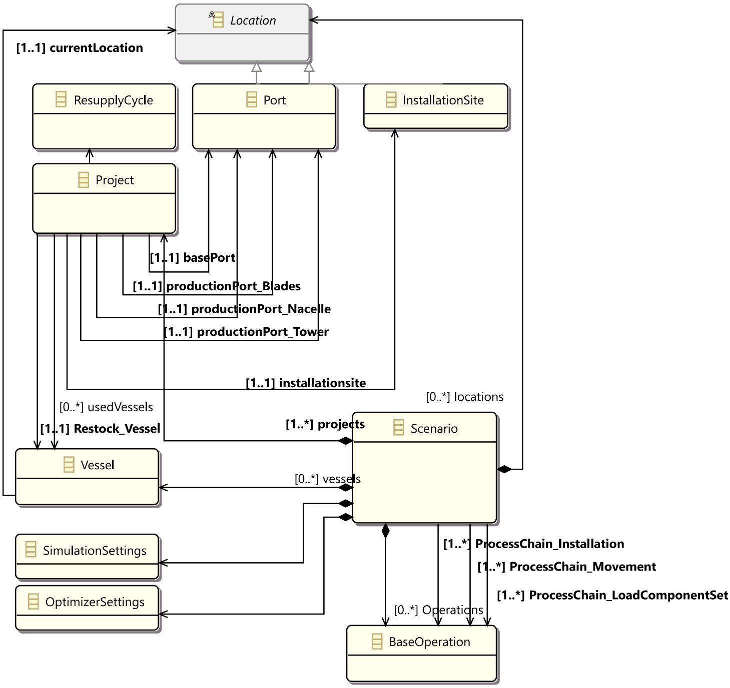

Figure 3: Simplified representation of the implemented eCore domain model as UML-Class Diagram

The following list describes the purpose and information contained for each of the other classes:

BaseOperations represent singular tasks an installation vessel needs to perform. Next to the operations name, this class consists of the operation's minimal duration and its weather restrictions. Thus, it more or less provides the information also given in Table.

Projects represent specific simulation or optimization experiments. Next to containing attributes to specify the project's starting and current dates, they also collect all information on the current state of the project, e.g., how many turbines the wind farm will have and how many already finished. Projects also specify the geographical layout and select vessels from the scenarios database actually to employ in the current scenario. Figure 3 depicts such selections as simple associations.

Locations describe geographical locations relevant to the installation project. Each location provides its longitude and latitude. Moreover, Ports contain attributes to define which resources the installation can access, e.g., the number of loading bays, or storage capacities.

Vessels accumulate all information regarding a specific vessel, e.g., its costs, movement speed, storage capacities, and its current state and cargo. Therefore, the domain model uses the same base class installation and heavy-lift vessels.

Resupply Cycles describe different routes for the resupply of the base port. On the one hand, these specify the order of visited production ports and the duration of loading operations. On the other hand, they also provide operations to calculate average cycle times and resupply amounts per cycle.

Settings aggregate additional settings for specific models. For example, these allow customizing the optimization model's time limits, the decision strategies used in the multi-agent simulation, or the time progression in the Petri-Nets simulation.

Compared to the original domain model, this adapted version does not explicitly include schedules and workforce. None of the targeted models includes workforce and, thus, this domain model also omits it in its current state.

4.2 Transformations

The proposed framework expects all targeted simulation/optimization models to either accept their inputs or entirely consist of text files, e.g., source code, JSON, or XML. This holds for most nonproprietary tools. Consequently, the framework proposes to apply the Open Management Groups Model-To-Text (M2T) standard. The M2T standard relies on providing templates of generated text files for eMoF objects, e.g., for EMF objects of the class project, scenario, or vessel. shows a small excerpt of such a template, which generates Matlab code using EMF objects for the project, scenario, and operations.

```
%%% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% %%%%%                         SCENARIO DATA                             %%%%%
%%% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

scenario.targetPlanTime =    [proj.maximumProjectDuration  /];
scenario.OWTsToBuild =   [proj.turbinesToBuild  /];

%%% %%%%% Process data %%%%%
[for (op : BaseOperation   | scen .Operations ) before ('scenario.opName       =  ['   )
                  separator (',\t') after ('];' )]"[op.name /]"[/for]
[for (op : BaseOperation   | scen.Operations  ) before ('scenario.opData(1,:)  =  ['   )
                  separator (',\t\t') after ('];' )][op.baseDuration /][/for]
[for (op : BaseOperation   | scen.Operations  ) before ('scenario.opData(2,:)  =  ['   )
                  separator (',\t') after ('];' )][op.maxWindSpeed /][/for]
[for (op : BaseOperation   | scen.Operations  ) before ('scenario.opData(3,:)  =  ['   )
                  separator (',\t') after ('];' )][op.maxWaveHeight /][/for]
```

Figure 4: Excerpt of an M2T template written in the Object Constraint Language (OCL). Black and green: text to be generated, blue: reference to EMF object attributes, purple: OCL statements.

As the prototype uses the Eclipse RCP and EMF to generate the domain model, it applies another Eclipse plug-in, which already implements the mentioned M2T standard: Eclipse Acceleo. Acceleo integrates directly with the EMF generated models and provides a simple text-based editor to write templates using the Object Constraint Language (OCL). This language allows referencing EMF objects, iterating through lists, or even performing complex calculations using attributes of the underlying model.

4.3 User Interface

The implementation uses yet another Eclipse plug-in, EMF-Forms, to generate and provide a user interface to manage, save, and edit instances of the proposed domain model. EMF-Forms allows generating editors for EMF model elements by visually assembling a set of standard controls, like tables or text fields. It then generates an appropriate JAVA code for the resulting editors and provides these as a new plug-in to be included in an RCP application (Figure 5).

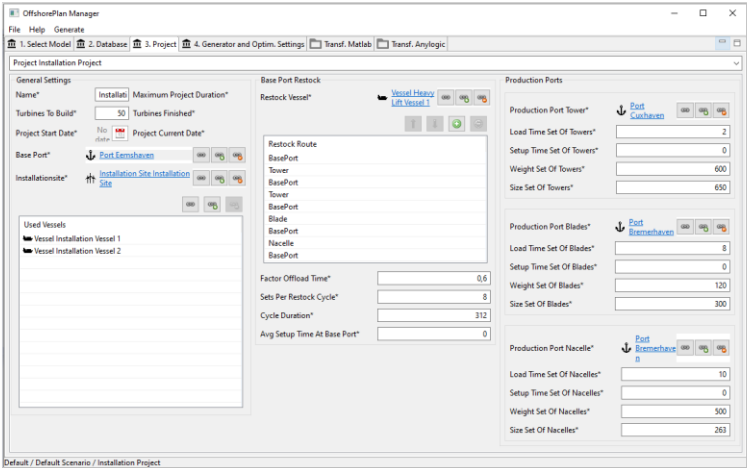

Figure 5: Screenshot of the user interface to edit projects

5 Application Examples

This section presents an application of the proposed framework for three different models found in the literature or from previous work. This article mainly presents a summary of the simulation/optimization model and the modifications required to enable the respective transformation, if any changes were necessary. Afterward, the next section presents a short discussion of each model's characteristics to highlight the advantages and drawbacks of using a particular model.

5.1 Multi-Agent Simulation

This research uses a slightly modified version of the AnyLogic model presented by Ait Alla, et al. (2017) and Oelker, et al. (2018). The model itself consists of agents for the installation and transport (resupply) vessels, the base port, and the installation site. While the "location" agents mainly store information, e.g., on storage capacities or finished turbines, the vessel agents implement a state diagram to obtain lists of orders, to decide which order to process next and to execute the selected order. The model provides two different decision strategies. The static strategy selects operations by a predetermined priority, i.e., installation operations exceed loading operations, and both exceed movement operations. The second strategy estimates weather-induced waiting times for operations and adjusts the priorities accordingly. The simulation evaluates these operations against current weather data in the planning horizon.

The original model required minor changes to enable model transformations, i.e., an adapter to read the generated scenario file. While it would be possible to generate the complete simulation model using an XML-based template, the prototype generates a scenario file instead. This JSON-formatted file defines relevant parameters like the number and characteristics of vessels or the geographical location of the ports and the installation site. The original model was modified to load this scenario file when the simulation starts. Before, these settings needed to be set during startup using AnyLogic's parameter interface.

5.2 Mathematical Optimization (Scheduling)

As the second model, the prototype targets the Matlab implementation of the mathematical scheduling model presented by Rippel, et al. (2019b). Therefore, the prototype generates Matlab code, which sets the relevant parameters, like process chains, durations, or vessel characteristics, and executes the model's main entry-point function. Due to the generation of the scenario as Matlab m-file, the transformation requires no changes to the model.

This model aims to calculate a globally optimal schedule while incrementally performing a simulation of the current weather conditions using a Model Predictive Control scheme and an optimization using a Mixed Integer Linear Program (MILP). This MILP uses a predetermined cost function and a fixed set of constraints. The model itself shows a high level of configurability, e.g., by modifying the number and characteristics of vessels and turbines, the geographical layout of the project, or even the sequence, duration, and restrictions of operations. Nevertheless, modifications of the baseline purpose (scheduling), the cost function, or the used algorithms for handling weather uncertainties are not possible without further code modifications. To incorporate weather, this model uses forecasts for the planning and simulates these plans against the current weather during the planning horizon.

5.3 Petri-Nets Simulation

Finally, the prototype targets a Matlab implementation of the Petri-Nets based simulation model of Peng, Becker and Szczerbicka (2020). Meanwhile, the authors reimplemented the model using the GPenSIM simulator in Matlab. As with the mathematical model, the transformation generates code to set the required model parameters, like process times or the number of vessels, and executes the model's main entry-point function to perform the simulation.

In contrast to the previously described models, this simulation model focuses on the process level and uses historical weather data instead of current data for the simulation. Therefore, it relies on a two-level definition of the process chain. The root-level describes the order of processes for the installation and the resupply of components—the second level models the details of each process, i.e., its weather-dependent duration and its restrictions. The model does not represent vessels directly but by the number of tokens, which traverse along the process chain (Petri-Net). Consequently, this model allows modifying and evaluating the effect of different assumptions about the weather and its related uncertainties on the overall process. In terms of the weather data, the model uses average weather of the past. Thus, given the available dataset, simulating the year 2000, it uses the average weather for each hour of the years 1958 to 1999.

6 Discussion

For the evaluation, this research instantiates all three targeted models with the same scenario. This scenario mostly follows the specifications given in Beinke, Ait Alla and Freitag (2017). This scenario assumes the weather restrictions and durations provided in Table. The logistics network consists of a base port in Eemshaven and production ports in Bremerhaven and Cuxhaven. The scenario applies a single jack-up vessel for the installation and one heavy-lift vessel for the transport. Finally, the scenario aims to install 50 turbines, starting at the randomly chosen date, 01 June 2000.

The models each focus on different aspects of the installation process, ranging from the decision logic of single agents over the handling of process restrictions to the global optimization of schedules. These differences allow project planners and modeling experts to select the most suitable model if they want to evaluate specific assumptions, methods, or strategies. Regarding these aspects, modeling experts can easily modify the appropriate models, e.g., the handling of weather dependencies in the Petri-Nets model, decision strategies in the multi-agent model, or the cost function in the optimization model. Applying the same changes to another one of these models might prove to be more difficult. In contrast, project managers can quickly adapt the scenario, once the modeling experts identified and implemented a suitable method. This second stage allows, e.g., experimenting with different starting dates, cost structures, or amounts of applied resources. The minor modifications required to enable interoperability between the framework and the respective models shows that the first hypothesis holds: Model transformations constitute a suitable tool to unify the modeling efforts by providing a common base model for different formulations.

To further evaluate the three models, this evaluation executed each model using the same base scenario and its default settings. Table summarizes the results in terms of simulation (execution) time, the project duration (optimality of decisions), and the number of unexpectedly delayed operations (handling of uncertainties). All models were executed on the same standard office computer (Ryzen 5 2600 - Six-Core, 16GB RAM).

Table 2: Simulation Results

	Multi-Agent	Petri-Nets	Math. Optimization
Simulation Time	0.51 sec	2.58 sec	1897 sec (31.6 min)
Project Duration	1892 hours	1855* / 1738** hours	1792 hours
Operations with unplanned delays	19	9* / 1**	4

* Only using Data for the current year to enable a comparison with the other models

** Using historic data for the years 1958 – 1999

The results in Table highlight different advantages resulting from the focusses of the different models. While the optimization results in the shortest plans for the current weather conditions (high optimality), it also comes in the highest computational time due to the repeated solving of a Mixed-

Integer optimization (21 times). The multi-agent model results in acceptable plans with short computational times. This formulation excels at its high transparency and flexibility. As it relies on standard JAVA for the decision-making, modeling experts can implement highly advanced decision logics using arbitrary JAVA libraries, e.g., for reinforcement learning or deep neural networks. Finally, the Petri-Nets model also shows short computational times. Regarding the results, it has to be noted that this model does not evaluate its plans against the current weather conditions, but provides an estimation using past weather records. Thus, the original results marked with ** represent expected values. These, in combination with the results of the optimizer, show that the weather in the year 2000 was a little worse than the average weather in the years 1958 until 1999. While the multi-agent simulation and the optimization aim to provide decision support using current weather data and forecasts, the Petri-Nets simulation aims to provide estimates before the project commences. To provide a direct comparison, the table also shows the results of the Petri-Nets simulation, if it only accesses weather data for the year 2000 (marked with *). In this case, the results are comparable to the multi-agent simulation.

7 Conclusions and Future Work

This article proposes a framework that allows a straightforward definition of installation projects for offshore wind farms and is capable of using model transformations to generate instances of several executable simulation or optimization models. Therefore, the framework employs several established standards from the Object Management Groups Model Driven Architecture.

The prototypical implementation of the framework shows that the use of standard tools, e.g., of the Eclipse Rich Client Platform and the associated plug-ins of the Modelling Package, allows a mainly automated generation of the framework. This automation reduces the efforts primarily to the specification of the domain model using a UML-like graphical editor and an implementation of the transformation templates. These templates require the simulation/optimization models to either be specified using text files or to accept textual descriptions as input. This requirement might need changes to the original model, e.g., as shown at the example of the multi-agent simulation. Such modifications and the initial setup of the transformation templates probably require the help of modeling experts. Nevertheless, afterward, the framework enables project managers familiar with the actual installation project to use the targeted simulation or optimization models without further knowledge about their structure or internal algorithms.

The evaluation of the three selected models shows the possible advantages of each formulation depending on the current task at hand. While the mathematical model aims at a global optimization of the schedule, it does not allow modifying aspects like decision strategies or the underlying weather discretizations. In contrast, the Petri Nets model focuses on a process view, which predominantly allows modifying and experimenting with different ways to represent processes, their restrictions, or their duration. Finally, the multi-agent simulation focuses on the decisions of single vessels and provides the opportunity to quickly modify decision strategies by assigning different priorities to single operations. In conclusion, the different models aim at the evaluation of different aspects of the installation process, which might not be viable using a single model due to the required complexity and interplay of these aspects. Although this article only evaluated the approach using three distinct models, it already shows the viability of model transformations to allow process experts access to a variety of models (first research hypothesis). Moreover, these models show comparable performances if provided with the same generated base-scenario. The discussion shows that each of these models focuses on another aspect of the installation process, which allows process experts to evaluate their plans under different assumptions and regarding different facets of their project. This result verifies the second research hypothesis, stating that each model has its particular specialty and that model transformations can render these specialized models available to the process expert without the need to construct and maintain separate model instances. Consequently, this article shows that the usage of different models can prove advantages, especially during the planning phase. The proposed framework enables project managers to specify and modify scenarios in an intuitive way and, after the initial setup, to instantiate different simulation/optimization models to perform a variety of evaluations.

Future work will focus on extending the framework for further models and formulations. This inclusion mainly covers the implementation of additional transformations and the identification and aggregation of model-specific parameters. As part of this extension, future work will integrate weather data and appropriate methods for their conversion into the domain model and the prototype. Currently, this vital baseline data has been converted manually for each model. Moreover, future work will extend the domain model to cover workforce aspects, like personnel planning and qualification. Finally, future work will focus on the development of techniques to retrieve and manage the results of targeted executable models back into the defined scenario. This extension will allow mixing different models during the planning by obtaining some results from one model, e.g., to define required capacities, and passing the new state to another one, e.g., to perform scheduling.

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