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THE EVOLUTION OF INTERMODAL TRANSPORT RESEARCH AND ITS DEVELOPMENT ISSUES

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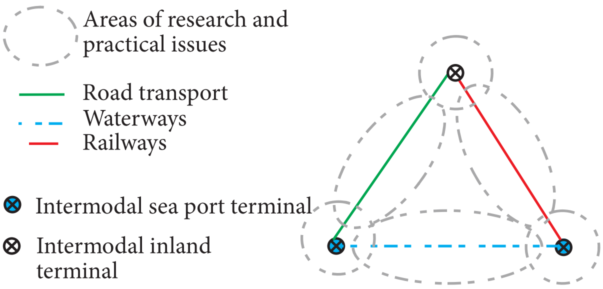
Abstract. Scientific papers related to intermodal transport research are reviewed in the article. Attention is focused on classification of scientific issues of intermodality. The methods, algorithms, models used for intermodal transport research are described. The areas of huge scientific focus and poor areas in intermodality research are highlighted.

Keywords: intermodal transport, container, terminal, sea port, transport research.

1. Introduction

The term "intermodal" was mentioned in the Concise Oxford English Dictionary of 1980. Intermodalism was far from a new concept even at that time. In the 1993 terminology it was changed to "a vehicle/container system, etc. employing, suitable for, or able to adapt or be conveyed by two or more modes of transport". In the 1999 edition of Dictionary definition of intermodalism was clarified by giving a more detailed description "involving two or more different modes of transport".

Today the term "intermodal" is understandable as door–to–door transportation of goods by a few modes of transport within intermodal loading units (ILU) and ILU are not recharged during the transportation process. The containers, trailers and swap bodies are called intermodal transport units here. Intermodality is mostly focused on surface transport – seaborne transport, road transport and railways. Air transport is not included because ILU are not the loading units of air transport.



Research areas of intermodal transport

The basic intermodal transport issues may be presented as a triangle in Fig., where each link is one of the three different modes of transport and each node is one of the three possible intersections (terminals) of different modes. The aim of the article is to analyse intermodality – focused researches that are carried out in these links and nodes in the world, and to classify the researches and to find the sectors that are poorly described.

2. General and narrow approach to research into intermodal transport

The question is raised by Woxenius: "What could be better – to do general research as a generalist or narrow specified research?" [1]. Persson [2] means that narrow focused topics and well defined research problems make it easier to reach precise results. One striking example is Löfsten [3] who starts out from a method perspective and claims to describe "the Swedish transport industry" while what he actually describes is forwarders offering general cargo transportation, i.e. – companies controlling only a small part of the total freight transport industry. So the crucial improvements in things that are not so important are nothing to compare with small improvements in important things. For a good verbal description of the transport industry, however with a European focus, see Hertz [4] instead. Among others, Porter [5] who has dedicated a whole book – Trust in Numbers – to defending this conception. Ackoff [6] means that it is very difficult to precis the difference between basic and applied research respectively. He argues that basic and applied research represent points along a scale that are hard to divide. The scale might represent whoever benefits from the research: other researchers within the field (or "science") or people representing the studied phenomenon. Samuelsson [7] argues that the scientific world would benefit from replacing the terms "basic and applied research" with disciplinary and transdisciplinary research or long-term and short-term research.

Woxenius [1] focuses on presenting conceptual models using a systematic and descriptive language (in a wide sense) rather than analysing and demonstrating the usefulness of the models. He represents the idea of Stock [8], it is natural that researchers in new disciplines borrow methods from older and mature disciplines. This is especially true in multidisciplinary fields such as logistics and transportation. Intermodal transport is clearly no exception.

The wide analysis of intermodal transport in general field is made by Love in [9], where juridical, organisational and technical aspects of intermodal transport in Europe are presented.

3. Transport network approach to intermodality

Network design models represent generic models for a wide range of applications in planning transportation, logistics, telecommunication, and production systems. In these applications, multiple commodities (goods, data, people, etc.) must be routed between different points of origin and destination over a network of nodes and arcs with possibly limited capacity. Moreover, other than the routing cost proportional to the number of units of each commodity transported over a network link, a fixed cost must be paid the first time the link is used, representing its construction (opening) or improvement costs. The general network design problem consists of finding a minimum cost design, i.e. a choice of arcs in the network to enable the flow of commodities such that it minimizes the sum of the fixed cost of including the arcs and the variable cost of routing the commodities on them. Presentations of different network design models and their applications can be found in papers of Minoux [10], Magnanti [11], Ahuja [12], Baublys [13], and Balakrishnan [14].

At the highest strategic level there have been several descriptive methods to analyze a regions transportation pattern by Crainic [15–19]. The system STAN is presented for strategic analysis and planning of national freight transportation systems by Crainic. The purpose of descriptive models is to model the transportation flows in a region given the infrastructure network and possibly the service network available. There are a number of contributions in the field of terminal location. Given transportation demand the models attempt to locate terminals in order to meet the demand and minimize transportation costs.

Labbé [20] presents an annotated bibliography concerning discrete location problems. These models are often referred to as network design models. Balakrishnan et al. [14] and Magnanti et al. [21] present a review of network design problems and their applications, mainly in freight transportation.

Network design models [22] are easy to formulate but are difficult to solve because of the constraints binding the capacity of the links modelled with binary (or integer) variables and the flow of the commodities. Several methods have been applied to solve network design models. Costa [23] presents a survey for the application of Bender's decomposition to network design problems. Chouman [24] presents a survey on valid inequalities of network design problems. Holmberg [25] presents a lagrangean approach to solving network design problems. Finally a wide range of heuristic contributions can be found for solving network design problems. To name a few, Ghamlouche [26, 27] presents a Tabu search based on meta-heuristic approach using cycle-based neighbourhoods to solve the general fixed-charge network design problem. Crainic [17] also uses a Tabu search based on approach with a combination of pivot moves and column generation to solve the same general fixed-charge network design problem.

Given the infrastructure, costs, and transportation demand, service network design models can be used to plan transportation services. Whereas the network design models in general are easy to formulate, service network design models are more complex given the higher level of operational detail they need to include. A general description of service network design models for freight transportation can be found in Crainic [17]. A wide range of applications of service network design models can be found. Huntley [28], Gorman [29–30], Joborn [31], Crainic [19], and Armacost [32] present service network design applications for CSX transportation, Santa Fe railways, Green Cargo, Canadian National, and UPS respectively.

Service network design models can be separated into two types of models; one where service frequencies are determined, and the other one where schedules are determined eventually determining the service frequency. The first type can be considered strategic/tactical and the latter as tactical/operational because of the higher level of detail represented by schedules as opposed to determining just frequencies.

Several contributions investigate modal choice and intermodal network design in a region. Such analysis can be found in Bookbinder [33] where intermodal routing options between Canada and Mexico under NAFTA are investigated. The results of the investigation give an indication of the modal choices between pairs of 5 Canadian and 3 Mexican cities using several American cities as transhipment points. Similar analysis can be found using the STAN software package which has been applied to the São Fransisco river corridor in Brazil by Crainic [15]. Whether operations research methods are used or not an initial strategic analysis of a region provides an operator with a decision support which can be used to determine its network coverage area. Given a strategic network of areas and customers to serve, the problem becomes one of choosing how often to run services. Previously, a widely adopted policy for running conventional freight trains was a "go-when-full" policy. This meant that freight trains were not scheduled and moved from their origin to their destination terminals when capacity on the rail network was available. This policy is still adopted in North-America whereas in Europe the policy is inefficient because of the large amount of passenger trains taking up the rail network capacity.

Time sensitive freight, the long transit times are unacceptable, and it is one of the reasons for the low share of the modal split in favour of rail transportation. Contributions from Crainic [19], Marin [34] and Keaton [35] all present service network design problems with train frequencies as outputs. The situation in Europe where rail business is separated into rail authorities and operators means that an intermodal train operator is not the proprietor of the infrastructure and not the sole operator using it. The representative of Deutsche Bahn has paid attention to the fact, that infrastructure capacities are divided among train paths. However, this concept allows solving routing problem but not the scheduling. Pedersen [36] suggested to use train channel concept instead of train paths. However, train paths here only represent a routing possibility, which is why we will refer to them as train canals instead. Train canals are time dependent paths on the rail network. They can be compared to a time-slot or time-window within which a train must operate on the rail infrastructure. This means that there is a departure time and an arrival time associated with each of the terminals visited along the path. The division of the infrastructure into predetermined train canals prevents conflicts between trains on the network and leaves it up to the operators to acquire the train canals they need to assume their operations. Passenger trains still have priority at acquiring train canals, and passenger train operators are often involved in the process of determining train canals. However, the European national rail authorities have started to cooperate in constructing a dedicated transcontinental network of train canals for freight trains as it is highlighted in the White Paper 1996.

Service network design is an extension where issues such as freight consolidation, service type choice, service frequency, delivery times, terminal congestion, and empty vehicle repositioning are considered. The planning scope is generally on a tactical level, as opposed to the strategic scope of network design models. The service network design problem for freight transportation is described in Crainic [16[and applications can be found in Barnhart [37], Cheung [38], and Powell [39] for road transportation, Joborn [31], Marin [40], Newman [41], and Cordeau [42] for railway transportation, Kuby [43] for air transportation, and Armacost [32], Kim [44], Nozick [45], and Jansen [46] for various intermodal transportation problems. Mapping problem of intermodal hubs in the transport network is presented in Racunica and Wynter paper [47].

The problem of the optimal location of hubs in a network has received attention over the past decade due to its importance to air transportation. The objective is to determine the posterior number of hubs to be opened and the paths used in the network, where a hub is opened only if it is profitable to do so. The definition of "profitable" is given in terms of hub opening costs and travel time savings, where the latter are, in principle, both due to sufficient consolidation and as well as trip time reduction. The basic model, presented by Racunica [47], has been studied and some algorithms proposed in the references by O'Kelly and Skorin-Kapov [48], O'Kelly and Bryan [49], Klincewicz [50]. Skorin-Kapov and O'Kelly [51], Ernst and Krishnamoorthy [52].

The model of virtual nodes is presented by Crainic [19]. Vasilis Vasiliauskas [53] highlighted that operation with different costs may be done in the same virtual node and it is need to evaluate.

Although some effort has been put into vehicle balancing and repositioning by Dejax [54], who presents a survey on the issue of service network models that equipment is available when needed and that the vehicle positioning and empty repositioning problems are done at an operational planning level. However, with carriers operating with minimal fleet sizes, the problems can significantly impact on the services offered. An example is the rotations that intercontinental ships perform. Each leg between calling ports can be considered as services. The individual legs are interconnected by the fact that they can not be offered unless the preceding leg on the rotation is offered. The resulting service network is a series of services following each other to perform a rotation enabling the same cyclic service pattern over a period of time. The same aspect of connected services can be seen in railway transport. An example of the latter is the intermodal shuttle trains operated in Europe rotating to and from two or more terminals. The first research issues on railway transport are done by Pedersen [36], on air transport by Barnhart [55] and Clarke [56].

The sufficient distance for intermodal solution in Europe is 400 kilometres and more. Nemoto [57] presented critical distance idea, where an important role is played by time of transhipment in terminals. Transhipment and handling in terminals always take a time and money, but in case of sufficient distance for railways or waterways, the intermodal door–to–door transportation is cheaper and faster. The general role of terminal costs decreases as well as distance of transportation by cheapest modes of transport increases. The model focused on the intermodal transport supply and demand is presented by Nierat [58]. In Europe as in the whole world there are many regions. Transportation market conditions are different in the regions. Labor force and time in different regions have different financial value. The traditions also differ. For example, delays are not tolerated in northern Europe, but in southern countries some delays are in the normal frame. However competition of intermodal transport in shorter distance may be achieved by improvement of terminal operations and making the supply market closer, as Trip [59] mentioned.

4. Scheduling tasks in intermodal transportation

Constantin [60] proposes a model to minimize total waiting time in a public transport system by finding optimal frequencies for each route, by taking into account travellers' behaviour regarding route-choice. However, the model does not include fixed timetables, thus synchronisation is not an issue. Transfer times are modelled as an expected value based on the frequencies. Ceder [61] presents a model for maximizing synchronization in timetables. The model defines synchronisation as an event where two vehicles arrive at a stop simultaneously, enabling passenger transfers. The model seeks to maximize the number of synchronizations. However, synchronization is only achieved if vehicles arrive simultaneously at stops, and the model doesn't consider the possibility of one-sided synchronization where one bus can connect with the other but not vice-versa. Klemt [62] presents a quadratic semi-assignment programming model with a set of covering constraints. The model assumes time-independent passenger transfer-flow patterns. A similar model is presented by Daduna [63]. Here too there is an assumption of transfer-flow patterns being independent of the transfer waiting time. This assumption means that the number of passengers of freight using a transfer are independent of the transfer waiting time. If there are only a few connections in a network the assumption holds, due to the fact that passengers will not have alternative choices. However Pedersen [36] in his work evaluated waiting time from transfer point of view.

Bookbinder [64] presents a model based on the model in Klemt [62] paper. The model includes stochastic transfer waiting times. Arrivals are described using a shifted truncated exponential distribution. Furthermore a second-degree polynomial relationship is used to describe the disutility as a function of the transfer waiting time. As for the original model proposed by Klemt [62] passenger flows are considered independent of the actual transfer waiting times. An interesting result is that when optimizing simultaneous connections in the network, deterministic and stochastic models only defer when arrival time of the feeder line is close to the departure time of the connecting line. Pedersen [36] assumed deterministic times and applied a buffer time to achieve this.

Other models that consider stochastic times are presented by De Palma [65], Knoppers [66] and Carey [67]. However, common to all three papers only the schedule of a single line is considered. Hence, system wide interaction of routes is not considered when scheduling. Schöbel [68] presents a problem dubbed into the delay management problem. The problem is derived from a situation where a train's arrival to a station is delayed.

Specifically for intermodal freight transportation (or consolidated freight transportation) a number of contributions deal with terminal operations. On the border between service network design and actual terminal operations there lies a number of train dispatching models. These models determine the optimal arrival and departure times for trains in accordance with a single terminals operational characteristics. Newman [69], Yano [70], and He [71] present dispatching models for rail terminals. A common approach to managing terminal operations is to use simulation models. There are numerous contributions for simulating terminal operations. Rizzoli [72] specifically deals with rail/road intermodal terminals. Optimization approaches have also been used for terminal operations. Contributions can be found in papers by Gambardella [73], Kozan [74], Newton [75], and Bostel [76]. The latter contribution deals specifically with transhipment of containers between trains and trucks in intermodal rail/road terminals. Newton [75] deals with railway blocking plans for conventional trains. The complexity of the operations and the costs explain why many intermodal services in Europe operate with a fixed make-up policy to avoid train composition and limit wagon handling in terminals. Also specifically for intermodal transportation some research has been conducted on the drayage transportation at each end of the intermodal trip chain. Regan [77] presents an analysis of the congestion issues on the American west coast experienced by trucking companies. The analysis shows that the congestion issue may prevent the further growth of the traffic in and out of the busiest ports proving that attention must be paid to the management of drayage moves. Morlok [78] reckons that in order to improve drayage operations closer cooperation between intermodal shippers, intermodal train operators and drayage move operators is essential. Taylor [79] presents a method for terminal selection in order to minimize empty vehicle movements and thus the total truck mileage used to perform drayage moves. A general survey of opportunities for operations research in intermodal transportation can be found in Macharis [80]. The survey covers all facets of intermodal transportation, although several contributions of interest in service network design are not included.

Several contributions can be found on train routing and scheduling and on applied service network design for train operations. Cordeau [42], Huntley [28] and Gorman 29] present service network design models with schedules for CSX transportation and Santa Fe Railways respectively. Yano [70] presents a dynamic modelling approach to schedule departures of freight and trains to and from a single terminal. Newman [41] presents a train routing model which includes schedules. However, freight demand is modelled to originate and is destined to rail terminals, thus drayage moves are not considered. Nozick [45] presents a linear MIP-model for planning intermodal freight routing. The configuration of the train schedules is given though. Gorman [29] presents a linear MIP-model for train scheduling with limited terminal operations and Hagani [81] proposes a linear MIP-model for scheduling trains that is similar to the one we will propose here. The MIP-models determine the optimal scheduling on a space-time representation of a network for two types of trains including the train make-ups and empty wagon repositioning problem. The models assume that trains can run within every time-period and therefore do not account for the fact that rail network capacity may be occupied by passenger trains. Pedersen [36] improved the model by additional constraint – free trains channels, that are not occupied by passenger trains.

Main idea of Tornquist [82] research was how computer-based decision support systems (DSS) can assist railway traffic dispatchers in the disturbance of management process and how to model and mathematically formulate disturbance management.

A collection of agents is usually referred to as a Multi-Agent System (MAS). The concept of MAS is a hiving off from distributed artificial intelligence (DAI) and provides a modelling approach that divides complex problems into sub-problems. The sub-problems are then allocated to several agents, which then cooperate to solve the larger problem. One of the advantages is that the sub-problems can be solved more or less independently, which reduces the computational time given that the agents run in parallel on different machines. Another advantage of using agents to represent parts of the problem is the possibility to tailor the behaviour of each entity differently and reflect a rather complex setting.

The mathematical models of the problems to be solved are usually divided into linear and non-linear programming models (LP and NLP). If some of the variables are discrete and others continuous, we have a Mixed-Integer Programming model (MIP). If all of the variables are discrete, the model becomes an Integer Programming model (IP). The task of solving problems with integer variables is referred to as integer programming or combinatorial optimisation. Well-known solution approaches to problems with discrete variables are Branch and Bound (B&B) and various decomposition schemes. Problems with a large number of discrete variables, such as the railway traffic re-scheduling problem, sometimes become intractable and very difficult to solve. Then another type of solution method that is often applied is heuristics. Some heuristics have difficulties performing a good search and may get stuck at a local optimum, thus not being able to move away to possibly better solutions. A meta-heuristic [83] is a master strategy to guide other heuristics by providing one or several rules to avoid the problem. Two well known meta-heuristics are Tabu search (TS) and Simulated Annealing (SA), and they use different strategies to avoid getting stuck at local optima.

There exist several proposed methods to handle the conflicts by rescheduling, see, for instance, the reviews in papers by Assad [84], Cordeau [42] and Törnquist [82]. It can be noted that very few implementations of running real-time decision support systems can be found. The reason for this is that re-scheduling of railway traffic is a complex problem to which solutions need to be generated within a short time frame. The complexity depends on the combinatorial characteristics, the size of the problem and the difficulties to represent it properly.

Some papers are focused on rescheduling problems using Genetic algorithm, Tabu search, Analogy simulation and various hybrids. It is described in papers by Tornquist [82], Higgins, Kozan and Ferreira [85].

5. Issues on tasks of intermodal terminals

From the explanation of the events that can occur on an intermodal trip and as mentioned in paper by Ferreria [86] it can be deduced that terminal operations play an important role. Bostel [76] presents a model and solution method to solve the transhipment problem between two trains. The model aims to minimize the container moves between trains. Rizzoli [72] presents a simulation tool for the entire terminal process including storage operations. From the time the container arrives at the terminal by truck or train until it departs again, the container does not cover any physical distance. Trip [59] highlighted why it is important to focus on developing technology to speed up and reduce handling cost of terminal. The unloading, transferring, and loading of containers onto trains can be done by gantry crane or by mobile crane depending on the available infrastructure at the terminal. There are only a limited number of tracks at a terminal. Thus only a limited number of trains may be present simultaneously at the terminal. The handling machinery can only perform a certain number of operations meaning that only a limited number of handling operations may occur in a given time period to avoid congestion and resulting delays. The resources available to perform terminal operations are thus limited and should be considered when designing intermodal train services.

Many researches focused on container terminals in ports are made by Wilson [87], Henesey et al. [88–93], Jansen [94], Gambardella, [95], Kia [96]. They determine issues as complex system that is difficult to model. The theory of the systems is described in Woxenius [1] paper.

A literature survey overview on transshipment operations has been provided by Vis and Koster [97] followed by a rather comprehensive survey on container terminal logistics by Steenken et al. [98]. A classification of container terminal operations is provided by Henesey [90].

In the last decade there has been increasing interest in software designs based on multi-agent systems (MAS), i.e. a range of techniques that share a common bond in that they describe systems in terms of aggregations of goal-oriented, interacting and autonomous entities, placed in a shared environment. There exist many definitions for describing software agents. According to Wooldridge [99] agent is a computer system that is capable of independent action on behalf of its user or owner and a multi-agent system consists of a number of agents which interact with each other, typically by exchanging messages. In the case of MAS, several agents are interacting in a goal or task oriented coordination that can be both cooperative and competitive. The interaction between the various agents in the system provides an interesting way for solving problems. Multi Agent Based Simulation (MABS) differs from other kinds of computer-based simulation in that (some of) the simulated entities are modelled and implemented in terms of agents. Similar to other micro simulation techniques, MABS attempts to model the specific behaviours of specific individuals.

Traditionally, seaports are focused exclusively on the berth, e.g. Thomas [100]. A queuing network based model of ship arriving is simulated with Visual SLAM software under various scenarios in a paper by Legato and Mazza [101]. The berth planning problem is argued by Lim [102, and Wilson and Roach [87, 103]. The proposal by Lim, [102] is that the berth problem be transformed to a graph that represents it. The berth management in a container terminal is evaluated by Moorthy and Teo [104] by modelling it as a rectangle packing problem on a cylinder and by use of a sequence pair based simulated annealing algorithm to solve the problem of home berth location. In reviewing public berths, Nishimura [105] tackles the berth-planning problem by employing genetic algorithms that solve a dynamic berth allocation problem that was addressed in earlier papers by Imai and colleagues [106–109]. The authors compare the Lagrangean Relaxation based heuristic algorithm with the Genetic algorithm (GA). The results using the GA showed no significant improved solutions for large size problems. There is some improvement in using GA in small size problems. Nishimura [105] evaluates the use of GA for the routing of trailers in a intermodal terminal.

A multi–agent systems approach is investigated in vessel berth allocation that is published in a series of papers by Lokuge et al. [110], which incorporates multi-agents for the decision tasks and an adaptive neuro fuzzy inference system in making final decisions considered rational. The use of fuzzy logic with an improved Genetic Algorithm is proposed by Zhou and Kang [111] for intermodal terminal resource allocation. Alternative methods for modelling a container terminal are investigated by Yun and Choi [112], they assume that a container terminal consists of a gate, container yard and berth. The authors use an object-oriented model to develop modules and are able to model at a higher level of abstraction. At the operational level of a control decision in berth allocation Imai [107, 108] proposes a dynamic berth allocation algorithm developed for assigning ship to public berths, which assigns berths to ships while work is in progress. In the paper by Kim and Park [113] and Ng [114], they investigate scheduling of multiple cranes with given set of jobs. The goal of both papers is to assign the most expensive resource, the quay cranes, optimally to arriving ships. Kim and Park [113], propose a branch and bound method for obtaining optimal quay crane scheduling using a greedy randomized adaptive search procedure (GRASP). Ng [114], proposes a dynamic program-based heuristics to solve the quay crane scheduling problem. The use of the stowage plans for container ships has been researched by Avriel [115], where the objective is to minimize total cost of shifting of containers on a vessel calling various ports.

A paper by Ambrosino et al. [116], proposes a linear programming model that incorporates heuristics for the pre-processing and pre-stowing procedure in the stowage of containers in a container ship, which they call a master bay plan problem (MBPP).

The tasks of container terminal may be divided into the following groups [91]: ship to shore, transfer, storage, and delivery and receipt.

Ship to shore task is divided into ro-ro and lo-lo cases. In many of research papers, in known scientific journals lo-lo case is analysed. The most important research issues are positioning of berth facilities and number and type of gantry cranes. In two papers by Wilson and Roach [87, 103], they propose a methodology developed for a generalized and a specialized placement for a container using a branch and bound algorithm and later a Tabu search. In the planning for berth allocation, Imai et al. [106–108] use mathematical programming to load and unload containers while considering the ship stability. The paper is concerned with the ship loading sequence, which in turn creates the transport sequence from the stack to the ship. In Steenken et al. [117] the ship-planning problem is tackled by using combinatorial optimization. The containers are portioned according to classes of types. The authors interestingly note that the export stacks can partially provide a sequence of containers to be loaded.

The containers are stacked under various characteristics, i.e. size of container, status of container, ownership of the container, etc. A large amount of research has focused on the constraints and the decisions that are made. The problem of solving resource allocation and scheduling of loading operations is formulated and solved hierarchically in Gambardella et al. [73]. The coupling of optimization such as a mixed integer linear program that formulates the resource allocation with simulation to test if policies are good.

The container storage in a series of papers by Kim et al. [113, 118–120], the planning of containers is viewed from a strategic to tactical time frame. The re-marshalling or handling of containers at the stack in the yard is argued by Kim, to contribute to the efficiency of the loading operations.

In a related paper, Kim [120], uses dynamic programming to determine the optimal storage space and number of cranes to handle import containers constrained by costs. An analytical model is formulated for transfer cranes and import container yard space is considered. Another use of simulation was used by Kia et al. [121], to simulate two ports, one in the United States and the other in Australia, that verify that increased container terminal performance is obtainable if straddle carriers are employed with electronic devices. The simulator identifies bottlenecks during the operation that may increase vessel-waiting time. Decker et al. [122]evaluate stacking polices for a container terminal using automation.

In Zhang et al. [123], they use a mixed integer program augmented with Lagrangean relation, which generates solutions for a terminal using rail tired gantry cranes (RTG). In addition Zhang argues that it provides fast solutions to the executing of a dynamic crane deployment in container storage. The authors do not consider the exports arriving at the gate and focus much attention to the marine side. In Kim et al. [124], they investigated what many researchers have not considered, i.e. the practice of using the information on weight of the containers for stacking. Motivation for the paper is to minimize the expected number of container handlings. An alternative approach to optimize the container transfers often found in terminals is described by Kozan [125] to be a network model. An optimization function is developed that seeks to minimize the sum of handling and travelling time–called throughput by the author.

Transfer System. Containers are moved from berth to the storage area to be stacked or placed in an area for dispatch or containers from the stack are delivered to the gantry crane at the berth to be loaded on a vessel. The import container information such as its number, weight, seal number, and other information are recorded along with the location identification to a central database, such as a yard system in the terminal. Depending on the operations, yard tractors, front loaders, or straddle carriers are employed as transport in this operation. The type of transport employed has a direct relation to the layout of the yard, operations of the terminal, and how the stacking is executed. The export containers are transferred from a location in a stack, thus notifying a yard system that the location is free and will be given to a gantry crane to be loaded on a vessel. There has been recent work conducted by Vis et al. [126], where linear algorithms are developed to minimize the number of transport equipment required to move containers between stacks and quay crane under a time-window constraint. Research by Kim [119] and Lehman [127] both presents methods for guaranteeing that the AGVs will be deadlock-free during the operations.

Delivery and Receipt System. The interface to other modes of transport lies in this system. The managing of the gate is to obtain information on containers coming into the terminal so as to be properly physically handled before ship arrival and also to release import containers before the arrival of trucks or rail. Controlling this access to the terminal is important in that it affects other parts of the container terminal system. The common use of shared resources, e.g. ships and trains requires coordination between many firms. The agents in MAS are able to perform diagnosis, and decisions on a simulation that has been validated with historical data from Voltri Terminal in Italy.

6. Conclusions

1. The huge part of intermodality related researches are focused on container terminals in the ports and railways scheduling areas.
2. The tasks of container terminal may be divided into the following groups: ship to shore, transfer, storage, and delivery and receipt. The researches into railways scheduling are focused on transportation of containers.
3. A lack of scientific attention is paid to transportation of other ILU, such as trailers and swap bodies. We could not say this is not important. Especially if we take into account EU exertion to shift trailers from road to railcars. Many of researches that were carried out for container ports were commercially oriented. The leading ports in the world were initiators of such researches. However, intermodal transportation of trailers and swap bodies is organised by SME companies, intermodal operators and forwarders, that are not so financially strong if compared to the leading ports and railways companies. The fact is that EU strongly promotes intermodality and related researches also confirms that.

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