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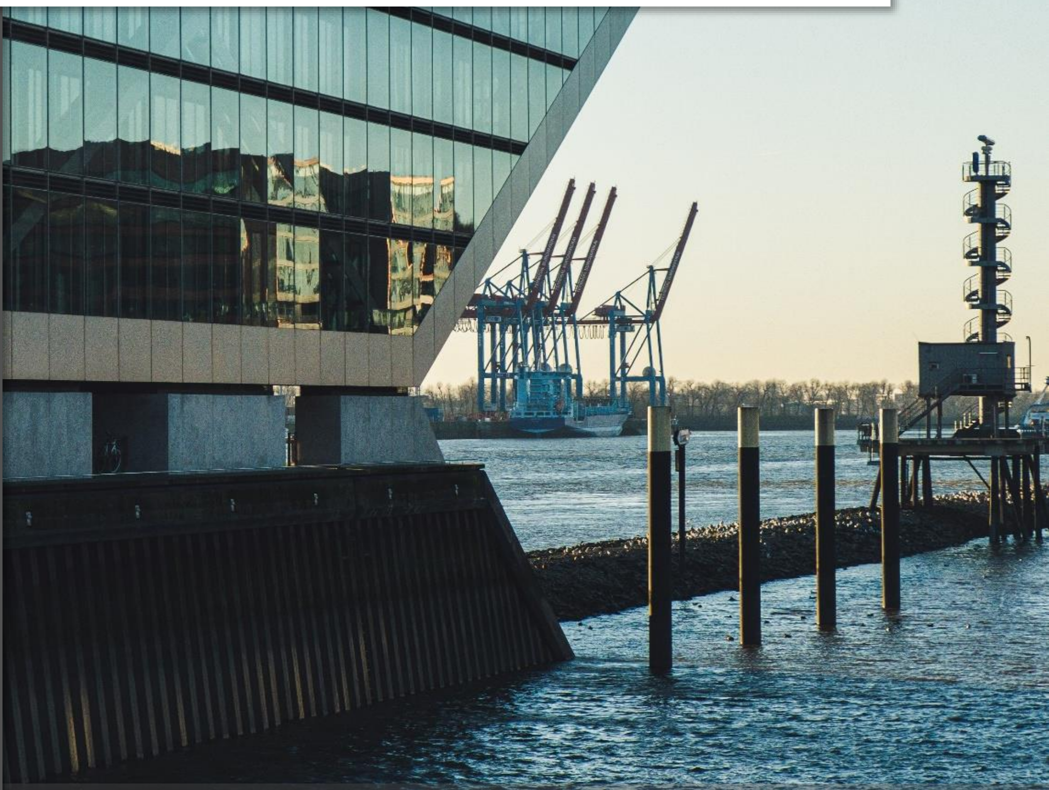

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Gantry Crane Scheduling and Storage Techniques in Rail-Road Terminals

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Purpose: *A rising global container throughput has necessitated the need for more efficient terminals. This work focuses on identifying past developments, important methods, key performance indicators and the future trends, related to the main decision tasks in an inland rail-road terminal. Prime focus is upon day-to-day operations performed on container entry through trains and trucks.*

Methodology: *A comprehensive systematic literature survey is carried out and a classification scheme developed, which is applied to the considered publications. Various techniques used to formulate the model and common solution approaches are identified for the key decision problems. Limitations in the current literature recognized and potential future research directions suggested.*

Findings: *Crane scheduling and storage space allocation are the most concentrated-upon problems. Simulation platforms have been largely used to model the problems and heuristics is the most common approach to solve other models. Time taken and costs involved are sought to be minimized.*

Originality: *In literature, marine container terminals have received greater attention as compared to inland terminals. Due to differing operation procedures, relevant research results from marine cannot be applied directly to railway terminals. Moreover, some of the existing works related to inland were found to disregard certain practical issues rendering them inapplicable for real applications.*

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1 Introduction

Globalization and the emergence of containerization has led to an enormous growth in freight transport over the years. Along with long distance maritime shipping, inland transportation corridors have experienced huge spikes in demands. The interfacial points where goods are transferred between the different modes of transport: terminals, act as crucial elements in this transport chain and are required to operate at highest efficiency (Guo, et al., 2018; Wang and Zhu, 2019).

Transport of freight essentially consists of many steps: choice of the transport medium (type and single or multi modal), management of the entire network, ancillary services like picking, packing & labeling, and the monitoring of the transit from seller to buyer. Multi modal mode is preferred for inter-continental transport using a single loading unit to tap into the advantages of all types of mediums. The main stretch of the journey is executed by deep sea vessels, trains & barges and the short connecting trips are on road (Dotoli, et al., 2013).

A lot of attention has been directed previously, towards the operations in a marine container terminal but literature on inland rail-road terminals is comparatively scarce. Due to differing operation procedures and rules, the relevant research results from marine cannot be applied directly to railway terminals (Wang and Zhu, 2014). Some of the existing works related to inland were found to disregard certain practical issues like container characteristics, rendering them inapplicable for real applications (Dotoli, et al., 2017). Hence, this work will concentrate on inland rail-road terminals.

Furthermore, the main focus is on operations that happen in a terminal, upon a container entry through train or truck, on a day-to-day basis. There are many decision problems based on the sequence of events that arise. Terminals aim at optimizing, the parking positions for trains and trucks, gantry crane scheduling, storage space allocation, train loading and energy consumption (Jaehn, 2013). Hence, these operation problems are focused on, in this study. Publications related to marine terminals or other kinds of inland terminals like rail-rail and barge terminals are not considered in this work. Concerning rail-road terminals, articles focusing on design and layout, as well as the train and truck routing and scheduling are also not considered.

The aim of this publication is to analyze the developments so far, to point out potential future research areas. To do so, an extensive literature review is conducted, and 67 papers finalized. A classification scheme for these publications is developed and applied to evaluate the current state of research, important methods, key indicators, and promising future research areas.

Chapter 2 presents an in-depth introduction to the field of intermodal transport, the related terminals types, rail-road terminals in detail, and the handling equipment and storage yards used. Additionally, a brief overview of the different operations that take place in a terminal on a daily basis is given. In chapter 4, the approach followed for the structured literature review, along with the search strings are shown. Chapter 5 presents the classification scheme and its application to all the considered publications. Brief explanations based on the different categories are then given. A summary of the prominent results and the potential future directions are listed in chapter 6.

2 Intermodal Transport: Overview

Intermodal transport can be broadly defined as the consecutive usage of two or more modes of transport for the movement of goods from one place to another. An important point to be noted is that the goods are transported in the same loading unit throughout without being handled themselves intermediately. The majority of the journey is through sea, inland waterways or by rail and the initial and last mile is usually covered on trucks by road, which is kept as short as possible (United Nations, 2001).

Intermodal terminals are the interfaces where all the transshipment activities happen between different modes. They act as vital elements in the freight transport chain connecting different shippers and carriers. The loading units can also be stored for a temporary basis before carrying on in their next leg of the journey. On a broad scale, these terminals can be of three types: Port Terminals, Inland Rail terminals and Distribution Centers (Rodrigue, 2020).

Rail-road terminals act as consolidation points for inland transport where containers are exchanged between trucks and trains. Generally, these terminals are small sized, with low container handling rate (300/day), short rail tracks (450-550m) and employing conventional technologies (Dotoli, et al., 2017). The terminals aim at maximizing the container throughput while keeping the waiting and processing time for trains and trucks at a low level. In recent years, there is a shift from road transport to other sustainable alternatives, mainly rail. Trains as compared to trucks require lesser amounts of energy to transport freight and also emit only a quarter of carbon dioxide per ton kilometer. The European commission has proposed a shift of around 30% by 2030 and 50% by 2050, for distances exceeding 300km (Garcia, 2015; Ricci, et al., 2016; Dotoli, et al., 2017; Otto, Li and Pesch, 2017).

The load units used to transport freight can be divided into three different sorts: the regular containers, semi-trailers, and swap bodies. A maritime container terminal handles only a handful kind of containers whereas the diversity in the case of a rail-road terminal can be pretty high. This leads to complications in terms of handling equipment and stackability (Carrese and Tatarelli, 2011; Bruns and Knust, 2012).

The core elements of a rail-road terminal are the driving roads for the trucks, rail tracks for the trains and storage yards to store the containers or other bulk goods for a short while of time. Small terminals make use of reach stackers for the transfer process and normally work on a one-to-one basis (one trackside space for both loading and unloading). In medium to large scale terminals, the transshipment of containers is carried out with the help of rail mounted gantry (RMG) cranes spanning the entire length of the tracks, functioning on a two to one basis i.e. distinct trackside areas for inbound and outbound containers (Boysen and Fliedner, 2009; Guo, et al., 2018).

A gantry crane is a kind of overhead crane with a horizontal bridge supported by two legs. The legs/portal are affixed on rails for movement (RMG) and is the most suitable handling option in a rail-road terminal. They come in a variety of widths & heights and can be powered electrically or by the conventional internal combustion engine. The rails of the crane run along the length of the railway tracks, with the portal moving on them facilitating motion. The cranes are equipped with a trolley to help in horizontal motion and a hoist/hook takes care of the vertical movement (Pap, et al., 2012). If more than one crane is sharing the same tracks, they are not allowed to cross each other and must always maintain a minimum distance to ensure safety. It is common practice to allot dedicated areas to every crane to avoid interference (static assignment), which can sometimes prove to be disadvantageous since terminals aim at minimizing the handling time. Assigning crane moves dynamically is hence catching up, making use of real time information systems with complex scheduling methods (Boysen and Fliedner, 2009).

Terminals aim at reducing the workload of the cranes and their efficiency is measured with crane rate and operating time. Crane rate is defined as the number of times a crane touches a loading unit. The cranes lift heavy loads and being heavy themselves, a lot of energy is expended when a crane operation is to be carried out. Some terminals might have fixed schedules of maintenance for the cranes based on specific horizontal distances they travel, and these maintenance checks can be time consuming and render the terminal inoperable (Jaehn, 2013).

Smaller terminals often use of reach stackers. They are more flexible and less expensive than gantry cranes. In cases of reshuffling, a crane just has to remove the containers that are placed on top of the required containers, whereas reach stackers need to remove all containers between itself and the target container. This has to be considered when choosing the handling equipment (Galuszka and Daniec, 2010; Pap, et al., 2012).

A key element of any terminal, storage spaces are used to store containers temporarily, which are unloaded from trucks and trains. Generally, stack piles three to four layers high can be observed. The assignment of these containers in the storage area, first into blocks if existing and then individually is one of the main decision problems in a terminal. Efficient storage space allocation ensures reduced retrieval times, reduced reshuffling, and increased throughput. The containers are broadly classified into inbound and outbound containers. Containers that arrive on trains from far off places, are stored for a particular amount of time and then carried away by trucks for delivery, are termed inbound containers. Whereas those that are brought in by trucks and leave the terminal on trains are called outbound containers (Wang, Zhu and Xie, 2017).

In these terminals, containers can either be placed directly on the ground and stacked one upon another, or on chassis. Loading containers onto chassis/skeletal trailers has an unusual advantage. These can be later picked up by trucks and need no further handling or crane supervision, hence minimizing double handling which would ensue if the containers were originally unloaded on ground. This is a common practice in North

America. The chassis can be parked parallelly to ease pickup and delivery or also at 60-degree angles to save space. Reefers/refrigerated containers need special provisions like power outlets and offsite depots can be used to store the empties (Rodrigue, 2020).

In medium to large scale terminals, it is a common practice to have two different storage areas. One along the tracks where containers can be unloaded momentarily or containers waiting to be loaded onto the next train can be pre-arranged. The second bigger storage yard which has many rows and columns allow containers to be stacked for an extended period of time. Containers in the temporary storage space can either be placed parallel to the direction of the train or even perpendicular depending on the orientation of the slot. It is a common practice, to store containers to be loaded on to the same train, or those that belong to the same client and will travel through trucks, together (Zeng, Cheng and Guo, 2017).

Freight trains typically travel at night and arrive at the terminals in the morning. They are processed throughout the course of the day and again depart by late evening. When a train arrives, it is assigned a vertical and horizontal parking position, where vertical basically refers to the particular track on which the train will enter and be parked. Horizontal positions are not very significant as the trucks can be parked right next to the target wagon of the train (Boysen, et al., 2013). The trailer or container loading locations are called slots. Utilizing the slots efficiently to increase the aerodynamic efficiency of trains has received some research attention (Lai, et al., 2007; Anghinolfi, Caballini and Sacone, 2014).

Trucks constitute an important means of transit in the inland transportation network, providing the much-needed geographical connectivity. Trucks are generally not bound by fixed schedules like for trains or vessels. The initial shipment from the client and the final delivery is facilitated through trucks. Though there is a drive to convert as much freight traffic from road to rail, the usage of trucks can never be eliminated owing their door to door delivery functionality advantage (Boysen, Scholl and Stephan, 2017).

3 Sequence of Events of Terminal Operation

The arrival and departure times of trains are prescheduled. Every container entering/leaving the terminal comes with certain necessary information: size, weight, position on the train and the corresponding client. Commonly, trains arrive on an entry/exit track and will be directed to a reception/dispatch track, where trains longer than the loading-unloading track are broken down. Once a loading/unloading track is available, the rail cars are moved onto it using a diesel engine. On completion of the required activities, the sequence of events is reversed (Garcia, 2015).

On arrival of trains, the containers are first inspected with regards to their destination. Some containers continue their journey by a different train, some depart by trucks, some are stored in the terminal, and some continue on the same train to a different destination. If the truck has already arrived, the gantry cranes directly unload the containers on the truck. For trucks arriving later, the containers are temporarily stored in the terminal. Those that will depart by another train are again directly shifted between trains provided the second train is on a parallel track already. After the completion of the unloading process, loading starts. If a truck carrying a container, arrives when the train is being loaded, the truck drives straight to the tracks and is unloaded directly by the crane. However, if it arrives earlier, the container will be stored until departure (Garcia, 2015).

A terminal can have two different kinds of storage areas, one under the gantry cranes next to the tracks, and the other located a few meters away. In terminals, the trucks can be loaded/unloaded in both the storage areas. Decisions regarding the patterns of storing are taken by the operator. The containers can either be placed on the ground or stacked one upon another. If stacked, it might result in rehandling when a lower placed container has to be retrieved, but it also implies a higher space usage. In order

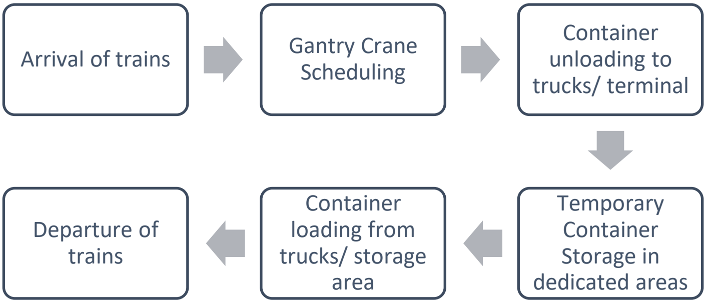

Figure 1: Daily Sequence of operations

to reduce the movements of the cranes in temporary storage next to tracks while loading/unloading, the containers are placed adjacent to the corresponding wagons (Garcia, 2015).

In total, there are three inter-related decision problems: First, selecting the storage area that minimizes container blockages. Secondly, pre-marshaling the containers based on the truck arrival information, utilizing the idle time of cranes. And finally, retrieving the containers from the storage area efficiently (Boysen, et al., 2013). The entire process is depicted in Figure 1: Daily Sequence of operations.

4 Research Focus

A widespread research on the most important scientific databases like Scopus, IEEE, Google Scholar, Research Gate and Science Direct was conducted. From this, an extensive foundation for the literature review was extracted. The keywords/search strings used for the search are shown in Table 1. The cited references for each of the attained papers are checked, and relevant publications meeting the focus of this work are added to complete the search. A total of 67 papers have been finalized for the analysis. These papers range from 1983 to 2020.

Figure 2 shows the paper count per year. A generally rising trend can be seen with a maximum number of publications in 2014. The paper count is expected to keep rising. Out of the total 67 papers, there were 3 papers published before 2000. In the next span from 2000-2005, 5 papers were brought out. 2006-2010 saw the field gaining considerably more attention with 17 papers being published. About 42 papers have come out so far in this decade. A lack of useful and sufficient literature with regards to the rail-road inland terminals in the early years is eminent. Concrete work dedicated to this field commenced from around the 2000's, more so around 2004-2005. Hence, more importance has been laid to the papers from the past 20 years, with a couple exceptions from before, in which the problems were introduced, and the necessity articulated.

Table 1: Search Strings

Problem Specification		Target Location
Storage & pickup	Gantry crane scheduling	Intermodal rail-road terminals
Container stacking	Loading & unloading	Rail-road container terminals
Assignment of storage locations	Train loading/load planning	Inland intermodal terminals
Container relocations	Container assignment	Inland freight terminal

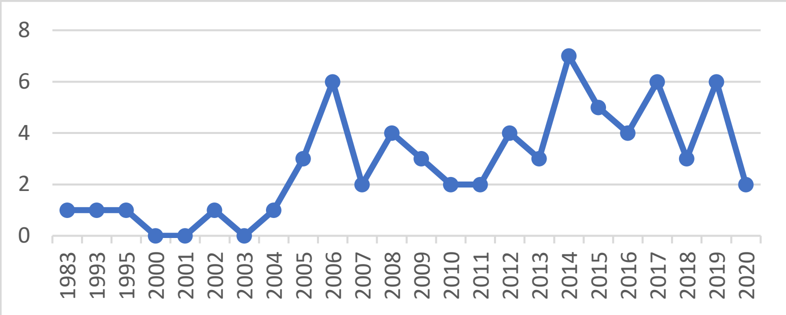

Figure 2: Publications per year

5 Classification

The papers are classified based on various parameters. Five main criteria are chosen, with 31 specifications in total. An overview of the classification parameters along with their individual specifications is given in Table 2. Every single specification can either be true/false, hence taking the value 1 or 0. This classification scheme is applied to the 67 chosen papers and is presented in Table 3.

Since the focus of this study is on the work that happens in a rail-road terminal after a train's arrival, many different decision tasks/problems can exist which are tackled independently. Hence, this is the first method of classification: by the aim or objective of the paper. The second step after aim recognition is to better understand the problems. For this purpose, the papers make use of techniques to model the problems. Hence, this is chosen as the next criterion for classification. The third criterion is the solution approach: after formulating the model, it is necessary to consider some constraints, make required assumptions and solve it, to obtain results. The next is key performance indices: to evaluate different models and to compare the results, certain parameters are necessary which can be quantified. The fifth and the last criterion is the continent of the terminal to which the paper is applied to.

Table 2: Proposed Classification Scheme

Classification Parameter		Specification
	1	Storage Space Allocation Problem (SSAP)
	2	Selection of Resource Handling Systems
	3	Crane Scheduling Problem (CSP)
Aim/Objective	4	Train Load Planning Problem (TLP)
	5	Minimize Reshuffling/Crane Rate
	6	Minimize Make span of container moves
	7	Others
	1	Simulation
	2	Integer Programming
	3	NP Hard
Model	4	NP Complete
	5	Binary Programming
	6	Optimization Problem
	7	Others
	1	Exact Solution Procedure
	2	Heuristics
Approach to solve	3	Genetic Algorithm (GA)
	4	Rolling Horizon
	5	Others
	1	Duration
Performance Measure	2	Cost
	3	Fuel Consumption

Classification Parameter		Specification
	4	Train Optimization
	5	Others
	1	Europe
	2	North America
	3	Asia
Application	4	Australia
	5	Africa
	6	Simulated Terminal
	7	No Application

Table 3: Classification applied to publications

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Anghinolfi, Caballini and Sacone, 2014				■									■			■				■				
Anghinolfi et al., 2012				■								■												
Boysen and Fliedner, 2009							■	■						■	■					■				
Boysen, Scholl and Stephan, 2017			■	■					■	■				■		■				■				
Bruns and Knust, 2012				■					■															
Bruns et al., 2014				■					■															
Caballini et al., 2008							■												■		■			
Carboni and Deflorio, 2020							■	■												■				
Carrese and Tatarelli, 2011	■				■					■				■			■				■			■
Cavone, Dotoli and Seatzu, 2016a						■		■												■				
Cavone, Dotoli and Seatzu, 2016b		■						■											■					
Colombaroni, Fusco and Isaenko, 2017					■			■									■				■			
Corry and Kozan, 2004				■				■	■	■						■		■		■			■	
Corry and Kozan, 2005				■		■						■				■				■			■	
Corry and Kozan, 2006a				■				■						■		■				■			■	
Corry and Kozan, 2006b				■									■			■							■	
Corry and Kozan, 2008				■				■	■							■				■			■	
Di Febbraro, Porta and Sacco, 2006							■	■																
Dotoli, Epicoco and Seatzu, 2015				■					■							■								
Dotoli et al. 2013				■								■												
Dotoli et al., 2014	■								■										■					■
Dotoli et al., 2017	■			■					■				■						■	■	■			■
Ferreira and Sigut, 1993							■	■													■			
Ferreira and Sigut, 1995							■	■																
Foti et al., 2012				■								■	■			■							■	
Galuszka, 2009			■		■						■					■								
Galuszka and Daniec, 2010					■						■					■								
Galuszka et al., 2010					■						■					■								
Garcia, 2015							■	■												■				
Garcia and Garcia, 2009							■	■												■				
Gronalt, Benna and Posset, 2007							■	■																
Guo et al., 2013			■						■		■					■				■				

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Guo et al., 2018			X			X			X							X				X				
Hejj, 1983		X						X																
Heggen, Braekers and Caris, 2014				X								X						X					X	
Jachimowski et al.,2018	X						X	X												X				X
Jaehn, 2013	X				X	X				X	X					X				X				X
Kostrzewski and Kostrzewski, 2019	X					X								X						X				
Kumar, et al., 2011				X			X																	
Lai and Barkan, 2005				X																		X	X	
Lai and Barkan, 2006				X																		X		
Lai, Barkan and Önal, 2008				X					X															
Lai et al.,2005				X																		X	X	
Lai et al.,2006				X																		X	X	
Lai et al.,2007				X																		X	X	
Lai, Ouyang and Barkan, 2008				X					X	X								X				X		
Malavasi, Quattrini and Ricci, 2006						X	X							X						X				
Mosca, Mattera and Saccaro, 2018		X						X												X	X			
Nie and Wang, 2019			X					X												X				
Otto, Li and Pesch, 2017			X											X	X	X				X				
Pap et al., 2012			X			X								X	X					X				
Rizzoli, Fornara and Gambardella, 2002							X	X																
Ricci, et al., 2016							X	X												X				
Stoilova and Martinov, 2019		X																	X					
Świeboda and Zając, 2016					X											X					X			
Wang and Zhu, 2014			X							X			X			X				X				
Wang and Zhu, 2019							X			X							X			X				
Wang, Zhu and Xie, 2014	X								X				X			X		X						X
Wang, Zhu and Xie, 2017	X		X										X				X	X						X
Xie, Wang and Yang, 2019			X																	X				
Zajac and Swieboda, 2014						X		X												X				X
Zajac and Swieboda, 2015a	X													X						X				
Zajac and Swieboda, 2015b	X													X						X				
Zając and ŻOŁĘDZIOWSKA, 2015	X		X													X				X				
Zeng, Cheng and Guo, 2017	X		X						X							X	X			X				

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Zhang and Zhu, 2019			■										■			■				■				
Zhang et al., 2020			■			■				■			■				■			■				

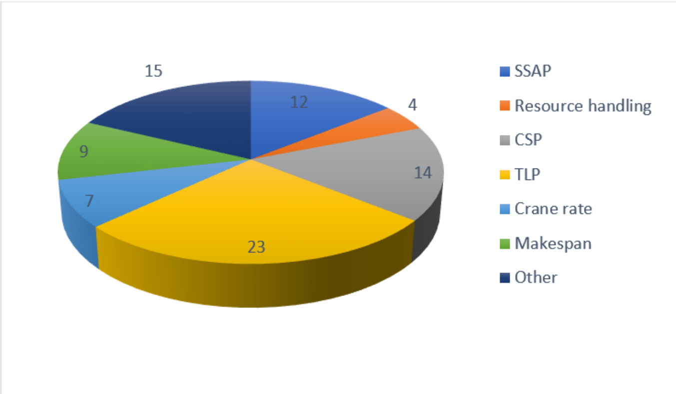

Figure 3: Classification based on Aims

5.1 Based on Aim/Objective Function

Categorizing the evaluated papers according to their aims gave rose to seven different subdivisions. Some of the papers have dealt with more than one problem also. 12 papers deal with the SSAP and 4 focus on resource handling. CSP has received the second most importance with 14 papers, behind TLP that is featured in 23 papers in total. The two optimization goals: make span and crane rate, have 9 and 7 papers respectively. 15 papers have been grouped in the other category, all of which are represented in Figure 3.

5.2 Based on Kind of Model

Many different methods of modeling have been found in literature, with some publications using more than one to compare between them. Figure4 gives the split of the papers and the respective counts. Simulation models have been utilized the most, in a total of 21 papers. Second most frequently used modeling technique is integer programming with 14 features. Optimization models have been used in 9 publications so far. NP hard and complete models are formulated 8 and 5 times respectively. 5

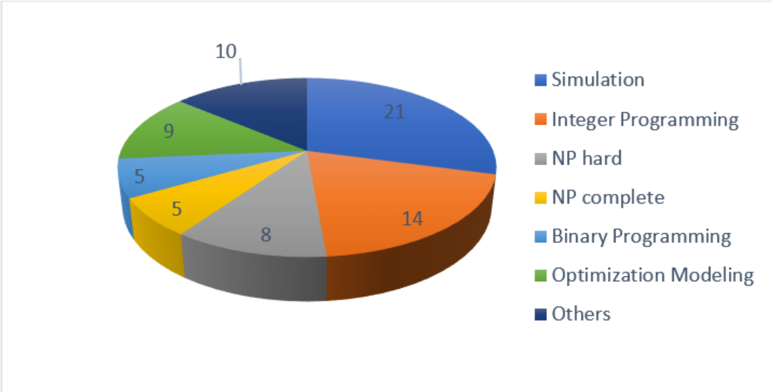

Figure 4: Classification based on Modeling Technique

papers are also found to make use of binary programming techniques. 10 other papers are found to use rare methods and are grouped together at the end.

5.3 Based on Approach to solve

Many different solution procedures are made use of, depending on the kind of solution sought. The problem can either be solved exactly to obtain precise solutions, or in some cases where that is not possible, other techniques come in handy to get a solution. In such cases, the problem is solved to optimality and often a comparison of many techniques is made to choose the best that fits the problem.

Even though GA is a kind of heuristic, due to the extensive use of this method in many publications, it has been set aside as a different specification. Multiple papers have also been seen to solve their models over a rolling horizon to account for the dynamic situations. To consider this, rolling horizon is taken as a specification as well. And the other non-frequent models are grouped together to one specification at the end. Almost every 1 in 3 papers are found to use heuristics, with 22 applications in total. Only 3 papers make use of exact solution procedures from the considered lot. 6 papers

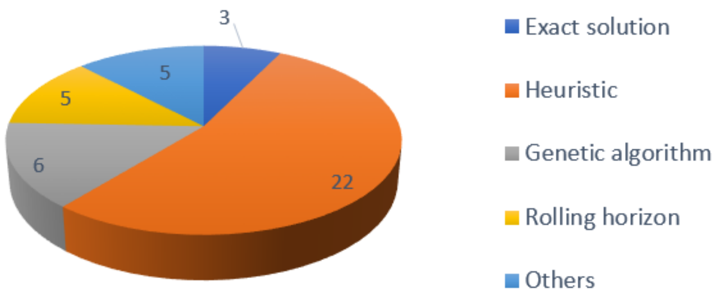

Figure 5: Classification based on solution approach

employ GA and 5 solve their models over a rolling horizon. 5 other papers are found in the 'other' specified group. Figure5 gives the split.

5.4 Based on Performance Measures

These are set as the objective functions in the papers while developing the models. Optimization of the performance measures is pursued, either maximization or minimization. Five main specifications, or sub-categories have been formed. The first being duration of operations (service time, waiting time, computational time, handling time, etc.), followed by cost (operations, purchase, maintenance, etc.). Fuel consumption is another important parameter which is to be reduced. Some parameters related to trains have been listed which are used in problem statements related to TLP problems. Like in other categories, the other left out functions are in the specification 'other'.

Close to half of the evaluated publications, 33 out of 67 have duration/time as their main/one of their objectives to optimize. 7 papers focus on reducing the costs involved and 6 on fuel consumption. Train specific parameters receive attention in 11 papers

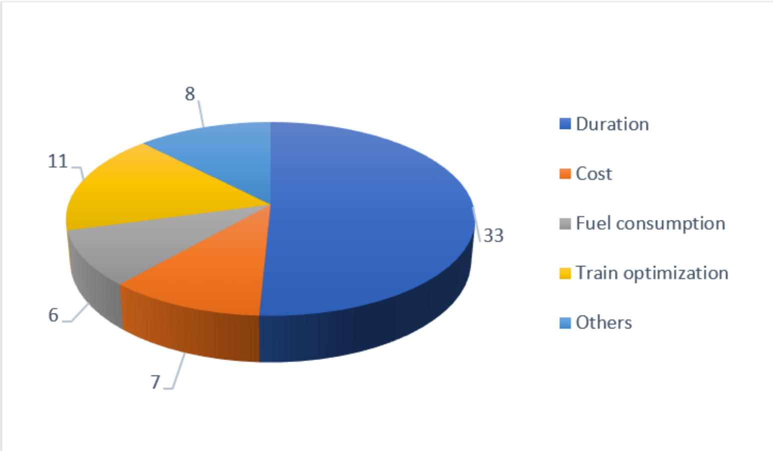

Figure 6: Classification based on Performance Measure

and 8 papers concentrate on other parameters as well. These are shown pictographically in Figure6.

5.5 Based on Continent

This section depicts how many publications have applied their findings to real terminals. Europe, Asia, North America, Australia, and Africa feature in the publications. Some of the papers develop a terminal in a simulation tool, not necessarily based on a specific rail-road terminal. And the remaining papers do not have any application of their approach to a real terminal, which make up the last specification.

Europe is found to be the place where a lot of work has gone into this field, with about 30 papers containing case study applications. 8 papers have focused on terminals and rail systems in North America. Asian terminals have been featured in 5 terminals in total.

Australia and Africa are the least common with 2 and 1 applications respectively.

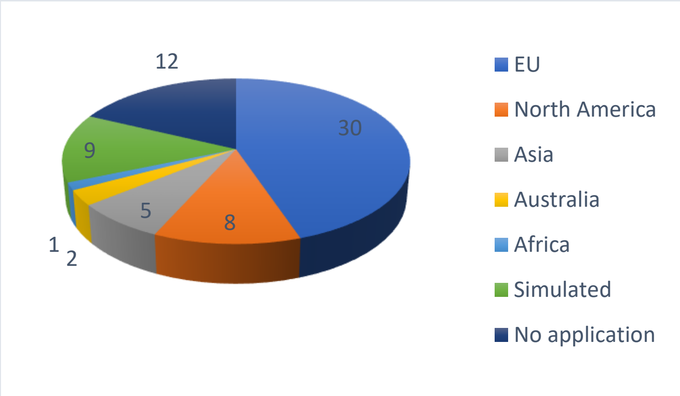

Figure 7: Classification Based on Continents

The pie chart in Figure7 gives a better idea. 9 of the publications considered, have constructed terminals in simulation platforms not necessarily based on a real terminal, and 12 papers do not have any application whatsoever mentioned in them.

6 Present and Future Research Areas

The main highlights of the present research are presented in this section. Gaps in the current state are identified and potential future research areas are briefly pointed out. Firstly, overviews for all the main aims are presented followed by a general summary.

6.1 Storage Space Allocation Problem

For the SSAP, division of yard into various zones and grouping of containers are commonly observed. The categorization might depend on factors like target locations, target trains, departure times, container sizes, and container owners among others (Dotoli, et al., 2014; 2017; Jachimowski, et al., 2018). Utilizing a grid pattern and positioning intermodal transport units (ITU) in defined sections, has proven to provide prominent outcomes (Jaehn, 2013). Some models and approaches have been further developed, which reduce train & truck service time and reshuffling of containers (Carrese and Tatarelli, 2011; Zajac and Swieboda, 2015).

Coming to the models and techniques, heuristics have been frequently used to get near optimal solutions (Carrese and Tatarelli, 2011; Jaehn, 2013; Wang, Zhu and Xie, 2014; Zeng, Cheng and Guo, 2017). Many two stage optimization models with a rolling horizon approach were developed and have proven to be very effectual to incorporate dynamic changes (Wang, Zhu and Xie, 2014; Wang, Zhu and Xie, 2017). An iterative procedure was suggested in Wang, Zhu and Xie (2017) which the authors proved to be very efficient for container assignment.

However, not much research has been focused on the integrated gantry CSP and SSAP. One of the papers Zeng, Cheng and Guo (2017) has formulated a mixed integer programming model and used the backtracking search algorithm (BSA) to solve it. To evaluate the performance, an artificial bee colony (ABC) algorithm and GA models are applied, for comparison. BSA has proven to be the most appropriate among the methods to solve small, medium, and large size problems (tasks and number of cranes)

This integrated crane scheduling and container assignment problem can receive more attention (Jaehn, 2013). Previously suggested models can be applied to real terminals as case studies and further new models and approaches developed. The problem can be further assimilated with the truck scheduling problem, thus considering the terminal as a whole merging the front-line operations to the backyard (Zeng, Cheng and Guo, 2017).

Increased use of mathematical programming models can help to incorporate real time scenarios and restrictions (Dotoli, et al., 2014). Simulation can be a tool which can be used cost efficiently, to inculcate stochastic parameters stimulated by real life information. Some previous works have used simulation for automatic container storage systems but not much application has gone into rail-road terminals (Kostrzewski and Kostrzewski, 2019).

Decision support systems (DSS) are designed to help the decision maker to keep a check on unpredictable events, providing more flexibility (Dotoli, et al., 2014; 2017). DSS can act as useful tools for optimization and automation. It can be directly interfaced with the existing software in the company, making it easily implementable. The DSS used in Dotoli, et al. (2017) can be further tested by applying to more case studies and also, observe under different scenarios, how the terminal performs with a what-if analysis. More applications of DSS for storage allocation problems can prove to be fruitful.

Additionally, a storage approach which takes into consideration and manages, the containers arriving and leaving the terminal at the same time, can be useful. When it comes to the piling of containers, some stacking restrictions were overlooked in previous literature, these might prove to be important as terminals usually operate with different sized containers (Jaehn, 2013). Automated storage space assignment models under uncertainty (delays in trucks and trains causing undefined arrival-departure times of containers) is another area which can be looked into (Wang, Zhu and Xie, 2017)

6.2 Resource Handling

Since handling equipment involve large initial investments, simulation is chosen as the most suitable method for this objective, which allows to study different kinds of scenarios and combinations before a purchasing decision is made (Mosca, Mattera and Saccaro, 2018). The selection of handling resources is found to chiefly depend on factors like cost of procurement, operational costs, stacking capacity, environment friendliness, maintenance costs and flexibility (Stoilova and Martinov, 2019). Small rail-road terminals serving lesser load find reach stackers most suitable. However, for medium and large rail-road terminals, compared to combinations involving reach stackers, techniques which involve gantry cranes are more cost effective (Stoilova and Martinov, 2019). As a result, waiting times for trucks are also found to be reduced. However, the initial investment for a crane is significantly higher, including other costs like floor reinforcement costs, which acts as a trade-off.

Multi criteria decision making methods (MCDM), like the name implies, finds its use when several alternatives are to be evaluated before making a choice. Stoilova and Martinov (2019) studied how this could be applied to a yard handling equipment problem but it hasn't yet been applied to a real terminal. This could be a potential future application to inspect an existing terminal or also before designing a new one. MCDM methods can also find its appliance to review other kinds of handling equipment or even other sorts of intermodal terminals. Further, it can be beneficial to study if advanced petri nets like colored and fuzzy, can be used to model and solve certain optimization issues (workflows and their processing times, to differentiate container typologies and control strategies with ambiguous information) (Cavone, Dotoli and Seatzu, 2016b).

6.3 Crane Scheduling Problem

A variety of modeling techniques have been used to formulate the CSP. Pap, et al. (2012) uses an exact solution approach. This is obtained using a Branch and bound method, whose implementation is straightforward and requires no additional costs. This is one of the first and noteworthy contributions to the CSP and to intermodal terminal optimization in general. Apart from the exact solution, heuristics have been used most commonly to solve the problem. A model based on Discrete Artificial Bee Colony (DABC) algorithm is proposed, which attains near optimal results within acceptable times. Compared to a GA, the DABC model is found to present better results making it a valuable technique to tackle CSP (Guo, et al., 2013). Alternately, an Ant Colony optimization model also gives near optimal results and is found to be another efficient algorithm to handle CSP problems providing reductions in idle and total handling times (Wang and Zhu, 2014).

A nearest neighbor heuristic has been used to solve a CSP for a special case of multi trailer trucks (road trains) (Boysen, Scholl and Stephan, 2017). Further, a Fix & Optimize approach is suggested to solve a CSP with External Trucks and is found to give favorable results (Guo, et al., 2018).

A BSA is proposed to solve the integrated SSAP and CSP, whose performance as compared to a GA and ABC model is found to be considerably better (Zeng, Cheng and Guo, 2017). The first promising future research could be the application of the DABC, BSA, nearest neighbor heuristic and branch bound models to real terminals and study their behaviors. Some assumptions were made in previous models regarding container dimensions, hence planning crane scheduling considering containers of different size as well as types could be a research direction. Similarly, most of the papers so far have not considered rehandlings when scheduling the crane moves and needs to be looked into (Wang and Zhu, 2014).

Another approach could be the integration of objectives of other stakeholders like transport providers, into the CSP (Guo, et al., 2018). Additionally, application of the Fix & Optimize algorithm proposed in Guo, et al. (2018) to other kinds of optimization problems can be studied. In terms of innovative concepts, a possible attempt could include applying the hybrid scheduling mode of multi-line flexible range loading and the synchronous handling mode to real terminals to study their complexity and also validate them (Xie, Wang and Yang, 2019; Zhang and Zhu, 2019; Zhang, et al., 2020).

6.4 Train Load Planning Problem

The TLP problem as a whole is complicated, making it difficult to get solutions for real size problems quickly through conventional methods. Hence, the model is usually broken down and meta heuristics are made use of, to arrive at near optimal solutions in a reasonable time frame (Corry and Kozan, 2005). The models are developed considering dimensions of containers, required number of pin changes, train height, separation of dangerous goods, maximum axle loads and weight constraints for wagons (Corry and Kozan, 2004).

Simulated annealing (SA) and local search (LS) heuristic models have been used in many articles, out of which SA has proven to be superior in most cases. However, LS takes lesser computation time, making it suitable in some special requirements (Corry and Kozan, 2004; 2005; 2006a; 2006b; 2008). These approaches and models act as a flexible framework for implementing to a range of terminal systems. It can be useful to apply the developed SA models and assignment models to more cases of real terminal systems and hence further validation of these models. The assignment model developed in Corry and Kozan (2006b) currently only applies for containers of same size. This can be extended to deal with different kinds of loading units as well as considering other aspects of a real case scenario.

Parameters like slot utilization, slot efficiency and use of empty loads and their effect on fuel consumption, aerodynamic efficiency and costs have been studied. An automated wayside machine vision system was also developed and an assignment model for load planning proposed (Lai, et al., 2005; Lai and Barkan, 2005; Lai, et al., 2006; Lai and Barkan, 2006; Lai, et al., 2007; Lai, Barkan and Önal, 2008; Lai, Ouyang and Barkan, 2008).

Similarly, the machine vision system proposed, has been developed and applied to trains and terminals in America. The usage or adaptability of such models in the European market can also be studied.

A DSS is also developed with very less computational times hence permitting changes even in the last instant, thus proving to be a great tool for optimization and automation (Dotoli, et al., 2017). Models to plan many trains together are formulated using a rolling horizon approach. And to ensure feasibility in all kinds of situations, a robust load planning model is developed (Bruns, et al., 2014). Real time train planning being integrated with real time crane routing can receive some attention in the future (Corry and Kozan, 2008). The DSS can be improved to include uncertainty, using fuzzy or stochastic programming methods. Improving the robustness models by trying to include uncertainties and also recoverable robustness (a greater choice to react to changes in parameters) (Bruns, et al., 2014).

Usage of CPLEX solvers is found to be satisfactory. These CPLEX solvers are extensively used in the logistics and transportation industry to tackle linear programming problems (Foti, et al., 2012). Loading plans of special cases like, one crane loading more than one train in a contemporaneous manner (Foti, et al., 2012). Another research study could be the combined planning of multiple trains, operated by the same operator departing from nearby terminals (Heggen, Braekers and Caris, 2014). Concerning train loading from road trains, to decide the division of containers across multiple deliveries, remains unsolved (Boysen, Scholl and Stephan, 2017). This model also needs to be validated for a real terminal.

6.5 Minimize Crane Rate

A new heuristic method called STRIPS representation is used to tackle this objective in many papers and it has given a good result (Galuszka, et al., 2010; Galuszka and Daniec, 2010). One of the articles Colombaroni, Fusco and Isaenko (2017) presents a double GA with trust region which provides an additional 5% reduction in the total costs.

The STRIPS representation analysis method presented is mainly applicable for reach stackers but not for cranes. It can be investigated if the same method can be adapted for cranes too, when evaluating larger sized terminals. The double GA method presented is for a situation involving a single crane. The same can be extended to analyze multi crane scenarios. Work needs to be done to also include and study reshuffling involved in dealing with intermodal terminal units of different sizes.

6.6 Minimize Make span

A queuing theory model was developed which has been widely adaptable to different kinds of terminals, dimensions and technologies and hence can be made use of to evaluate the existing terminals as well as while planning new terminals (Malavasi, Quattrini and Ricci, 2006). Applying the queuing theory models to more terminals in the form of case studies and fine tuning it would be a potential work. An approach to compute the total transport time of the goods by integrating the queuing theory model into a broader, more holistic model can be carried out.

In a different publication, a first order hybrid petri net model is proposed which worked well in an open loop condition but not so much in a congested state (Cavone, Dotoli and Seatzu, 2016a). Application of the petri net model to the congested situation needs to be investigated further. The further usage of petri net models to terminals handling other means of transport can be studied.

6.7 General

Simulation models have been used from a long time to evaluate alternate scenarios and make a comparison to choose the best fit, averting expensive investments. They can be used to design and study a wide variety of operations in a terminal. Specific simulations like monte carlo simulation can be employed to identify critical issues, the possible bottlenecks and take necessary actions (Cavone, Dotoli and Seatzu, 2016b). Simulation tools can also serve to evaluate new potential markets.

Mathematical programming models out of all the analytic models are found to be efficient in incorporating limitations and real characteristics (Dotoli, et al., 2014). Exact solution approaches like branch and bound do not involve additional costs for implementing and are found to be user friendly (Pap, et al., 2012). Complicated problems where exact solutions cannot be obtained in reasonable times, are resolved with heuristics. Computation times required in solving these heuristics dictate their application further.

A novel double GA suggested in (Colombaroni, Fusco and Isaenko, 2017) provided better results as compared to a single GA. This can be used to study other optimization problems in the terminal. An MCDM method can be applied to situations involving many criteria before a decision is made. Further, DSS provide high flexibility, and can be used for dynamic scenarios. They can be directly integrated with the existing company software and hence all in all act as a wonderful tool for optimization and automation purposes.

Coming to the future trends, a lot of attention has gone into the energy efficiency problem recently, but a majority of it concerns the marine terminals. Some works are being tailored to the inland intermodal terminals, and to promote environment protection and sustainable development, more attention can be focused on this. A study which concentrates on the effect of indirect energy consumption in rail-road terminals can be included (Wang and Zhu, 2019).

With regards to the external customer trucks, the European and American systems mainly have two different strategies. In EU, the trucks are permitted in the transshipment region whereas in America, the external trucks drop off the containers in the holding areas which are then moved by trailers internally. Both the techniques have their respective advantages and disadvantages. A comparison of the policies can be undertaken (Boysen, et al., 2013).

In the same field, allotment of parking areas to trucks which come into the terminals for dropping off or/and picking up a container has not been dealt with much (Boysen, et al., 2013). In some situations, such as when a train arrives, there might be congestion which leads to delay, hence this is an area which can be explored. A work to study how changing the parking positions of trains can lead to better train processing in tandem with the yard partition problem (Boysen and Fliedner, 2009).

With regards to the container moves assignment to different cranes, many papers have so far concentrated on the static approach (with cranes having separate working areas) but not on dynamic (overlapping working areas). Improvement in crane and terminal efficiency can be seen with the latter (Wang and Zhu, 2014; Otto, Li and Pesch, 2017).

A holistic modelling approach which considers gantry crane scheduling, storage space allocation and TLP problems together has not been undertaken yet (Bruns and Knust, 2012; Heggen, Braekers and Caris, 2014; Otto, Li and Pesch, 2017). Further, exploring different critical scenarios in the operation of the terminal and applying the existing models or developing new ones to enhance terminal resilience (Carboni and Deflorio, 2020).

7 Conclusion

The chief objective of this work is to assess the current state of art with respect to inland rail-road terminals. An extensive literature review was conducted, and 67 relevant publications identified. A classification scheme was developed and applied to the chosen articles. In this scheme, the papers were mainly categorized based on their principal aims or objectives, the kind of models the authors develop to represent the problem, the solution approaches introduced to tackle these models, the key performance indicators used to quantify and compare the results as well as according to the continent of the real case terminals these models are applied to.

A broad overview of the individual categories with their respective publications has been provided. The research area consists of the operations performed when a train and truck arrive at a terminal. It was found that the papers mainly focused on decision tasks like SSAP, CSP and TLP problem among others. Simulation models were found to be used in around half of the papers reviewed, with integer programming, binary programming, optimization modeling and NP models also being occasionally applied. The models were either solved exactly or to near optimum using heuristics of different kind. The objective functions formulated mainly aimed at minimizing the time duration of operations and the costs involved. With regards to case studies on real terminals, about half of the papers were based on European terminals, whereas about one-third of the papers are still theoretical with no practical validation. And finally, the prominent results in each operation problem were listed and possible future research areas recognized.

Overall, the past developments in the topics of scheduling of gantry cranes and container storing strategies are presented and the gaps in literature identified. Key factors are summarized, and the essential methods detected. Judging from the current state, a lot of developments have been happening recently in the domain of inland rail-road terminals along with many works being published. Still, a lot needs to be done and for this, the possible future research directions are listed.

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