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TOWARDS A SIMULATION-BASED DECISION SUPPORT TOOL FOR CONTAINER TERMINAL LAYOUT DESIGN

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ABSTRACT
Recently, seaports have paid much attention to container transportation by rail to evacuate huge container flow received by sea. In this line, Le Havre seaport, as the first French port in terms of containers' traffic, plans to put into service a rail-road terminal near the Paris region. The main purpose of this new inland terminal is to restrict the intensive use of roads on the Le Havre-Paris corridor and achieve a better massification share of hinterland transportation. Containers are routed by train between Le Havre and this terminal and the last/first mile remains done by trucks. This paper aims to propose a decision support tool based on simulation for the layout design problem of this new terminal. This tool is tested using a set of scenarios and the obtained results are then discussed.

Keywords: Modelling, Discrete event simulation, Decision support tool, Rail-road terminal, Layout design problem

1. INTRODUCTION AND LITERATURE REVIEW

Nowadays, some ports seek to achieve a better massification share of hinterland transport by promoting rail and river connections, because containers are moved massively to and from ports at economic costs and in more environmentally friendly manner than road mode. However, they are only profitable over long-haul destinations (Boysen et al. 2010). Besides, geographical constraints heavily penalize rail and river modes, since pre- and end-haulage of containers by road is needed to reach the final destination. In Europe, and particularly in France, the predominance of road-only culture is obvious for door-to-door transport (see Figure 1). In order to restrict this intensive use of roads, the European Union, since recent times, encourages environmentally friendly transport mode as part of a long-term strategy that aims to reduce greenhouse gas emissions (Woodburn 2013), thus executing container transportation in an ecologically efficient way.
Following this strategic vision of green transport, the massification of door-to-door transport has become a core concern for Le Havre seaport authority. The aim is

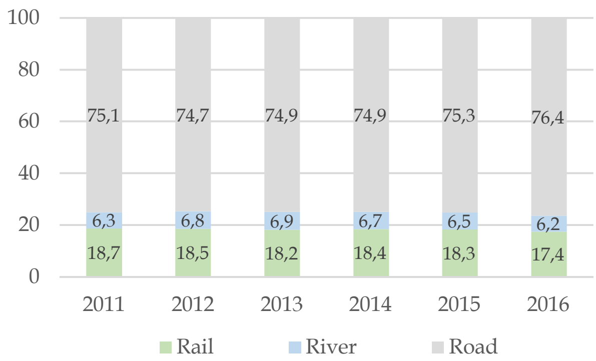

Figure 1. Modal split of inland freight transport in 2011-2016. Source: (Eurostat, freight transport statistics 2019)

to achieve a better massification share of hinterland transport, which is currently quite weak compared to that of its major competitors in the northern European range, such as Hamburg, Rotterdam, Bremen, etc. To this end, recently the GPMH (Grand Port Maritime of Le Havre) put into service a multimodal terminal that acts as a link between the port and its hinterland. In addition, to provide a more cost-attractive transportation service by rail between the multimodal terminal and Paris, the GPMH plans to build a new rail/road terminal near the Paris region (Figure 2). The main objective is supplying containers as close as possible to their final destinations by rail in order to reduce the part of road mode.
This new rail/road terminal is a logistic platform with two interfaces (railside and roadside) and an operating yard. Import containers (inbound flow) arrive at the terminal by railside on mainline trains and leave terminal by trucks for the last-mile distribution to customers. Conversely, export containers (outbound flow) are delivered to the terminal by trucks and moved to Le Havre seaport by mainline trains. In the operating yard, containers move from trucks to trains and vice-versa, and some of them might be stacked temporarily in storage spaces, called buffers, waiting for further transportation. This yard includes transshipment tracks for trains, driving lanes for truck traffic and transfer points for handling operations on trucks. The railside is equipped with holding tracks for receiving, disassembling and reassembling of mainline trains, and the roadside

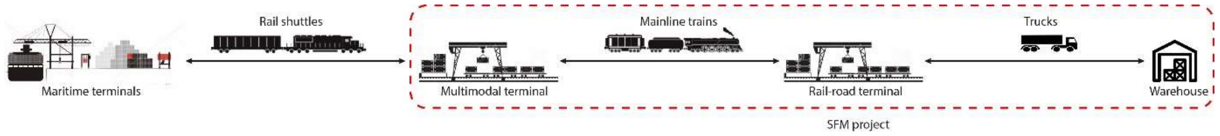

Figure 2. The proposed door-to-door container-transportation service between Le Havre and Paris.
*SFM: Service Ferroviaire Modulaire Project

contains entry and exit gates, a gauge control gate where the physical control of the container takes place, parking lots for waiting trucks and traffic lanes.
The literature is full of studies addressing container terminal problems (Stahlbock and Voß 2008), however, the majority of research focused on maritime terminals because seaside operations are the most complex ones, besides specific papers on rail/road terminals are scarce. Container terminal' layout design problem has been widely addressed particularly using simulation-based decision support tool. However, most papers have focused only on strategic and tactical decisions, (Ballis et Golias 2002), (Lee et al. 2006), (Lee et al. 2008), (Benna et Gronalt 2008), (Caballini et al. 2009),(García et García 2012), (Cartenì et de Luca 2012), (Leriche et al. 2015) et Chen et al. 2018), a few ones have included operational decisions in their models (Liu et al. 2002) and (Sun et al. 2013). Indeed, it is important to take into consideration all decision levels because they influence each other, i.e., decisions made at a higher-level influence those at lower-levels and vice versa. In addition, most reviewed papers used only one types of handling equipment (for example, gantry crane, reach stacker, etc.), although it would be interesting to evaluate container terminal layout with different types of equipment to figure out which one fits with the designed layout.
The objective of this study is to develop a simulation-based decision support tool that allows wide flexibility in terms of equipment and resource choices. Moreover, this tool evaluates the designed layout according to the incoming container flow as well as the handling rules and management policies to be used in the terminal. As perspective, we plan to integrate into our simulation model, a heuristic based approach for container processing problems (unloading-loading and storage-retrieval of containers), internal equipment scheduling and resource allocation.
This article is a part of work done under the project SFM (''Service Ferroviaire Modulaire'': modular rail service). In this project, we also focused on the optimization of container drayage by trucks. Here, we introduce only the connection with the optimization model, more details will be given in (Benantar et al. 2019).

2. SIMULATION-BASED DECISION SUPPORT TOOL

2.1. Discrete event simulation model

Container terminals are dynamic and distributed platforms where containers are received from multiple modes of transportation and are then subjected to diverse operations that are linked to each other. Simulation is a suitable approach to study this kind of complex system. It offers the possibility of analyzing system behavior to a given action over time, also simulation makes it possible to check what is theoretically valid is actually applicable and priori will have the expected effects. Designing a simulation model for a complex system requires a modeling approach, i.e., a roadmap to build the model. In this way, the conception of our model was guided by an iterative approach with a set of steps: analyze, design, implementation, and verification. This process is iterative because, for example, in the implementation step one can notice that certain insights or assumptions included in the first step are incomplete or erroneous. More details are given in (Abourraja et al. 2018a).
The proposed simulation model for the studied rail/road yard is illustrated in Figure 3. This model is made up of three main processes, namely, train transportation process, terminal management process, and truck transportation process. These processes include all activities related to receipt and departure operations of transportation mode, resource allocation, internal equipment scheduling and deployment, handling tasks assignment, storage space management, handling operations and container flow generation.
Train transportation process concerns the generation of day-to-day incoming trains and import containers flow. Trains are injected into the simulation model at each arrival moment. Containers are loaded on trains according to the following parameters: container arrival date and size, maximal filling rate and length of trains, and the number of trains per day.
Each incoming train is broken up in smaller fragments called "coupons" (i.e., a set of railcars) at the Railside (Figure 4). A handling schedule of all coupons is established to decide on which coupon is to be moved first and so on, and then one by one, coupons are pushed over a link track to the operating yard. Afterward, handled coupons, called full coupons, return back to their respective holding track where they are assembled with the existing full coupons to make an outgoing train to Le Havre seaport. When the departure time is reached, mainline trains leave the terminal.
As regards trucks, they arrive at the terminal through entries gates, then those with containers (full trucks) move first towards the check gate while the unladen ones (without containers) go directly to their position within the terminal. For loading or unloading operations of a truck, a vacant transfer point in the operating yard is assigned, otherwise, all transfer points are busy, the truck is forwarded to the parking area and once one becomes available again, it is assigned to the truck. Besides, if the container to be loaded on a truck is not yet arrived at the operating yard, the truck must wait for it in the parking

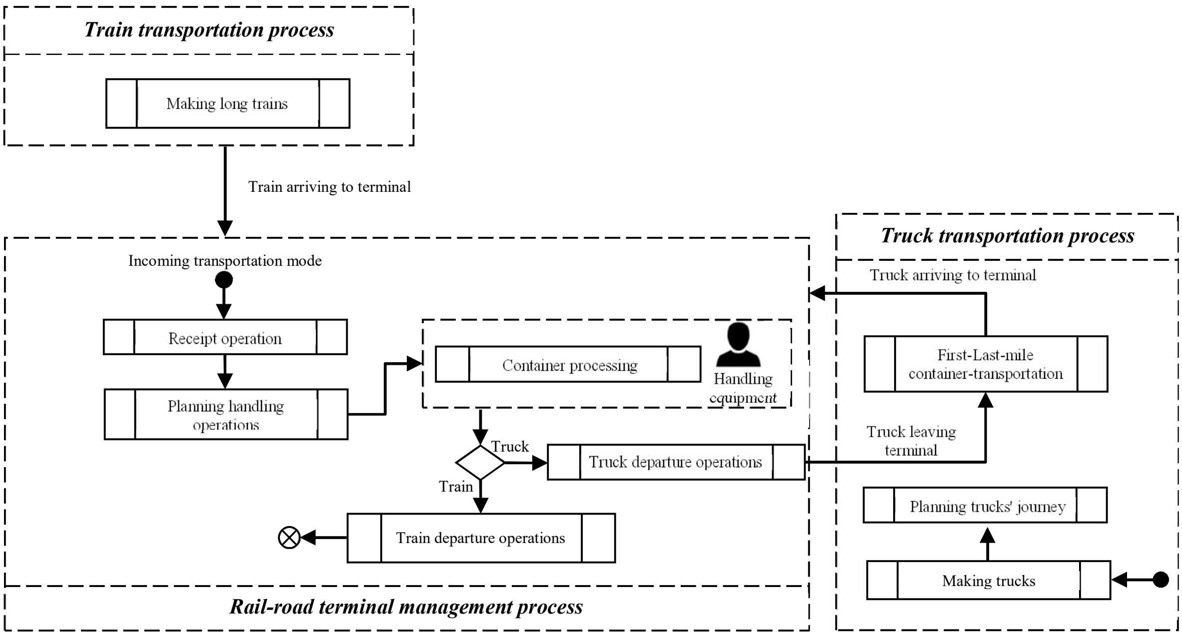

Figure 3. Simulation model

area. When the handling operations are performed, the truck moves to the exit gate of the terminal.

Container moves between trains and trucks are processed in the operating yard by handling equipment. Handling equipment carries out loading and unloading tasks according to the chosen handling rule. A container is picked up from a transportation mode or a buffer and then dropped off either on another transportation mode or on a buffer. In the buffer, the containers are conventionally grouped by departure date, size, flow type, outgoing transportation mode, or a mix of criteria, etc., see (Abourraja et al. 2017) and (Abourraja et al. 2018b).

The last process concerns export containers flow and deals with trucks routing problem, it plans a journey route each day. This decision depends on the daily container flow to be delivered and/or collected to/from customers in addition to the availability date of each container. More details about this process will be given in (Benantar et al. 2019). Resources allocation to transportation mode is ruled by FIFO policy, and trucks have priority during handling operations, so they can leave the terminal as quickly as possible.

2.2. Decision support tool design

The decision support tool is designed based on the simulation model and it is implemented on Anylogic simulation software. The tool contains three modules, namely, layout settings, simulation settings and dashboard.

The first module is to set parameters for all facilities needed to build the layout. As described above, the terminal includes three areas: railside, operating yard and roadside, each of them consists of a set of elements. These elements are defined by the following parameters: dimensions (length, width), number, stack height, and equipment type. The first parameter concerns rail tracks, container slots, buffers, parking lots and driving lanes. Number is a common parameter, and the last parameters are for buffers and handling equipment, respectively.

The second module adjusts simulation parameters, such as arrival rate of transportation modes (timetables), motion speed, handling times for loading and unloading operation, service time at the terminal gate, inspection time at gate control, and handling and management rules. These parameters have a significant impact on how operations are progressing into simulation runs. In reality, the values of these parameters are not known with certainty because they are related to humans and system behavior; there are only estimated values (Cartenì and de Luca 2012). Thus, the randomness is introduced in the simulation model to evaluate terminal designed layouts under different scenarios.

The dashboard module is used to report simulation outcomes. The obtained results help users to make reasonable decisions about terminal facilities (equipment and infrastructure) that might be used to serve on time the incoming transportation mode and container flow. The results concern equipment' activity and utilization, trains and trucks turnaround times inside the terminal, and the used capacity of the sized resource. A design is accepted if all mainline trains and trucks are served during the working day and container delivery delays are avoided. In addition, from the used capacity metric, the designed tool determine the needed entrance/exit gate, transfer points, buffers, handling equipment, parking lots and containers slots. For example, if the used capacity of parking is 50 %, we deduce that only the half of the parking positions is sufficient to receive the incoming truck fleet.

3. EXPERIMENTS AND RESULTS

Different scenarios are tested (Table 1). The estimated container flow per day is between 78 and 98 FEU (only forty-foot equivalent unit containers are considered in the model) on import and export. Each day one train arrives at the terminal at midnight and leave soon the next day. A train can be composed of six or seven coupons of seven

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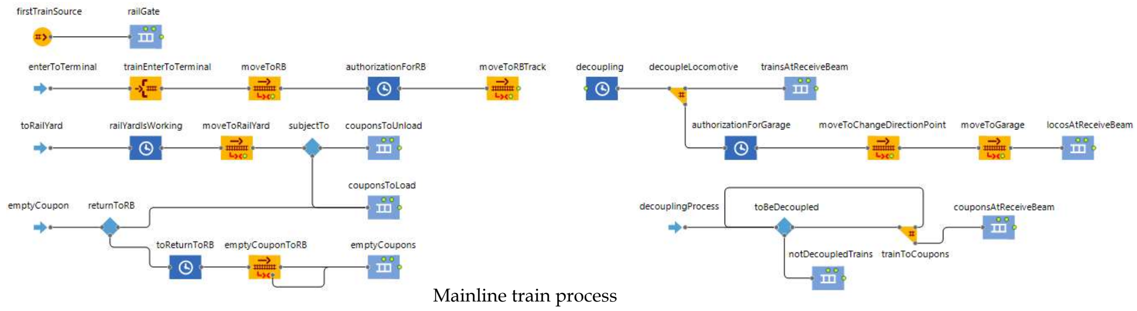
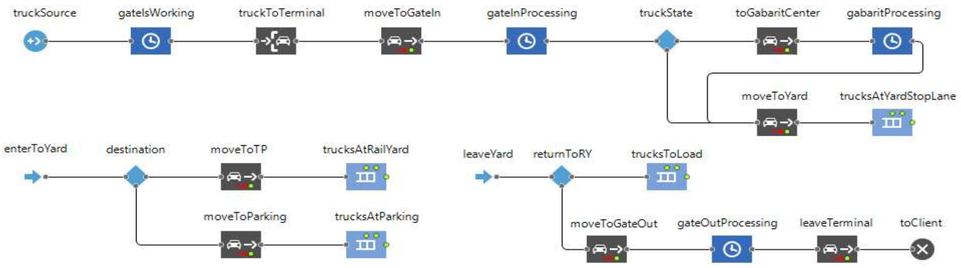


Mainline train process



Truck process

Figure 4. Trains and trucks activities diagram

wagons. Whereas the number of trucks varies from day to day according to import and export container flow, and they start arriving at the terminal after 6h am. The terminal will operate using one of the following working shifts: (1) [00:00 - 05:00] - [06:00 - 20:00] named separate shifts; (2) [06:00 - 13:00] - [13:00 - 20:00] named joined shifts. In the first working shift, trains are served between midnight and 5 am, and trucks are unloaded and loaded within the second part. While, in the other working shift, both of them are handled simultaneously. This data was collected from documents provided by Le Havre Port Authority. Table 2 exposes input values for design parameters, the designed tool run on these values to determine the needed resource for each scenario. All the experiments were carried out by using simulation' parameters reported in Table 3, more details are given in (Cartenì and de Luca 2012). The used handling rules in this paper are explained in (Leriche et al. 2015).

Figure 5 plots the obtained results for each scenario and Figure 6 gives a simulation screenshot. In the real-world yard, import and export containers are stacked in separate buffers, however, although some terminals use mixed storage mode, import and export containers are not put on top of each other. In this study, separate storage mode

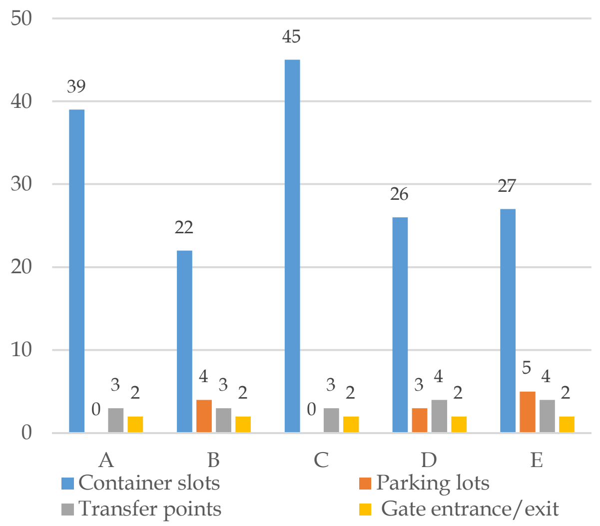


Figure 5. Scenarios results

is used. As can be seen from Figure 5, scenarios A and C need more container slots than other ones. The reason behind this is the usage of the separate working shifts. Indeed, with these working shifts, all containers are first moved to buffers before later being loaded on their respective transportation mode, that is, only double handling moves are performed. Whereas, in the other

Table 1. Simulation scenarios

Scenarios	Container flow (TEU)	Trains per day	Train start arrival	Train dimension (coupon x wagons)	Trucks per day	Trucks start arrival	Work shifts
A	78	1	00:00 h	6 x 7	45	06:00 h	[00:00 - 05:00] - [06:00 - 20:00]
B	84	1	00:00 h	6 x 7	45	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]
C	90	1	00:00 h	7 x 7	48	06:00 h	[00:00 - 05:00] - [06:00 - 20:00]
D	95	1	00:00 h	7 x 7	54	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]
E	98	1	00:00 h	7 x 7	54	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]

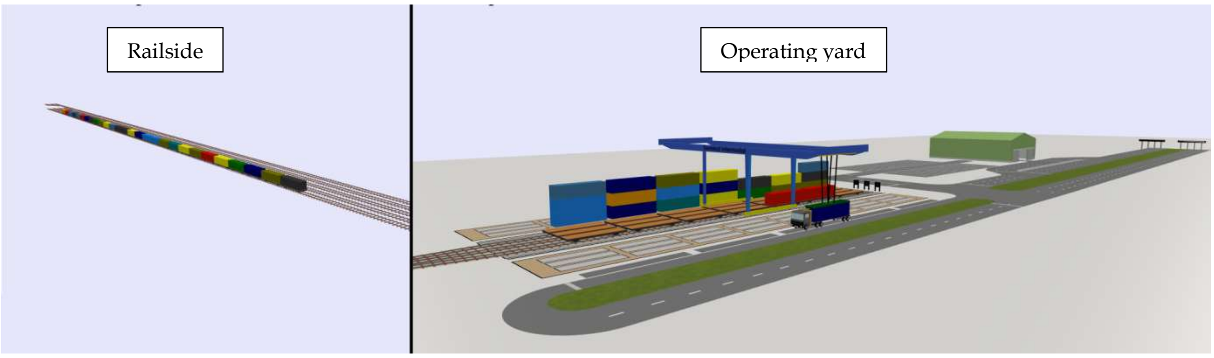


Figure 6. Simulation screenshot

scenarios (B, D and E), direct container moves from train to truck or vice-versa are also carried out by handling equipment. It is also obvious that in scenarios A and C there is no need for parking positions since all import containers are already waiting for trucks at buffers, thus trucks move directly to the operating area to be unloaded and loaded. As regard transfer points and gate entrance/exit, they are fairly similar for all scenarios. We can also notice that the required transfer points increase with an incoming truck fleet and container flow growth. As regard handling equipment, the workload and the distance traveled are more important in the case of separate shifts, because equipment has to move twice per each container. In spite of that, these shifts minimize the turnaround time of transportation mode and allow rapid evacuation of containers to their destination.

4. FUTURE AND CURRET WORKS

4.1. Connection to the model of container drayage by trucks

The optimization model (see (Benantar et al. 2019)) plans the working journey for each truck. This decision depends on the daily container flow to be delivered and/or collected to/from customers in addition to the availability date of each container. This planning is introduced into simulation via "Truck transportation process". The simulation in turn recalculate the availability date for each import container and provides these dates as input data for the optimization model to produce a new trucks planning in the next iteration. The availability date is specified when an import container arrive to the operating yard, that is, the container is ready to be loaded on its respective truck.

Table 2. Input data

Container slots per buffer	Parking lots	Transfer points	Gate entrance/ exit
96	15	5	3

4.2. Further improvements to the simulation model

To improve our simulation model, we are developing an optimization approach for container processing in the operating yard. This section describes briefly this approach. In this yard, handling equipment moves containers across the yard from their pick-up position to their drop-off position. A position might be a railcar position, a container slot in a stack or a transfer point. In addition, a container has one origin position, one or more intermediate positions, and one target position. The origin and target positions of an import container are a railcar position and a transfer point, respectively, whereas it is the opposite for export containers, i.e., they are transferred from a transfer point (origin) to a railcar position (target). The intermediate position can be only a container slot and in the case of reshuffling, containers move from one to another. Therefore, to decide on the containers' position in the operating yard over the working days, the following problems must be resolved:

- Container storage problem: assign containers to blocks, i.e., container-to-block allocation, and assign containers to specific locations within the selected block, i.e., container-to-slot allocation (Carlo et al. 2014).
- Train un/loading problem: consists in determining the best assignment of export containers to railcar positions.

Table 3. Simulation settings

Motion speed	Crane speed	$\bar{x}$=11.498 and s=4.586 km/h
	Train speed	6 km/h
	Truck speed	12 km/h
Handling time	Crane time to get a container from a shuttle	$\bar{x}$=0,888 and s=0,352 min
	Crane time to get container from stack	$\bar{x}$=0,769 and s=0,380 min
	Crane time to get a container from a truck	$\bar{x}$=0,888 and s=0,352 min
	Crane time to put container in shuttle	$\bar{x}$=1,331 and s=0,434 min
	Crane time to put container in stack	$\bar{x}$=0,760 and s=0,309 min
	Crane time to put container in truck	$\bar{x}$=0,888 and s=0,352 min
Service time	At gate entrance	$\bar{x}$=2 and s=1 min
	At gate control	$\bar{x}$=10 and s=4 min

- Transfer-point-to-truck assignment: consists of assigning export and import containers to transfer points where they will be pick-up from and collected by trucks, respectively.

To provide solutions solving whole problems together, we are developing a genetic algorithm. Because, the three described problems are fairly similar. Genetic algorithm (GA) is chosen because it is suitable for these kinds of problems. The proposed algorithm is based on rolling horizon approach, that is, at each planning epoch, the algorithm draws a 3D matrix that indicates the position (or positions) of each incoming or existing container in the operating yard.

5. CONCLUSION

This paper has focused on layout design for a new rail-road terminal. To this end, first, a simulation model is designed, second, upon this model, a decision support tool is built to size terminal layout under different scenarios. Then, the obtained results are reported and discussed. As can be seen, the designed tool needs improvements, so as perspective we plan to integrate in our simulation model, an optimization approach for container processing (unloading-loading and storage-retrieval of containers), internal equipment scheduling and resource allocation. Moreover, an optimization model for container delivery and pickup by trucks is developed and it will be coupled to our simulation model.

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