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An allocation-scheduling heuristic to manage train traffic in an intermodal terminal

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ABSTRACT

Intermodal terminals are responsible for assigning routes to freight trains entering and leaving the facility, for establishing priority rules when there exist potential conflicts between trains, and for re-planning operations in the event of an incidence. Seeking to automate this process and to increase the efficiency and capacity of the system, we propose here a heuristic method to assign destination points inside the terminal to the inbound trains and to schedule the movements of inbound and outbound trains so that the delays derived from conflicts are minimized. This procedure, combined with navigation and ground hardware, has been implemented in the Seville port in Spain, and is successfully tested here for a series of congested scenarios.

1. Introduction

The movement of freight trains that enter or depart from intermodal terminals can be a complex planning problem, incorporating waiting times and inefficiencies into an intermodal chain where the pursuit of efficiency is constant to compete against door-to-door road transport and against other neighboring terminals. With intermodal terminals increasingly bigger, more complex and more congested, the operation of trains may represent an additional bottleneck, causing unnecessary delays and synchronization problems. Furthermore, an unexpected incidence occurring in the network requires the re-planning of the whole schedule in a matter of minutes, with important inefficiencies resulting again from suboptimal solutions. Terminal operation planners often accomplish the scheduling of freight trains by hand, which combined with the safety policies in operation usually leads to an "one train at a time" scenario, where new trains are not given permission to start moving until the precedent train has reached its destination inside the terminal or left the terminal's network.

Nevertheless, the official safety requirements for these internal terminal networks are far from comparable to the ones applicable to passenger rail networks, for instance, where two trains cannot share a line segment or where safety distances are forcefully large. Inside intermodal terminals, operational speeds are relatively low (often down to a man's pace), and the responsibility to establish safety standards corresponds to the terminal itself, which allows managers to seek a more efficient approach without necessarily adding any risk to the system. But having several trains moving at the same time and assigning much shorter time slots requires much more detailed planning and monitoring of the network, and also requires the ability to re-plan operations as quickly as possible in case an incidence occurs.

Another characteristic of the operation of trains in intermodal terminals is the flexibility of their destination. A given berth, stacking yard or transshipment area may be serviced by several lines, accessible through different routes, and therefore the assignment of destinations and the planning of routes or trains adds further complexity to this scheduling problem. Terminal managers need to assign destinations to the different trains, and then organize their entry and exit schedules and routes so that the system is free of conflicts between trains. Given this complexity, the incorporation of OR techniques can be extremely beneficial to this decision-making process.

We propose here a methodology based on a backtracking algorithm to assist in this planning process. This methodology efficiently assigns destinations to trains, builds the schedule of entries and exits, and organizes the route to be followed by each train. The application of this methodology is illustrated for the port of Seville, an inland tidal terminal in the South of Spain seeking to increase its rail capacity to increase its competitiveness in Spanish and European intermodal corridors. We use simulation to test and validate this methodology with increasingly congested scenarios,

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proving the efficiency of the solutions it provides. The methodology can be used by terminal managers to plan their daily schedules or to re-plan operations in real-time in case of an incidence, recalculating routes accordingly and assigning new destinations and new schedules to the remaining trains.

The structure of the paper is organized as follows: in the following Section 2 we review the existing literature on the management of transport operations in terminals, showing why the operation of trains needs to be faced as a novel type of problem with distinctive characteristics. Then Section 3 describes our proposed system to optimize that type of train operation, with the details of the different modules of the algorithm in Section 4, and of the simulation of the case study used to validate it in Section 5. The paper ends with an analysis of the results obtained from the simulations and the conclusions in Section 6.

2. Managing transport in intermodal terminals

The operation of train movements in an intermodal terminal is a type of routing-scheduling problem, similar to other planning problems involving transport means in logistics terminals. These problems have common features, like the consideration of arrival times, service times and capacities, deadlines, etc., but also involve some specific characteristics that distinguish the basic formulation of each type of problem. These characteristics are the following:

- Route planning: expresses whether the problem in question requires the definition of some type of route between an origin and a destination, as opposed to the situation where it suffices to simply indicate what the origin and destination of the transport operation will be.
- Avoidance of interferences: indicates whether the planning of the transport operation needs to take into account the possibility of segment capacity, deadlocks, blockages, conflicts, etc., in order to avoid them.
- Flexible destinations: transport operations with this feature can choose their destination from a range of possibilities, thus expressing that the operation really consists of a combination of destination allocation and movement towards that destination.
- Flexible loads: appears when the decision regarding what transport element carries what load needs to be taken. Again, the operation is a combination of load allocation and movement.

Table 1 contains a classification of the main transportation problems that may arise in the management of a freight terminal, according to the above four characteristics. It includes the consideration of different transport modes, from vessels or trains to trucks or other transport elements like AGVs or straddle carriers. This table shows why the management of trains in intermodal terminals is different in nature from other vehicle scheduling problems, and should therefore receive specific consideration.

With respect to vessels, [20] offer a thorough review of the different models and solution methods applied to the berth allocation problem (BAP), seeking to determine which berths are the best to receive the incoming vessels at a port terminal. Despite being a well-analyzed problem, over the last years the BAP has evolved towards a combined formulation with the quay crane scheduling problem [3].

Truck fleet planning is present in many forms, which may or not include route planning, in the management of transport operations at a freight terminal. Crossdock scheduling [4] constitutes a typical combinatorial optimization problem, where the objective is to allocate load/unload bays to trucks at a cross dock terminal and also to determine the service sequence for the different inbound and outbound trucks involved [6]. This problem is therefore similar to the integrated scheduling of an intermodal terminal, with inbound and outbound shipments that need to be synchronized with the customer-fixed timetables and an in-between inventory that should be kept within bounds [27].

The planning of internal truck fleets, carrying containers to and from the storage yard, is also present in intermodal container terminals. This problem does not differ essentially from a classical VRP formulation with a set of transportation jobs with sequence-dependent processing times and different ready times to minimize the makespan of all the jobs [33]. Its differentiation comes from its integration with quay crane scheduling [24], with yard crane scheduling [9] or with the storage allocation problem [28], in case the desired location of containers in the yard is not determined beforehand. With respect to the operation of hinterland drayage fleets, trucks can be assigned to a large variety of tasks, carrying full and empty containers between shippers, receivers and the terminal [22]. The formulation of these problems can benefit from the sophistication present in other VRP types, including dynamic re-planning according to real-time information updates [15], the consideration of several depots [34] or the possibility of incorporating appointments to improve terminal efficiency [47]. Finally, the planning of AGVs and straddle carriers is analyzed by [11], with [18] concentrating on the avoidance of deadlocks in the case of AGVs.

According to our classification, the operation of trains in intermodal terminals has distinctive characteristics as an optimization problem, combining route planning, the need to avoid conflicts in the traffic arising when several trains are operating in the same network at the same time, and a certain degree of flexibility in the assignment of destinations, when the same train can be serviced in different locations inside the terminal. However, and despite its relevant role in the landside connection of intermodal terminals, the most complete review works related

Table 1
Classification of transport problems arising in a freight terminal with respect to their distinguishing characteristics.

Type of vehicle	Type of problem	Problem characteristics			
		Route planning	Avoidance of interferences	Flexible destinations	Flexible loads
Vessels	Berth allocation			X	
Trains	*Train operation in intermodal terminals*	X	X	X	
	Shunting yard operation			X	
Trucks	Cross dock allocation and truck scheduling			X	X
	Terminal truck operation	X		X	X
	Hinterland truck operation	X			X
Other	AGV fleet operation	X	X		X
	Straddle carrier operation		X		X