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Optimization challenges and literature overview in the intermodal rail-sea terminal

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Abstract

This work focuses on a particular node of the intermodal chain of transportation, i.e. the maritime port area that represents the link between rail and sea transportation modes. Since this exchange node of the chain has not been addressed much yet, the aim of the present study is to provide a description of the process of rail operations in port area, to give an overview of the optimization challenges and to review the existing literature on it. The purpose of the paper is to attract the researchers attention on this particular intermodal node, where there is room for improvements.

Keywords: intermodal rail-sea terminals; port rail shunting operations; rail maritime terminal operations; literature overview; optimization challenges.

1. Introduction

Many transportation systems are multimodal, that is, they support various transportation modes, such as truck, rail, air, and ocean/river navigation. Then, broadly defined, intermodal transportation refers to the transportation of people or freight from their origin to their destination by a sequence of at least two transportation modes. Transfers from one mode to the others are performed at intermodal terminals, which may be sea ports or inland terminals (Bektaş and Crainic (2007)).

This work focuses on a specific node of the intermodal freight transportation chain: the link between rail and sea transportation mode, that is the maritime port area.

Goods arrive and leave the port area by either rail / road transport or ships. In many cases, the portion of goods transferred by rail is lower than the one using road. If the rail process within the rail-sea yard were fast and efficient, rail

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could be used more to transfer goods to and from origin and destinations, instead of using the road. That is important because road transportation has several negative externalities, such as, for example, road congestion, accident rate, air pollution, noise pollution. In fact, one of the main issues in this field is to balance the modal split between rail and road modes in the flows planning through maritime terminals (Iannone (2012)).

The main operations in the rail-sea link of the chain are the transfer of trains between the railway station and the maritime terminals, the loading and unloading of trains and the storage management of goods in dedicated yards. Depending on the specific ports, sometimes trains approaching the area have to be split into cars and then these latter are transferred to terminals of destination (and viceversa for the import cycle).

Unfortunately, this passage, from the rail network to the maritime terminals and vice versa, has been rarely addressed in the literature, therefore the purpose of this work is to attract the researchers attention on it, where there is room for improvements.

This paper aims at describing the rail process and the optimization challenges in port area, together with surveying the few related literature.

The paper is organized as follows. Section 2 introduces the rail process while Section 3 shows the main optimization issues. Section 4 proposes the literature overview. Conclusions are reported in Section 5.

2. Process analysis of rail operations in port area

Sea ports play an important role as interfaces between sea and land transport (Krämer (2019)).

Usually, a general layout of a rail-sea exchange node includes three elements: a train station, a shunting zone and a maritime terminals zone. The train station is connected with both the whole railway network, on one side, and the shunting zone, on the other side. The latter connects the railway network with the maritime network and thus has an important role. The shunting zone, in fact, permits the transfer of trains from the railway network to the terminals and vice versa. The shunting zone may be composed of tracks for transferring trains and one or more parks where the trains can wait.

The process within this area involves several stakeholders, for example, railway undertakings, shunting operators, infrastructure providers, energy providers, maritime terminal operators, port management organizations, and so on.

An example of a typical railway process could be explained as follows. (A general rail process related to the port area is also described in Krämer (2019)).

First, trains travelling on the railway network arrive in the last rail station before the port area (export cycle). The physical rail transport between hinterland origins and seaports is generally conducted by railway undertakings. In some cases, they are the owner of cars and/or locomotives and, in other cases, they operate with chartered or leased equipment.

Then, trains are transferred from the rail station, where they can wait if necessary, to the shunting park inside the shunting zone introducted above.

In some ports, arriving and departing trains transport goods belonging to different maritime terminals, in other ports all cargo loaded on a train has a single maritime terminal as destination/origin. Therefore, in the first case, trains arriving at the shunting park have to be split into cars depending on the terminal of destination (note that the departing trains have to be composed of cars arriving from different terminals). In the second case, the whole train arriving at the shunting park has to be transferred to the terminal of destination (and viceversa for departing trains).

In the first case, the main shunting activities of the export cycle consist of receiving freight trains from the hinterland and shunting the freight wagons depending on their final terminal of destination. Considering the import cycle, the activities consist in receiving the wagons from maritime terminals, accumulating wagons according to their hinterland of destination and allowing the freight train to depart. Of course, besides these main activities, other operations related to the preparation of customs documents, border police controls, technical check of wagons, etc., might be carried out within the shunting park. The route of the wagons through the shunting park completely depends on the topology of the area. The lines inside the station are grouped according to the main activities to perform. Therefore, the tracks in the shunting park are organized into Receiving Tracks, Classification Tracks, and Departure Tracks. The transfer of wagons between Receiving Tracks and Classification Tracks is performed, is some cases, by crossing over the hump of the yard. The trains from land (also called the inbound trains) wait on Receiving Tracks. The trains' engines are removed and other engines (belonging to the station) for maneuvers are attached. The technical and the commercial activities are made, and the train stops to exist as an entity. Wagons are separated according to the destination (in this case, maritime terminals) using the shunting installation. This latter could be composed of one or two humps, a braking system, and an inclined plane (Rusca et al. (2019)).

Going ahead, in the second case, when cargo on a train has a single maritime terminal as destination (or origin), the process simply consists in the transfer of the whole train from the rail station to the maritime terminal.

In some cases there is a direct link, in terms of tracks, between the rail station and the maritime terminals zone that permits the direct transfer from the rail station to the maritime terminal of destination without passing through the shunting park.

The drivers and the wagon technicians form together the shunting team for performing these operations,which are called shunting operations. The shunting locomotives and the shunting teams are typically provided by dedicated port shunting companies.

Finally, the train or a section arrives at the assigned maritime terminal. The operators of the terminal have to conduct control and supervision works on both the train and the cargo (i.e. seal-check).

After these checks and only if everything corresponds to what is expected, the unloading process by rail mounted gantries, rubber tyred gantries or other types of equipment can finally begin.

A comparable opposite process is related to the departing of trains from the maritime terminals. After the completition of the train loading process, specific checks, brake tests and load control works must be performed on cargo trains with import goods.

The unloading and loading operations from/to a train in the maritime terminal must be performed within specific time windows. Let us consider a containerized cargo. When the train (a set of wagons) arrives at the maritime terminal it must be unloaded: export containers are unloaded and transferred for their loading on the ships. More attention is required for the management of import containers, in order to efficiently perform their loading on trains. Import containers can be stored either in the general terminal yard or in a dedicated area, closer to the tracks and used as a buffer (Gillen and Hasheminia (2018)).

The dedicated rail yard can be used either to store containers that have to leave the terminal by trains for example in few days, or simply as a buffer to prepare and prestow containers for their loading on the next leaving train. In this latter case, the terminal adopts a premarshalling strategy in such a way to have containers to load ready near the tracks. This approach permits to avoid reshuflles and other movements in the storage area. Reshuffles are unproductive moves required to gain access to a desired container that is blocked by other containers.

Therefore, the storage space assignment deals with finding the best allocation of containers to storage spaces. A good storage space assignment is one that reduces the storage yard operations cycle time (i.e., the time to store, retrieve, and reshuffle). The fitness of a storage space assignment depends on the availability and quality of the arrival and departure time information.

As a result, today, the port railway process is much more complex than truck and barge ones; this represents a competitive disadvantage for the rail transport mode. Real innovations within the rail cargo sector, especially in the European area, are rare, even if good ideas do exist. As a consequence, rail transport of cargo until today is, in many cases, very traditional and old-fashioned. From the actual steady situations, a fast and efficient rail process could be reached following several intermediate steps, such as, simplification of operational processes, optimization of infrastructure usage with savings on future investments, reduction of operational efforts and costs through reduction of workers (Krämer (2019)).

3. Optimization challenges

Having described above the process related to rail operations to perform on trains arriving and departing to and from the port areas, this section provides some optimization challenges.

Note that, port areas have some problematic and peculiar aspects, such as, limited access, large volume of cargo flow from mega ships to the territory, a fixed schedule for the departure/arrival of ships, as well as limited land availability to develop new infrastructure to deserve flows between maritime and land networks. Many of these aspects represent constraints to decision makers, constraints acting at three different decision levels: strategic, tactical and operative.

The strategic level concerns mainly the layout and the configuration of the port area dedicated to rail operations, and involves many stakeholders, many commercial interests and might develop in huge investments in the rail infrastructure. As explained in the previous section, the considered area includes the rail station zone, the shunting zone, the maritime terminals zone and the connections between them. The challenge here is to understand which could be both the optimal layout and the optimal sizing of the area. In the optimal sizing problem, we include decisions about the number of rail stations connected with the port area, the number of parks inside the shunting zone, the number of tracks composing the rail station/s, the shunting park/s, the terminals track park, the position and the number of rail yards in the terminals, and the connections capacity betwen the different zones. The objective is related to the best management of rail traffic in the port area, which means to increase the traffic or to minimize the total time needed to complete the process.

When the configuration of the port area is defined, the tactical challenges refer to the capacity of management trains through it. Going more in details, the decisions are related to the number and type of locomotives, number of shunting teams, type and number of handling equipment both in the terminals and in the shunting area. Other problems involved in this level could be to decide if some trains have to pass on specific tracks or connections and if the park or the rail station have to be devided into dedicated areas (import/export, depending of the maritime terminal of origin/destination, etc.). Finally, given the planning of both the trains in the railway network, on one side, and the ships, on the other side, the schedule of the shunting activities within the port area has to be defined for transferring trains from the rail stations outside the port area to the maritime terminals of destination and viceversa. Scheduling the shunting activities means defining the starting and the ending time of each operation through the tracks belonging to the layout decided at strategic level. The scheduling has to be made taking into account the feasible paths given by the tracks in the considered area and the available resources (shunting teams, locomotives, equipment). The objective is again the improvement of the management efficiency of the area and the increasing of the rail traffic in the link.

The operational level consists in solving some problems in the shunting area such as the re-scheduling of the shunting activities, which may be done in real time if delays or disturbances occur. This optimization problem includes decisions about new starting and ending times for each operation with the objective to follow the predefined plan as closely as possible. As for the scheduling problem, this latter has to take into account the feasible paths given by the tracks in the considered area and the available resources (shunting teams and locomotives). Other operational problems arising in the terminals are the planning of trains loading and the execution of loading/unloading of the trains. Terminal operations on trains are influenced by the handling equipment available and the layout of tracks and rail yards, derived by decisions taken at strategic and tactical level. The main aim is generally the efficient management of the operations and the efficient usage of the equipment.

The following section reports an overview of the main existing literature on the optimization problems in the rail processes in port area.

4. Literature overview

Rail operations in the port area can be divided depending on the zone where they mainly happen. We use subsection 4.1 for the works dealing with operations in the shunting zone and subsection 4.2 for the ones on the rail maritime terminals.

4.1. Rail in the shunting zone

As already said, the rail process through the shunting zone of a port area has rarely been addressed and, as consequence, the related literature is few. In this section, we cite the works dealing with the optimization problems in this field.

Concerning the strategic level, some simulation approches have been proposed, as explained in the following.

In Rusca et al. (2018), the authors analyze the topological structure of port shunting yard and evaluate transit capacity through its various compartments. A discrete simulation model is developed with ARENA computer simulation software for wagons shunting process and various scenarios and possibilities for shunting process are tested to identify which one may bring an increase of the transit capacity for the port shunting yard.

Rusca et al. (2016) propose a simulation model developed with ARENA computer simulation software suitable for shunting yards which serve sea ports with access to the rail network. In this work, the principal aspects of shunting yards and adequate measures to increase their transit capacity are investigated. They propose the idea of improving the yard capacity by changing a normal shunting process with a single train, to simultaneous shunting processes, i.e. two train are shunting in same time, when the infrastructure allows it.

Again, Rusca et al. (2019) enriches the discrete simulation model taking into consideration the input flow characteristics of both freight trains from land network and freight wagons from maritime terminals, the number of tracks in a port railway station, the technology used for separation of freight wagons on destinations (inside the port or from hinterland), and the duration of technological processes. Using the simulation model, comparisons between different shunting yard typologies can be made to hierarchize the investment in the short or long term.

In Caballini et al. (2016) and Fioribello et al. (2016), the authors studied a discrete-time model in order to size port rail networks and planning shunting operations only for container terminals and from the containers point of view.

Then, to the authors' knowledge, there are really few works dealing with scheduling and re-scheduling of shunting operations, i.e. operationals level.

Ambrosino and Asta (2019) is the first attempt to solve the port rail shunting scheduling problem introduced above. The authors present a discussion on possible approaches for solving this problem, together with a first approach based on an operations-time network.

To the authors' knowledge, no more literature exists on these scheduling and re-scheduling problems for the port rail shunting activities. However, a huge number of papers on general scheduling and re-scheduling problems in the rail field can be found.

Among these we want to cite two works, Tomii et al. (1999) & Tomii and Zhou (2000), because the problem that the authors address is really similar to the port rail shunting optimization one, even the area considered is different.

They deal with the shunting scheduling problems set in a rail station, called here depot. The problems include the schedule of both tasks, shunting and workforce assignment. Movement of trains between tracks is called here shunting.

The procedure that they used foresees two consecutive steps. The first step for producing a candidate solution in which assignment of side tracks and workforse are temporarily decided and execution times of tasks shunting are not explicitly considered. Then, they try to adjust the execution time of each shunting so that all constraints are satisfied.

A difference between port rail shunting and depot shunting scheduling problems consists in the fact that in the first only the shunting activities are to schedule while in the second there are tasks to perform. The tasks are realized on a specific track and need the assignment of a workforce while shunting activities are related to the transfer of trains through the port area involving the whole infrastructure.

In Tomii et al. (1999), the authors propose an algorithm for depot shunting scheduling problems combining genetic algorithm (GA) and Program Evaluation and Review Technique (PERT), so that the candidates for answers in GA are evaluated by PERT. This enables them to reduce the search space of GA to a great extent. To this end, they focus on the following two points. One is to develop algorithms to make transportation schedules automatically. Although little attention seems to have been paid to automatic scheduling at the moment, it is helpful to improve the efficiency of transportation scheduling. The other is to develop algorithms that are applicable in various kinds of circumstances irrespective of the differences caused by the specific conditions of the site of application. They proved that the algorithm works quite fast and confirmed its effectiveness through experiments using actual train schedule data.

Finally, Tomii and Zhou (2000) introduce an algorithm that makes depot shunting schedules automatically. One of the characteristics of this algorithm is that it is not dependent upon the specific conditions of depot such as the track layout and other factors.

Papers dealing with the management of the trains splitting are focused on the operations in the hinterland terminals, instead of port area that is the focus of this work. For those interested, see the following reviews: Cordeau et al. (1998), Ahuja et al. (2005), Boysen et al. (2012) and Borndörfer et al. (2018).

4.2. Rail transport in maritime terminals

To the authors knowledge, papers dealing with rail transport optimization problems arising at strategic and tactical level in the maritime terminals are rare.

Concerning the rail yard layout, Gillen and Hasheminia (2018) evaluate the advantege of having a rail yard in the maritime terminal in terms of dwell time. In Xiea and Song (2018), the authors propose an integrated model to optimise the decisions of both container prestaging in a rail buffer and container flow rates in the presence of uncertainties. Flow rates, defined as container movements between the rail terminal and the storage yards, change dynamically over the discharging and loading time windows.

In Schonemann (2010) the transhipment process between ships and railways in German seaports is analysed, pointing out the importance of flow of information in terms of time reduction. These results can have an impact on tactical decisions, for example in defining and implementing new procedures for flow information management.

Caballini et al. (2016) model the movements of containers in the maritime rail terminal area in order to optimise the timings of the trains and the use of the handling resources devoted to rail port operations. In a previous work, Caballini et al. (2012), the authors propose a discrete-time model for optimizing the rail port cycle from the point of view of the containers. In particular, they represent the transfer of import containers from their storage area until their exit from the terminal by train.

This model can be used for evaluating the impact of different terminal handling equipment on the rail process.

At operational level, problems related to the rail operations in the maritime terminal fit into the landside transport optimization and storage and stacking planning processes, as defined in Steenken et al. (2004) and Stahlbock and Voss (2008). The main problems concern the management of the storage area and the definition of trains loading plans. Concerning the storage yard operational strategies in container terminals, a deep analysis is proposed in Carlo et al. (2014). The authors mainly refer to export containers. The main decisions in the yard include storage and retrieval of containers, in particular, storage assignment of containers and dispatching and routing of material handling equipment. Rarely studies refer to the rail yards in maritime terminals.

The major part of literature focuses on the train load planning problem. Steenken et al. (2004) define it as the problem of determining on which wagon a container has to be placed; this decision generally depends on the destination, type and weight of the container, the maximum load of the wagon and the container location in the storage area.

A review of the models proposed for defining the train load planning problem is presentd in Heggen et al. (2016). The first study on train loading problem in a maritime terminal extended the work of Bruns and Knust (2012) for including some aspects related to the storage of containers. In a sea terminal context is essential to combine the aim of maximising the train utilisation, minimising the unproductive operations in the terminal, with particular attention to the rail storage yard (minimising the reshuffles in the storage area (Ambrosino et al. (2011))), and minimizing the equipment utilization (unproductive movements of cranes) (Ambrosino and Siri (2015)). Anghinolfi and Paolucci (2014) consider a sequence of trains with different destinations with the aim to minimise the distances between the container locations in the storage area and the assigned wagons extending the model presented in Ambrosino et al. (2011). Mantovani et al. (2018) study the double-stack load planning problem, characteristic of North America intermodal railway terminals. The authors include in the analysis and in the proposed optimization model complex loading rules that the load plan must satisfy and that depend on specific container and railcar characteristics.

5. Conclusions

This paper focuses on a particular node of the intermodal freight chain of transportation, i.e. the maritime port area that represents the link between rail and sea transportation modes.

This paper aims at describing the optimization problems arising in the rail process of the port area, together with the few related literature.

The purpose of the paper is attract the researchers attention to a process rarely addressed yet, which presents some interesting challenges for optimization field.

After having described the rail process in Section 2, in Section 3 the possible optimization challenges at different decision level (strategical, tactical and operational) are discussed. In Section 4 the literature review on rail operations in the port area is presented.

Subsection 4.1 is related to the rail operations in the shunting zone. Few papers address the rail shunting operations related to the management of cars/wagons only thanks to simulation models (while these problems are well studied for inland terminals). When the shunting operations concern the whole train, the scheduling (and re-scheduling) of the shunting operations is described and some solution approaches are discussed; this problem is only faced from a container terminal point of view.

The rail operations in maritime terminals, discussed in Subsection 4.2, are more studied than rail shunting operations. The storage management is addressed with particular attention to export containers. The rail yard storage management has received less attention, even though the importance of having one or more rail yards in the maritime terminal is emerging in recent studies. In fact, the loading of trains is strongly affected by both the storage of the cargo in the yard and the distance of the yard from the tracks. On the other hand, the train load planning problem is the most studied one.

Optimization models for improving the efficiency of the whole rail process of the rail-sea terminals are necessary. The challenges that we presented in the present work should be more studied and addressed in the future in order to improve the management of this important intermodal node.

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