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Stowage Planning for Inland Container Vessels: A Literature Review

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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.

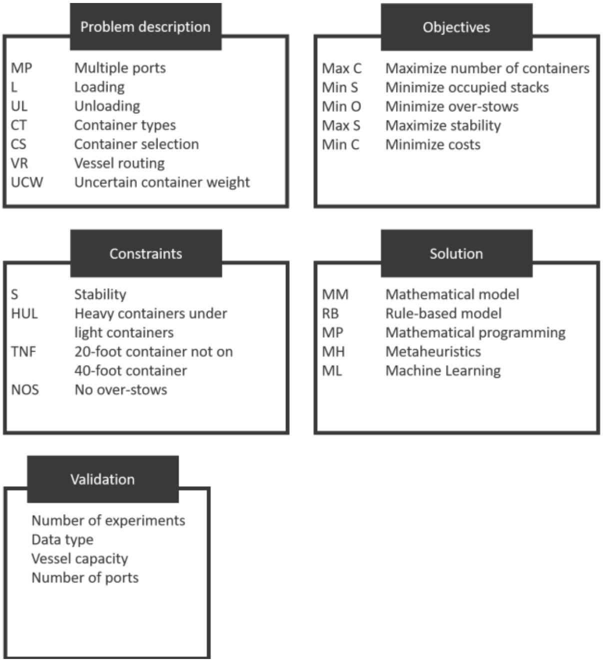

Figure 1: Sections and categories of classification scheme

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.

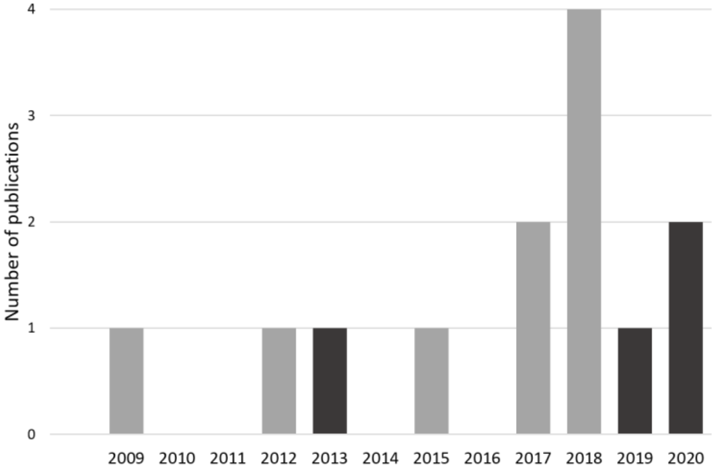

Figure 2: Number of publications per year

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.

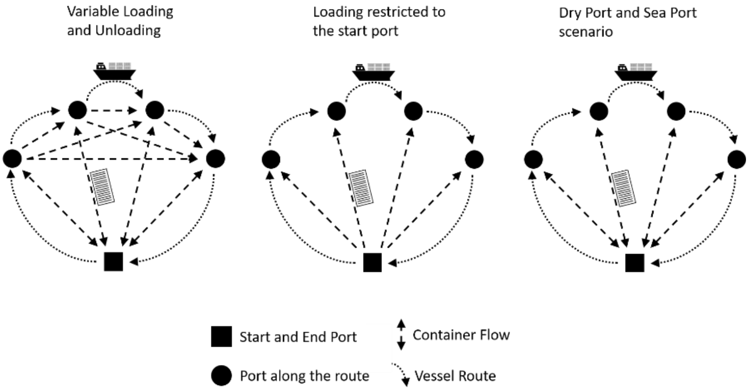

Figure 3: Types of container flow

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

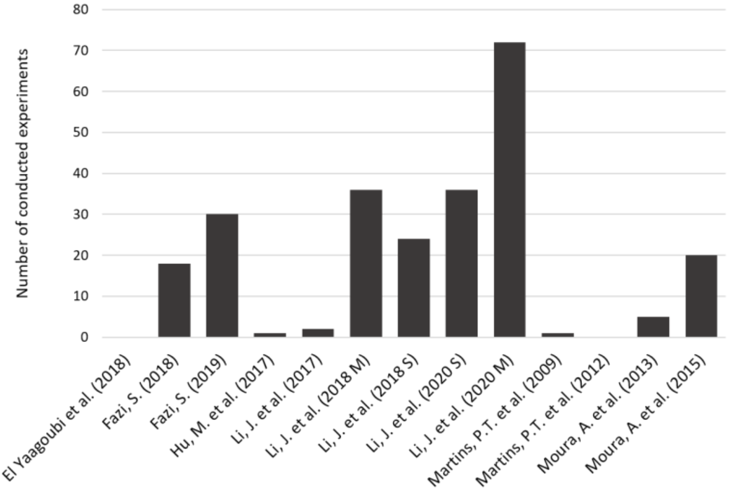

Figure 4: Number of conducted experiments

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.

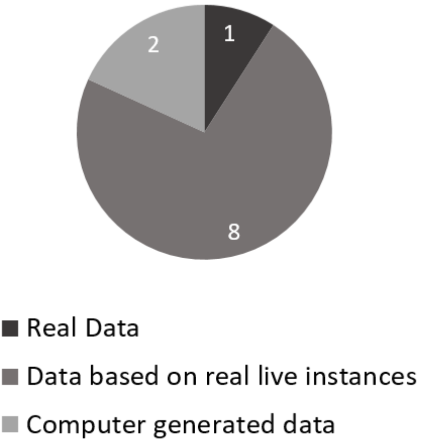

Figure 5: Number of publications per data type

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.

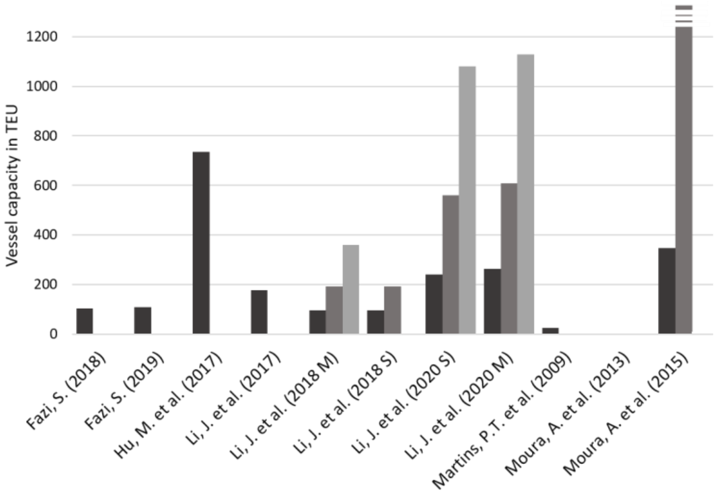

Figure 6: Capacity of test vessel

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.

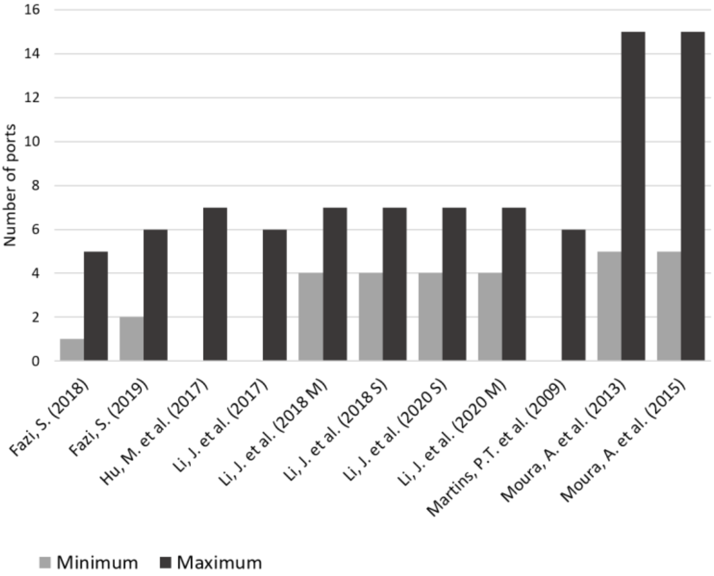

Figure 7: Minimum and maximum number of ports

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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