IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received April 18, 2017, accepted May 25, 2017, date of publication July 11, 2017, date of current version July 31, 2017.

Digital Object Identifier 10.1109/ACCESS.2017.2713246

A Multi-Agent Based Simulation Model for Rail–Rail Transshipment: An Engineering Approach for Gantry Crane Scheduling

MOHAMED NEZAR ABOURRAJA[1,2], MUSTAPHA OUDANI[3], MOHAMED YASSINE SAMIRI[1,2], DALILA BOUDEBOUS[2], ABDELAZIZ EL FAZZIKI[1], MEHDI NAJIB[3], ABDELHADI BOUAIN[1], AND NAOUFAL ROUKY[2]

[1]Cadi Ayyad University, Marrakesh 40000, Morocco
[2]Normandy University, UNIHAVRE, 76600 Le Havre, France
[3]Private University of Marrakesh, Marrakesh 42312, Morocco

Corresponding author: Mohamed Nezar Abourraja (abourraja.mednezar@gmail.com)

ABSTRACT Le Havre Port Authority is putting into service a multimodal hub terminal with massified hinterland links (trains and barges) in order to restrict the intensive use of roads, to achieve a more attractive massification share of hinterland transportation and to provide a river connection to its maritime terminals that do not currently have one. This paper focuses on the rail–rail transshipment yard of this new terminal. In the current organizational policy, this yard is divided into two equal operating areas, and, in each one, a crane is placed, and it is equipped with reach stackers to enable container moves across both operating areas. However, this policy causes poor scheduling of crane moves, because it gives rise to many crane interference situations. For the sake of minimizing the occurrence of these undesirable situations, this paper proposes a multi-agent simulation model including an improved strategy for crane scheduling. This strategy is inspired by the ant colony approach and it is governed by a new configuration for the rail yard's working area that eliminates the use of reach stackers. The proposed simulation model is based on two planner agents, to each of which a time-horizon planning is assigned. The simulation results show that the model developed here is very successful in significantly reducing unproductive times and moves (undesirable situations), and it outperforms other existing simulation models based on the current organizational policy.

INDEX TERMS Le Havre seaport, container terminal, multi-agent system, engineering strategy, crane interference, modeling and simulation.

I. INTRODUCTION

In recent years, the container has become an important asset in multimodal cargo transportation. It has contributed extensively to the sustainable development of supply chains by improving the transportation conditions of goods and handling operations. Furthermore, container flow around the world has undergone exponential growth, especially in recent decades, increasing from 120 million TEU (twenty-foot equivalent unit) in 1994 to 679 million TEU in 2014 [1]. However, in 2009, a slight decline was recorded in world-wide container port traffic as a result of the economic crisis in 2008. This fast growth containerized cargo is due to the revolution in global trade and the rapid development of industrial sectors, especially within economically strong and stable countries.

On the other hand, the main concern of logistic service providers is to ensure smooth and secure transportation for the container at a low price. In addition, door-to-door transportation for the increasing traffic of containers shipped by sea requires a reliable and efficient port-hinterland connection (by road, rail and river). In general, the road-only culture predominates [2]. The attractiveness of this mode arises from its flexibility, reliability and reasonable cost. Recently, some ports have sought to promote massified transportation in order to reduce greenhouse gas emissions [3], which are a drawback of road transportation. In line with this vision of transportation, Le Havre Port Authority is putting into service a multimodal terminal linked only with massified hinterland connections in order to limit the heavy use of roads and to improve its massification share of hinterland transportation, which is currently much lower than that of its major competitors in the northern European range (Rotterdam, Hamburg, Antwerp, Bruges-Zeebrugge and Bremen) [4]. This new multimodal terminal (MMT) acts as a hub for several maritime terminals (MTs) of Le Havre port through an efficient scheduling of the intra-port transfer activity of containers by rail shuttles.

Operations management and resource allocation within container terminals are laborious and complex tasks. Indeed, the dynamic and distributed nature of these platforms, the diversity and complexity of handling operations, and the uncertainty and lack of information needed to control the containerized flow complicate the decision-making process. Handling processes are governed by a set of time and space constraints which aim to optimize the use of the available resources in order to derive maximum benefit and to guarantee the container's delivery time. However, the annual growth in container flow causes many problems for container terminals, mainly the avoidance of landside congestion and the receipt of new container ships with high capacity. To deal with these problems, container terminals must adopt an operating system that allows efficient scheduling of handling tasks in order to speed up container processing.

A common issue in terminal operating areas is crane interference. In real-world yards, container handling cranes move on the same track to carry out non-preemptive jobs on transport vectors. A job involves handling a container from a given area on a transport vector. Crane arms cannot be crossed, that is, they cannot perform adjacent jobs simultaneously, and a minimum safety distance must be kept at all times. If an interference situation emerges, one crane must wait for the other to move away before achieving its remaining jobs. Much research in recent years has addressed this problem with various non-crossing constraints [5], [6]; despite this, little attention has been paid to gantry cranes in rail yards.

In the present paper, we propose a simulation model for the rail yard of the MMT. This model is based on two planner agents, to each of which a time-horizon planning is assigned. Additionally, we focus particularly on reducing unproductive moves and on minimizing undesirable situations, such as those in which cranes are waiting (unproductive times). In this way, we design an improved scheduling approach for gantry crane interference problem. This approach contains a novel partition mechanism for the rail yard with a new configuration that eliminates the use of reach stackers involved in the container exchanges between crane areas. Using a numerical study, the developed model is evaluated and compared to other existing simulation models for the MMT. The simulation results show that our model is very successful in significantly reducing unproductive times and moves, thereby improving the productivity of rail gantry cranes.

The rest of the paper is organized as follows. Section II provides a brief description of related works. Section III describes the multimodal terminal of Le Havre seaport. Sections IV describes the design of the proposed multi-agent based simulation model. Section V presents the scheduling approach for gantry cranes. The process of model implementation is illustrated in Section VI. This is followed in Section VII by a discussion of the simulation results. The final section summarizes this paper and highlights future work.

II. RELATED WORKS

Modeling is a concrete or conceptual representation that makes a complex and dynamic system easier to understand [7]. Various modeling techniques have been used to go from the informal description to the formal specification of a given system (e.g. object-oriented modeling, agent-based modeling, Petri net, cellular automata, etc.). On the other hand, the simulation allows the modeler to check whether the designed model reflects the expected behavior of the studied system as accurately as possible. Moreover, it offers the possibility of ascertaining the reaction of the simulated model to a given action [8].

Bielli *et al.* [9] developed an object-oriented simulation model for the container terminal of Casablanca in an attempt to provide a decision support system for terminal managers. Wiegmans [10] developed a dynamic simulation model in ARENA to compare the performance of various rail-rail exchanges. Ottjes *et al.* [11] provided a simulation model based on elementary functions (transfer, transport, stacking) to compare three forms of inter-terminal container transportation within the Rotterdam-Maasvlakte terminal. Likewise, in the paper by Benghalia *et al.* [12], the authors designed a discrete event simulation based on an object model for comparing and evaluating three modes of container transfer between maritime terminals and the multimodal terminal of Le Havre port. Dubreuil [13] used an ARENA simulation tool to describe and analyze the handling operations of a container terminal. Cartenì and de Luca [14] proposed several microscopic discrete event simulation models for a container terminal. These models share the same logical architecture, but differ in the way in which handling activity time duration is estimated. Validation was carried out by analyzing the local and global indicators of each model. Finally, the authors compared their models in order to find the best one. Leriche *et al.* [15] studied the economic and strategic interests of the MMT of Le Havre using a multi-method simulator (Anylogic).

Henesey [8] used an agent-based simulation model to assess and analyze the impact of operational policies and strategies on container terminal performance. Sun *et al.* [16] built a multi-agent simulation platform called MicroPort to assess the operational efficiency of various designs of container terminals. The structure of MicroPort consists of three layers: (1) the Functions layer contains basic tools to support the higher layers; (2) the Applications layer is managed by a multi-agent system that represents the operating system and ensures tactical and operational decisions; and (3) the Extensions layer acts as an interface with the users. Likewise, Najib *et al.* [17], [18] proposed a multi-agent simulation platform for the TDF (Terminal De France) terminal of Le Havre which involved a high-risk container management process

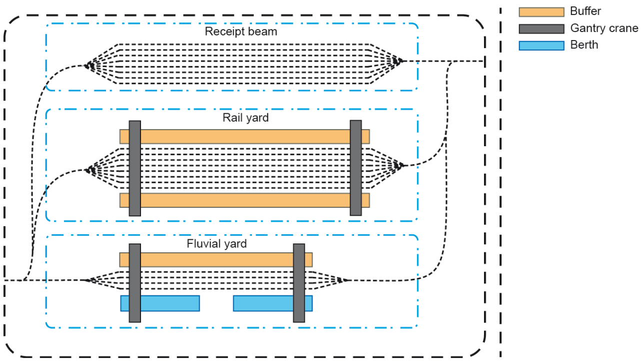

FIGURE 1. MMT.

to target containers with unlawful goods. Fotuhi *et al.* [19] modeled yard cranes as reinforcement learning agents, taking into consideration interference issues.

Petri nets are also employed in the modeling of container terminal operation, particularly to describe the sequence of the activities in container processing as a cycle format [20], [21].

III. MULTIMODAL TERMINAL LOGISTIC SYSTEM

The multimodal terminal (MMT) of Le Havre is an industrial massification platform equipped with two interfaces (landside and waterside) and can handle 200,000 containers per year. It includes three zones (Fig. 1): two operating areas (the rail yard and the fluvial yard) and a receipt beam.

The receipt beam is composed of eight electrified railways for various uses: receiving long trains, sorting and composing rail shuttles, etc. After arriving at the receipt beam, long trains are decoupled from their electric locomotives; following this, they are coupled to their allocated traction unit and then transferred to their target operating area, unlike shuttles that can access an operating area directly. Once a freight train's wagons (a freight train is a long train or a rail shuttle) are on the assigned track, the traction unit is decoupled and moves (or returns) to the receipt beam. The rail yard is designed to receive a maximum of eight freight trains. It is divided between two gantry cranes, spanning all tracks, and two buffers with a storage capacity of more than 1000 TEU. Additionally, according to Boysen *et al.* [22], this rail yard can be considered modern rail–rail transshipment yard of the third generation. This paper focuses on rail yard operations. The fluvial yard is the zone in which containers are loaded onto barges and unloaded from them. It contains four tracks under two gantry cranes, a temporary storage area and a quay 400 meters in length.

Meanwhile, the gantry cranes carry out jobs. It should be noted that a ''job'' is the handling of a container from a given area on a transport vector and is composed of two tasks: a pick-up task and a drop-off task. A job is performed using several actions: firstly, the translational motion of cranes; secondly, the trolley direction; and finally, the pick-up or drop-off movement. Once the handling operations of a train have been completed, the departure operation step is executed. This consists of calling a traction unit either to help long train wagons to reach their electric locomotive and then leave the MMT or to transfer shuttle wagons to their MT.

The intra-port transfer activity of containers via rail shuttles is seen as a key performance indicator of Le Havre port. Several rail shuttles are formed and deployed in each Le Havre port terminal with regard to daily container flow, i.e., the containers to be distributed and collected from the MMT. Moreover, rail shuttles have priority during handling operations since they have a short processing-time window.

IV. MULTI-AGENT BASED SIMULATION MODEL

A multi-agent system (MAS) is a powerful method for research, and is suitable for large-scale and complex problems. A MAS is a distributed and robust system consisting of one or more sub-systems, also called organizations, in each of which several agents communicate, negotiate, and collaborate with each other to achieve specific goals. Agents are computer systems that able to act in an environment via certain behaviors and to adapt their internal states to the changes that take place [23]. Agents may be autonomous and even learn from their experiences or make decisions, in order to efficiently solve a given problem.

Designing multi-agent based model for the operation management of a complex and dynamic system is often a laborious and tedious task, which requires the definition of a modeling approach in order to simplify the design process. In this way, we defined a top-down approach with several steps of specification, conception, implementation and verification-validation. The first step is the capture of requirements and definition of system context. It starts with the highlighting of the external actors related to the system, internal actors acting on the system and internal components existing in the system. Then, the business processes and functional requirements of the system are split into a set of consistent units. Finally, these consistent units and the identified actors are clearly mapped. More details of the business modeling and requirements are given in [24]. The second step concerns agentification, i.e., each system actor is modeled as an agent, and agent-to-agent interactions and agent-to-environment influences are then defined in respect to the relationship between the internal state and external perception of each agent. In addition, agents are classified in this step into two sub-systems based on a coherent functional grouping. The agentification is more described in the paper of Garro and Russo [25]. In the third step, we focus on coding, debugging and running the model using the AnyLogic simulation tool. The final step is the verification and validation of the simulation model to demonstrate its ability to reflect the studied system's behavior.

A. OPERATION CONTROL SUBSYSTEM

The proposed operation control subsystem includes all activities related to resource allocation, operation planning, equipment and transportation vector deployment and container

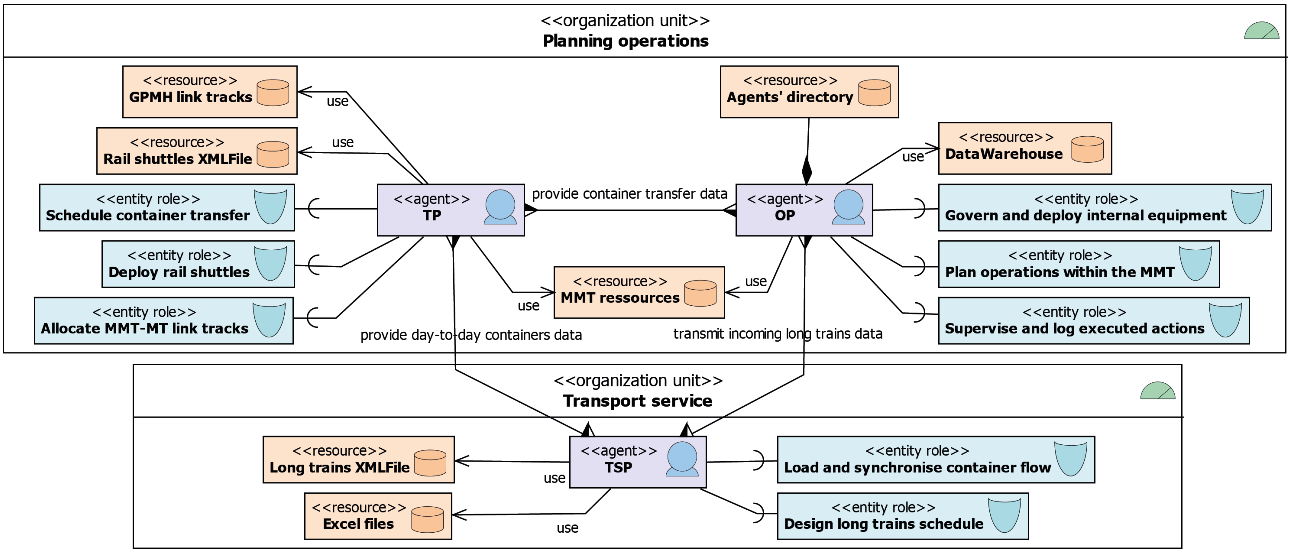

FIGURE 2. **Agents' social relations, theirs roles and used resources.**

flow generation. This workload is shared between three control agents, namely an operational planner agent (OPA), who takes short-time planning decisions, a tactical planner agent (TPA), who schedules intra-port container transfer activities (medium-time planning decisions), and a transport service provider agent (TSPA), who creates long freight trains and plans their arrival and departure dates from MMT. The social relationships of these control agents, their roles and resources are illustrated in Fig. 2 using Agent Modeling Language (AML) specifications.

The TSPA agent represents rail transportation actors, and coordinates container routing to and from Le Havre seaport over its hinterland. At the beginning of each working day, the TSPA loads the inbound and outbound container flow passing through the MMT from an Excel file (provided by Le Havre Port Authority). Next, the TSPA checks whether there are any containers remaining on buffers from the previous working day and then creates long trains. Finally, the TPSA saves the created dataset in its own XML File and sends it to the TPA.

The TPA agent uses the received dataset to determine the required number of shuttles to be deployed on Le Havre seaport terminals by taking account of the containers' characteristics (such as size, type, origin and target terminal and date of arrival at maritime terminals and the MMT, etc.), in addition to rail shuttle deadlines at the MMT and the number of rail cars allowed by shuttle. In this study, we assume that import containers arrive on time at the MMT. Thereafter, the TPA plans the all-day intra-port container transfer activities in order to avoid empty journeys of shuttles. Then, it records the designed plan in its own XML File. Furthermore, any rail shuttle which wants to use a GPMH (Grand Port Maritime du Havre) link track first needs to ask permission from the TPA. At the end of each working day, this agent sends to the TSPA a list of the containers remaining on buffers, in order to synchronize the container flow for the following working day.

The OPA manages short-time operations within the MMT, dispatches internal equipment, communicates the contact information of an agent to other interested agents, supervises and receives information in real time from other agents about simulation progress, and logs the metadata of executed operations in a data warehouse (start and end date, operation type, duration, distance traveled, resource utilization rate, etc.). As soon as this agent receives notification of an incoming freight train from another control agent, it begins preparation for its reception, using three phases. The first is the receipt operations phase. Here, the OPA assigns an identifier to the incoming freight train, determines its needs and adds it to the agents directory (agentType@id). The second phase involves resource allocation. The order of execution of operations in this phase varies depending on the freight train type (long train or shuttle). In the case of a long train, the OPA reserves two railways, one at the receipt beam and another at the rail yard, and a traction unit (shunter); this is because long trains arrive directly at the receipt beam to be decoupled from their electric locomotives. For a shuttle, the OPA reserves only a railway at the rail yard. The OPA concludes this phase by sending an access authorization to the freight train that details the resources reserved for it. The final phase involves operations planning and sending the established plan to the rail gantry cranes. Once handling operations on this train are complete, the OPA executes the departure operations. These consist of calling a traction unit, either to help long train wagons to reach their electrified locomotive and then leave the MMT or to transfer shuttle wagons to their maritime terminal. In conjunction with these operations, the OPA releases the allocated resources and logs all the actions executed (see Fig. 3).

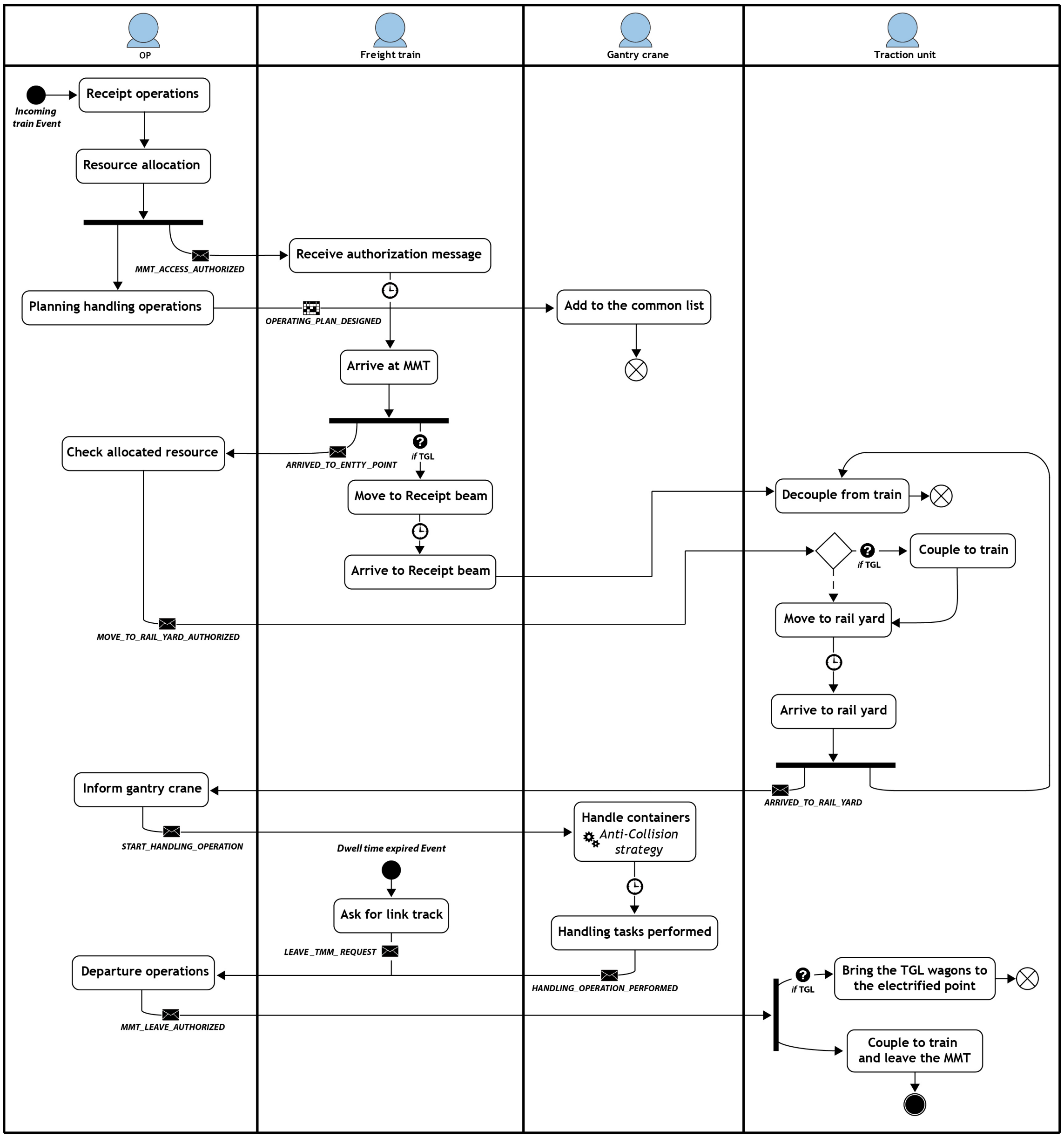

FIGURE 3. Serving freight train process.

B. REPRESENTATION SUBSYSTEM

This subsystem comprises agents representing real entities acting or spending time in the MMT, i.e. gantry cranes, traction units and freight trains. The goals of this representation subsystem are to reproduce the transfer, transportation and storage operations, and also to provide the output data needed in the model verification process and in the analysis of the impact of the proposed scheduling approach on the global system performance. Fig. 3 shows the functioning of this subsystem, and Fig. 4 gives an overview of the relationships existing between the various agents.

When each incoming freight train has nearly arrived at the MMT landside border, the OPA designs an operating plan which contains the priority index of the freight train, the containers to unload and their positions on the train, and the containers to load and their locations in the MMT. The priority index determines the freight train that will be handled next (see the formula 1); as a rule of thumb, cranes operate first on the rail shuttle with the highest priority index, and if there are no shuttles at the rail yard, they apply the same rule to long trains. This priority index was proposed and discussed by Leriche *et al.* [15]. Generally, the shuttle gathers the export containers intended to be supplied to its maritime terminal, as long as there is a vacant position, favoring those with an urgent delivery date, and leaves the MMT as soon as its deadline has expired, even if there are more containers

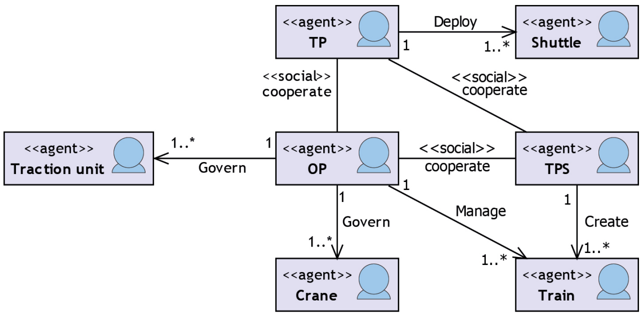

FIGURE 4. Overall agent diagram.

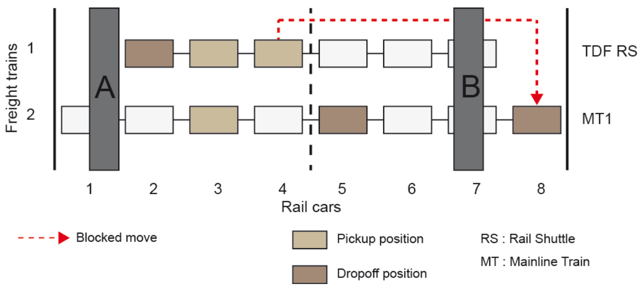

FIGURE 5. Crane blocked move.

to transfer. Long trains, on the other hand, enter the MMT early in the morning and leave the MMT when they have received their entire import container. After arriving at the MMT, the long train agent instructs the OPA to call the allocated traction unit. Thereafter, the long train is decoupled from its electric locomotive, and its wagons are coupled to the traction unit and then transferred to the rail yard, unlike shuttles, which arrive directly at the rail yard. Once the freight train wagons are on the track, the traction unit is decoupled and returns to the receipt beam. The freight train's parking position at the rail yard is determined in an attempt to achieve a good workload balance between cranes (sharing containers equally between cranes). Meanwhile, gantry cranes carry out handling jobs under an anti-collision strategy (described in the following sections); when they finish working, each one returns to its initial position and stands by for upcoming jobs.

$$P_i = \frac{\alpha_1}{ed_i} + \frac{\alpha_2}{dt_i} + \frac{\alpha_3.nc_i}{\sum_{j=0}^{n} nc_j}(1) \quad (1)$$

Such as:

$\alpha_i / i \in \{1, 2, 3\} \sum \alpha_i = 1$: weighting parameters which determine the importance given to each term.

ed_i: export deadline of the most urgent container of train i.

dt_i: departure deadline of train i.

nc_i: number of containers in train i.

V. GANTRY CRANE SCHEDULING APPROACH

In some situations, the movement of a crane can be blocked by another (Fig. 5), when one is operating in between the start and target position of the other, since cranes cannot move beyond the borders of the working area. In a deadlock situation such as this, another piece of equipment is required to enable container processing across both working areas; in the MMT, reach stackers carry out this task. However, this causes additional waiting times in avoiding interference between cranes and reach stackers, and increases the overall costs (handling and equipment costs) and energy consumption. To overcome these drawbacks, we propose here a new configuration for the operating area to govern the behavior of crane agents.

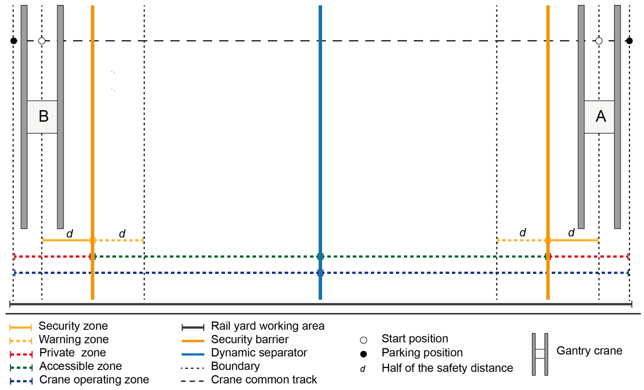

FIGURE 6. The proposed rail yard structure.

TABLE 1. Comparison between all defined zones.

Zone	Size	Location	Role
Operating zone	Dynamic	Fixed	Indicating to a crane its own zone.
Accessible zone	Dynamic	Fixed	Indicating to cranes where they may perform their next movements.
Private zone	Dynamic	Fixed	Indicating a free-collision space.
Warning zone	Dynamic	Dynamic	Indicating a situation which is risky to another crane.
Security zone	Fixed	Dynamic	Indicating to a crane its own minimum safety spacing.

A. SYSTEM ARCHITECTURE

The rail yard working area is composed of several zones (Fig. 6); each zone has a set of properties, including size, location, and role. The diversity of the theses zones helps gantry cranes to choose feasible jobs and to reduce waiting time. Zones follow the motion of the crane to which they are attached; as a consequence, they may be enlarged or narrowed or even change their location. This mechanism is essential for the functioning of this scheduling approach. Fig. 6 illustrates the proposed rail yard structure and Table 1 shows the main differences between the defined zones. The main goal of all zones is to provide collision-free spaces for both cranes.

The rail yard is divided into two operating zones (dashed blue segments). The right-hand zone relates to crane A and the other to crane B. Cranes cannot move outside of the borders of their operating areas, and moving within these is also subject to certain constraints. These constraints are related

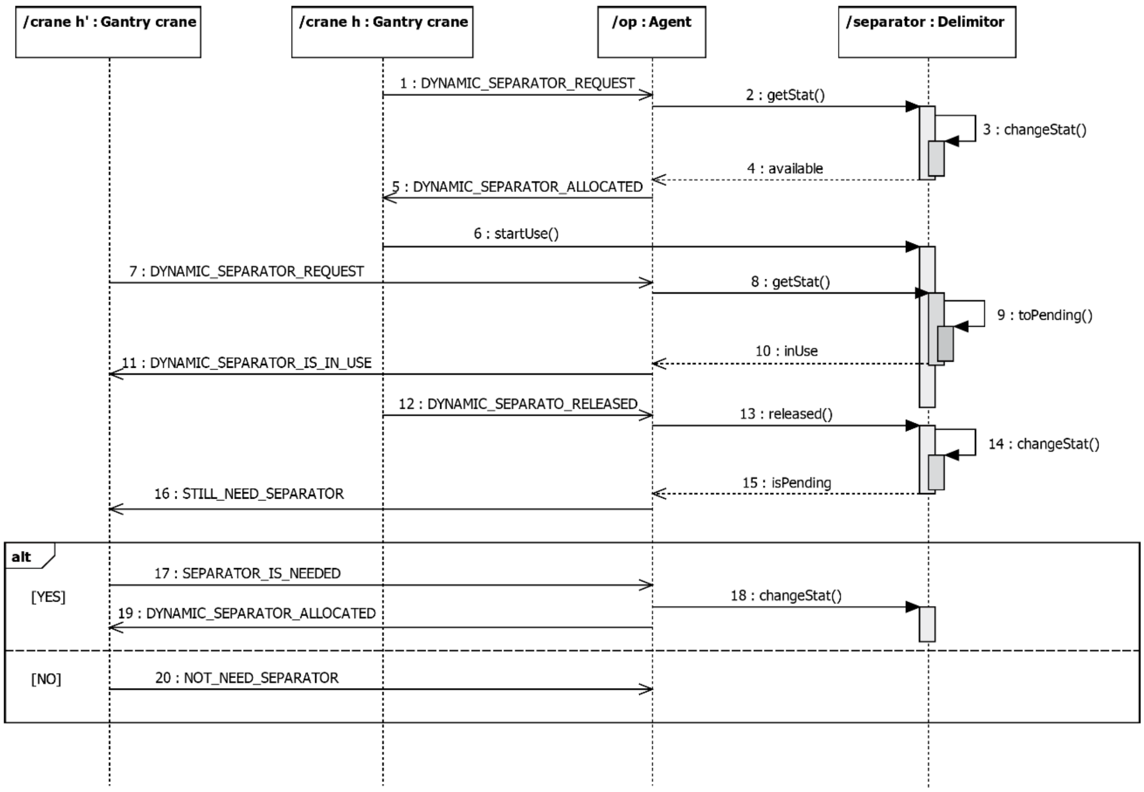

FIGURE 7. **Dynamic separator allocation process.**

to the composition of these zones. Each zone is subdivided into two sub-zones. The first is an accessible zone (dashed green segments) and the second is a private or inaccessible zone (dashed red segments). In the accessible zones, both cranes can handle containers; however, before moving they must adapt their own operating zones according to the position of their chosen containers. For instance, if crane A intends to pick up a container from the accessible zone of crane B, it must first enlarge its operating area so that this container will lie inside. Conversely, the private zone is reserved for its owner, that is, one crane never enters the private space of another (a strong constraint). Furthermore, the private zone is a non-zero area, while the accessible zone may be null if the distance between the two cranes is equal to 2d, i.e., equal to the safety distance. In an attempt to describe the system architecture in a formal way, we present the components explained above as follows:

$$\begin{cases} Z^* = Z_A \cup Z_B \\ Z_h = Z_h^+ \cup Z_h^-, \quad h \in \{A, B\} \end{cases} \tag{2}$$

Such as:

Z^*: the rail yard.

Z_i: the operating zone of crane i.

Z_i^+: the accessible zone of crane i.

Z_i^-: the private zone of crane i.

To ensure the safety distance between both cranes, each private zone has a security zone located at the end (solid orange segments) which is designed to have an area of fixed size (always equal to d). Likewise, each accessible zone comprises a warning zone, characterized by a length which does not exceed the distance d and is located at the beginning (dashed orange segments). Security zones are used to ensure a minimum spacing between cranes and delimiters (dynamic separator and security barriers). A warning zone is a risky area for another crane, that is, crane A may not handle a container situated within the warning zone of crane B. A common property of these two additional zones is that they have a dynamic location (they follow the movements of the cranes). In addition, they inherit the characteristics of their owner zones; thus, security zones are non-zero areas and warning zones may be null. We can formulate these zones and the relationships with their owners as:

$$Z_h^s \in Z_h^-, \quad length_{Z_h^s} = d \wedge Z_h^{s'} \in Z_h^+, \ 0 \leq length_{Z_h^{s'}} \leq d \tag{3}$$

Such as:

Z_i^s: the security zone of crane i.

$Z_i^{s'}$: the warning zone of crane i.

As can be seen from Fig. 6, there are two type of delimiters: a dynamic separator and a security barrier. Firstly, the dynamic separator is the line separating the two operating zones (the blue vertical line). It is considered the main delimiter of this strategy, as its role consists of synchronizing the manipulation of the working area (the two operating zones). In other words, in order to update the dimensions of its own operating zone, the crane must have control over the dynamic separator. Note that only one crane can control this at any given time, and the other must wait until it is released. The OPA is the agent which take cares of this critical resource, as illustrated in Fig. 7. Secondly, the security barrier is the line that divides the security and warning zones of a crane (the orange vertical line). It also indicates the limits of the dynamic separator, that is, the dynamic separator cannot outpass a security barrier since it is subject to this strong constraint:

$$S \in \bigcup_{h \in \{A,B\}} Z_h^+ \tag{4}$$

For example, if crane A intends to handle a container situated at the warning zone of crane B, it must first enlarge its operating zone using the dynamic separator and according to its next movement. Following this, it must update the dimensions or the location of all elements composing its operating area (zones and security barrier). We assume that the dynamic separator is allocated to crane A. As a result of this, both security zones will be intersected, since the dynamic separator will outpass the security barrier of crane B. Finally, the safety distance will be not respected.

B. NEXT CRANE MOVEMENT PROCESS

A change in the configuration of the working area can be done only by one crane at any given time, because it is a critical process and in order to avoid dysfunctional situations. This process of manipulation of zones is inspired by the ant colony approach, and contains three steps: (1) defining of the list of feasible jobs; (2) selecting of a feasible job; and (3) adjustment of zones. The goal of the ant colony approach [26] is to find the best path on a weighted graph. Here, ants are modeled as crane agents. The solution is incrementally constructed by moving on the graph. In each iteration (run), a list is prepared of jobs to be performed and pheromone values are initialized on the graph, either using the values of the previous iteration or a starting value (for the first iteration). Then, crane agents are placed in a random position within their operating areas before being launched. The execution order of each job depends on the pheromone quantity of the chosen path in the graph (to which the job belongs) and the visibility of the job to the cranes. This process is detailed below.

Defining the list of feasible jobs: crane h chooses from the operating plan the jobs that have not been executed and which respect the constraints of the system components. The list of feasible jobs is defined by the following constraints:

$$\left(P_{c_{origin}}, P_{c_{\text{target}}}\right) \notin \left(Z_{h'}^- \cup Z_{h'}^{s'}\right), \quad \text{such as } h, h' \in \{A, B\} \tag{5}$$

$$g\left(crane_h\right) = true \tag{6}$$

Such as:

$P_{c_{origin}}$: the origin position of the container.

TABLE 2. Values of the parameter γ_j^c.

$P_{c_{\text{target}}}$ \ $P_{c_{origin}}$	Z_h^-	Z_h^+	$Z_{h'}^+$
Z_h^-	3	2.75	1.75
Z_h^+	2.5	2.25	1.5
$Z_{h'}^+$	1.25	1.25	1

$P_{c_{\text{target}}}$: the target position of the container. This is the nearest position to $P_{c_{origin}}$, and may be a wagon (rail-rail transshipment) or a buffer stack (when the freight train has not yet arrived at the operating zone).

$g : h \to boolean$: a function that returns a Boolean and indicates whether or not the separator is allocated to the crane. If this is evaluated as true, the separator is allocated to the crane h.

The constraint 5 means that the two positions of the container must be outside of both the private zone and the warning zone of crane h'. If so, crane h adds the container to its list. Moreover, any job situated within the operating zone of the other crane requires the manipulation of the separator. However, if the container has an urgent delivery date (that is, its shuttle will leave the MMT soon), it will be treated as a priority without checking these constraints or executing the next step. In this situation, this crane forces the other to move away if it is too close, in order to perform this urgent job. Otherwise, when a crane has other jobs to perform but none of them are feasible, since none of them respect Constraints 5 and 6, the crane will return to the parking position and remain motionless pending a feasible job (a waiting situation).

Selecting a feasible job: the crane's next job is chosen using the following equation:

$$j = \arg max_{u \in J_i^k} \frac{\left(\tau_{iu}(t)\right)^{\alpha}\left(\eta_{iu}(t)\right)^{\beta}}{\sum_{m \in J_l^k}\left(\tau_{lm}(t)\right)^{\alpha}\left(\eta_{lm}(t)\right)^{\beta}} \quad \text{if } q \leq q_0 \tag{7}$$

We start by generating two random numbers. The, q_0, is a fixed parameter in the interval [0,1], and q is a random value between 0 and 1. The next feasible job is then chosen using Equation (7). The crane selects the job with highest probability, if $q \leq q_0$. Otherwise, it selects a random job in order to explore other paths in the graph. The visibility, $\eta_{iu}(t)$ of a container candidate u, when the crane is the origin position i, is given by the following formula:

$$\eta_{ij}^c(t) = \frac{\gamma_j^c}{T_{ij}}, \quad \text{where } \gamma_j^c \in [1, 3] \tag{8}$$

The parameter γ_j^c varies with the zone in which the container is situated and where it will be deposited. The possible values of γ_j^c are reported in Table 2. The further away the job is from the private area of the crane, the more its visibility decreases. This allows the left- and right-hand cranes to handle the containers in the left- and right-hand zones, respectively. The pheromone coefficient $\tau_{iu}(t)$ saves the intensity of the

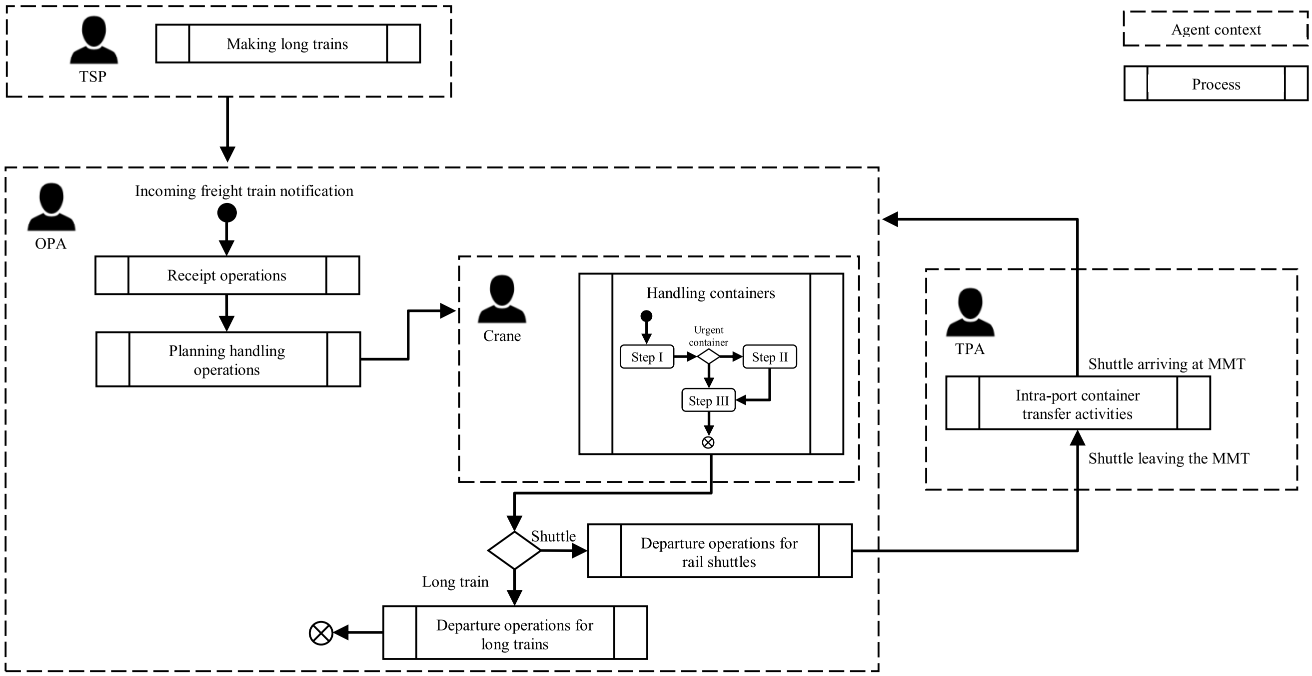

FIGURE 8. Simulation model.

next target, u, while a crane is in the origin position, i. This coefficient is built up from one iteration to the next using the previous crane's agents (ants), as shown in formulas 9 and 10 below.

Adjustment of zones: the crane areas are determined for each container movement, and we therefore distinguish two cases: (1) $P_{c_{origin}} < P_{c_{target}}$ and (2) $P_{c_{origin}} > P_{c_{target}}$. In the first case, changes are applied only according to the target point for both movements (pick-up and drop-off) since the origin position lies between the target position and the separator. In the second case, the origin position is used to adjust the zones during the pick-up and the target position during the drop-off. To extend or reduce an operating zone, the agent crane calculates the new location of the each delimiter (D) using $P_D = P_c \pm d$. Then, all elements affected by this change are adjusted.

C. UPDATING PHEROMONES ON PATHS

The pheromone quantity deposed by each crane agent within iteration t is calculated as follows:

$$\Delta\tau_{ij}^{c}(t) = \frac{q_1}{L^c} + \frac{q_2}{A^c} + \frac{q_3}{S} + \frac{q_4}{D} \tag{9}$$

Such as:

L^c: is the workload of crane c.

A^c: is the waiting time of crane c.

S: is the sum of the workloads of the two cranes.

D: is the absolute value of the difference in workload between the two cranes.

$q_i/i \in \{1, 2, 3, 4\}$: are coefficients in the interval [0, 1].

At the end of each iteration, the pheromones on the graph are updated using the equation below:

$$\tau_{ij}^{c}(t+1) = (1-\rho)\,\tau_{ij}^{c}(t) + \Delta\tau_{ij}^{c}(t) \tag{10}$$

VI. IMPLEMENTATION AND VALIDATION OF THE MODEL

A. SIMULATION MODEL PROCESSES

The simulation model is a planning distribution-driven model, in which the tactical planner agent (TPA) makes medium-term decisions (all-day intra-port container transfer activities) and the operational planner agent (OPA) makes short-term decisions (Fig. 8). This distribution is motivated by the plurality of handling operations and by all decisions to be taken. In addition, it aims to build a modular and robust system. Planners interact with each other and cooperate collectively to achieve specific goals. For example, when "serving rail shuttles", the TPA agent sends an arrival notification for a rail shuttle to the OPA agent, which will then plan the handling operations for this incoming shuttle.

Fig. 8 shows all the processes making up the simulation model. Firstly, the TSPA agent creates long trains from the Excel file provided by Le Havre Port Authority and the data given in Table 3. Secondly, it informs the OPA about the arrival time of each train. From this data, the TPA generates rail shuttles and their schedule (Table 4). Both TPA and TSPA record the generated dataset in detail (long trains and rail shuttle) in XML files. These files are used to feed all iterations of the model with the same dataset (see the last part of this section).

When a transportation mode arrives at the MMT, the receipt operations process is triggered. Typically, freight

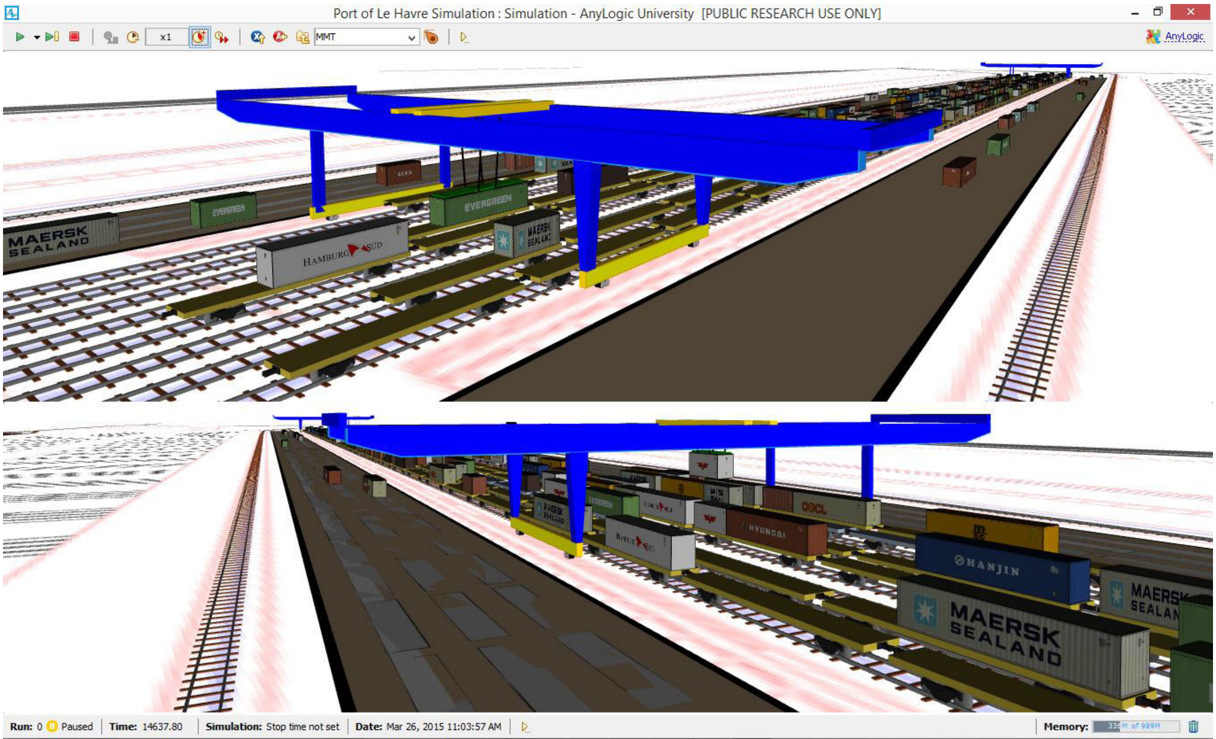

FIGURE 9. 3D simulation screenshot.

TABLE 3. Simulation settings.

Basic data		Export/Import container destination/origin	
Rail containers per year	97600	ATL	10 %
Export start arrival time	7:00 h	TDF	50 %
Import start arrival time	11:00 h	TPO	20 %
Mainline train length	25 - 40 rail car	TNMSC	20 %
Rail shuttle length	15 - 30 rail car	Total	100 %
Rail shuttle dwell time	90 min		
Rail car capacity	3 TEU		
Safety distance	24,384 m		
get/put container	1 min		

TABLE 4. Deployed rail shuttles at GPMH terminals.

	ID	Origin terminal	Departure date from origin	Arrival time at MMT	Import container transported
Day 1	1	TDF	10:00 h	11:00 h	32
	2	ATL	10:30 h	11:30 h	14
	3	TPO	12:00 h	13:00 h	28
	4	TDF	14:00 h	15:00 h	38
	5	TNMSC	16:00 h	17:00 h	28
Day 2	1	TDF	10:00 h	11:00 h	31
	2	ATL	10:30 h	11:30 h	15
	3	TPO	12:00 h	13:00 h	30
	4	TDF	14:00 h	15:00 h	44
	5	TNMSC	16:00 h	17:00 h	30
Day 3	1	TDF	10:00 h	11:00 h	26
	2	ATL	10:30 h	11:30 h	13
	3	TPO	12:00 h	13:00 h	27
	4	TDF	14:00 h	15:00 h	40
	5	TNMSC	16:00 h	17:00 h	27

trains begin arriving at 6:00 am. Then, the incoming mode moves to its assigned position in the MMT to deliver its containers and to receive others. Long trains spent more than 45 minutes before being transferred to the rail yard, whereas shuttles take around 15 minutes and remain at the rail yard for a maximum of 90 minutes. This time is due to the travel time and certain operations such as coupling, decoupling and rail switching. During their travel time, cranes receive the operating plan (planning handling operations) and use the manipulation process to choose a feasible job (handling containers). The job may be from a given area on the incoming transport vector or from other freight trains the rail yard. Note that a job may take three minutes at most; this includes pick-up and drop-off time (two minutes, as shown in Table 3) with an additional one minute for the crane's moving time for a job. When the handling operations are ended, the transportation mode waits for its traction unit and then leaves the MMT (departure operations). The service period ends with the departure of the last freight train.

B. IMPLEMENTATION PROCESS AND VERIFICATION

The AnyLogic [27] simulation tool was used to implement the designed simulation model (Fig. 9). AnyLogic was developed using Java; it supports various simulation approaches (agent-based simulation, discrete-event simulation, and system dynamics) and allows the user to combine these. In addition, it provides several modeling elements (state diagram, activity diagram, flow diagram and libraries). The simulation model was run on a PC Intel(R) Core(TM) i5-3337U CPU @ 1.80 Ghz with a memory of 8 GB.

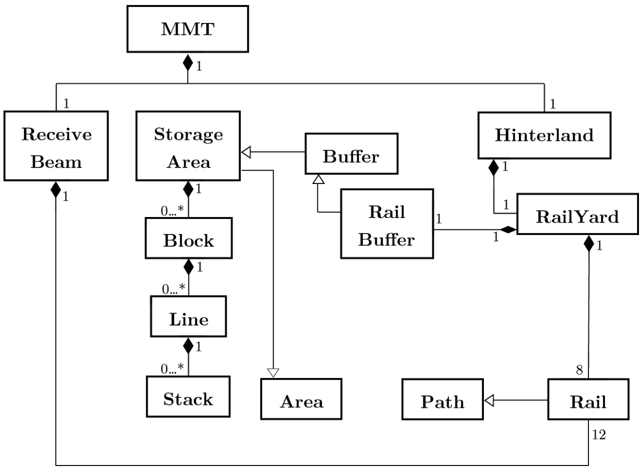

FIGURE 10. MMT infrastructure model.

TABLE 5. Organizational indicators for day 1.

	Number of handlings per container	Average handling time per container
Simulation model	1.36	2.24 min
Tolerated values	2	3 min

Firstly, the infrastructure of the MMT was designed, as shown in Fig. 10. We used the Rail Library, space markup elements, geometric shapes, and 3D objects. Secondly, agents and simulation processes were implemented using the Agent Library, State Chart, Rail Library and Process Modeling Library. Finally, the Anylogic debugger tool was employed to detect possible errors in the code.

Model verification is a necessary step in order to ensure that the model is reasonable, correctly implemented and reflects the desired behavior. In this work, we carried out two forms of verification: graphic output verification (Fig. 9) and simulation output verification. Graphic output provides visualized data in order to locate and correct any dysfunction. The simulation output verification was performed by comparing two performance indicators calculated from the simulation model to tolerated indicator values, as shown in Table 5. Note that a container can be handled at most twice, i.e., unloaded from a shuttle and then put in a stack. Later, it is picked up from the stack and loaded onto a long train.

C. VALIDATION OF THE ENGINEERING STRATEGY

To validate the developed engineering strategy, all executed jobs were tested using a time-space formula (formula 11). This formula proves that the safety distance is respected while the model is running. All tasks were performed in collision-free spaces if and only if the following formula was valid, as shown in Fig. 11:

$$\forall k, j \in T, \quad and\ I_j \neq I_k, \quad if\ Z_j^- \cap Z_k^- \neq \emptyset \longrightarrow [S_j, F_j] \cap [S_k, F_k] = \emptyset \quad (11)$$

```
Input: J, n // size of the executed jobs list J
for i := 0 to n do
    j ← J [ i ];
    for m := i + 1 to n do
        k ← J [ m ];
        if (Ij ≠ Ik) ∧ ( Zj⁻ ∩ Zk⁻ ≠ ∅) ∧ ([Sj, Fj] ∩ [Sk, Fk] ≠ ∅ ) then
            return false;
        end if
    end for
end for
return true;
Output: boolean
```

FIGURE 11. Validation method.

$T = \{1, 2, 3, \ldots, n\}$: the set of all executed tasks. A job is two tasks.

I_j: the crane that ensures the execution of task j.

Z_j^-: the private zone designed by the crane to execute task j.

E_j: the task execution time. $E_j > 0$.

S_j: the task starting date. $S_j \geq 0$.

F_j: the task finishing date. $F_j \geq 0$, such that $F_j = S_j + E_j$.

D. ITERATIONS AND PARAMETER CALIBRATION

To calibrate the model, a number of iterations for each simulation were carried out using a dataset recorded in XML files; this is illustrated in Fig. 12. AnyLogic provides a Parameter Variation Experiment that stops the iteration loop after a minimum number of iterations, when the confidence level is reached [28]–[30]. If the confidence level is not met, the Parameter Variation Experiment ends when the maximum number of iterations has been exceeded. For each parameter setting run, the results of the iteration with the lowest completion time for operations were captured for parameter calibration.

The confidence level was fixed at 95%, constructed around the mean of the completion time of operations, and the error percentage was set as 0.5. The minimum and maximum number of iterations were set as 10 and 500, respectively (we used a limited version of AnyLogic "University Researcher Edition"; this version enabled us to use a memory of only 1 GB and that way the number of iterations cannot surpass 500).

Another important point is parameter calibration. We used the Design of Experiment (DoE) method and the best iterations (results) to find the suitable value for each parameter used. Thus, the factorial experiment implemented in the Minitab [31] tool was employed to calibrate the parameters; see Table 6 for the parameter settings of the engineering strategy model.

VII. EXPERIMENTAL RESULTS AND DISCUSSION

In a prior study by Leriche *et al.* [15], the authors discussed three handling rules with a non-crossing constraint to

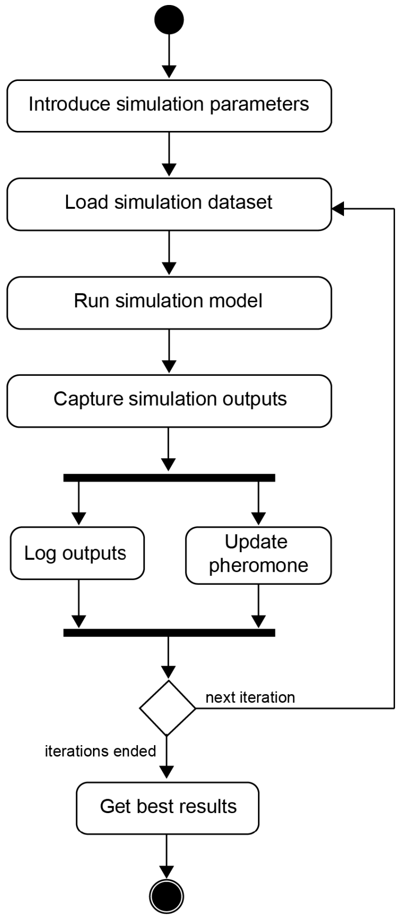

FIGURE 12. Parameter Variation Experiment loop.

TABLE 6. Optimal parameters values after tuning.

q_0	q_1	q_2	q_3	q_4	α	β	ρ
0,8	0,9	0,9	0,9	0,9	3	2	0,6

TABLE 7. Gap values between each rule model and the engineering strategy model.

	Rule 1	Rule 2	Rule 3
Service time	0.7%	1.7%	0.7%
Waiting time	63%	64%	58%
Distance traveled	11%	13%	13%
Empty cranes moves	12%	15%	13%
Activity ratio	1.8%	1.8%	1.8%
Idle ratio	18%	18%	12.5%
Difference workload	51%	53%	48%

TABLE 8. Results of all involved simulation days.

		Engineering strategy	Rule 1	Rule 2	Rule 3
Day 1	Service time (s)	75580	76091	76881	76120
	Waiting time (s)	729	1966	2016	1732
	Distance traveled (m)	27082	30531	31052	31004
	Empty cranes moves (m)	16943	19313	19892	19530
	Activity ratio	82%	83%	83%	83%
	Idle ratio	17%	14%	14%	15%
	Difference workload	0.98%	2%	2.1%	1.9%
Day 2	Service time (s)	75703	76614	77012	76598
	Waiting time (s)	812	1998	2254	1976
	Distance traveled (m)	28188	31067	31486	31432
	Empty cranes moves (m)	17139	19874	20160	19981
	Activity ratio	83%	85%	85%	84%
	Idle ratio	16%	12%	12%	15%
	Difference workload	1.1%	2%	2%	2%
Day 3	Service time (s)	74516	75746	76295	75581
	Waiting time (s)	761	1640	1873	1767
	Distance traveled (m)	26793	29619	30329	30102
	Empty cranes moves (m)	16546	18547	19729	18434
	Activity ratio	81%	84%	85%	84%
	Idle ratio	18%	14%	12.5%	14%
	Difference workload	1%	1.9%	2%	1.8%

determine the next movements of gantry cranes at the rail yard of MMT, namely the 'less distance' rule, the 'less distance without comeback' rule and the 'left-to-left' rule. However, these rules give rise to several waiting situations for cranes and thus reduce their productivity and extend container processing time.

The effectiveness and capability of the engineering strategy are investigated with regard to the rules described above, and the experimental results of a typical day (Day 1) are reported in Figs. 13-15, the results of all three simulation days (see, Table 4) are summarized in Table 8 below. Figs. 13-15 show simulation outputs for the engineering strategy model, the less distance rule model (Rule 1), the less distance without comeback rule model (Rule 2), and the left-to-left rule model (Rule 3), respectively. In Table 7, we report gap values (difference in percentage) between each rule model and the engineering strategy model in day 1. The gap value is calculated as follows:

$$\frac{\max - min}{max} \times 100$$

Fig. 13 displays the movements of gantry cranes (crane A + crane B) and Fig. 14 shows the times spent by cranes in handling operations (crane A + crane B) during the whole day (Day 1). The first bar in Fig. 13 represents the overall distance traveled by cranes, and the last bar shows the total distance traveled without a container. In Fig. 14, the time between the beginning and end of handling operations is called the service time, and the time during which cranes stop working in order to avoid collisions, is the waiting time. In Fig. 15, crane utilization is reported (the average values of both cranes). The first two bars indicate the proportion of time during which cranes were busy and not in use, respectively. Not in use means that cranes were in their initial positions, waiting for upcoming jobs. The last bar highlights the difference in the workload between gantry cranes.

As can be seen from the figures and tables given above, the designed engineering strategy is advantageous at all levels. It improves the productivity of the cranes and accelerates the freight train's processing time. From Fig. 14, it is clear that the waiting time is reduced by more than half. In addition, the waiting time in our approach does not exceed 1% of the service time, while in other models waiting time represents 2.58 %, 2.62 %, 2.27 %, respectively for Rule 1, Rule 2 and Rule 3. This finding proves that the dynamic

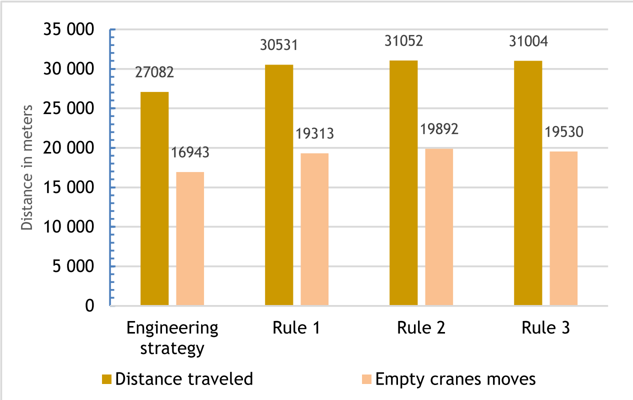

FIGURE 13. Distance traveled by cranes.

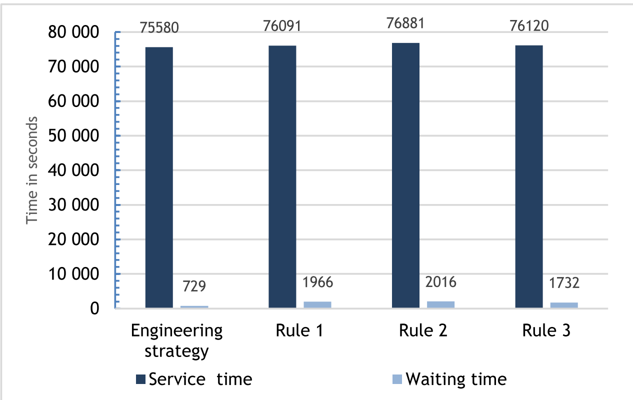

FIGURE 14. Times spent by cranes.

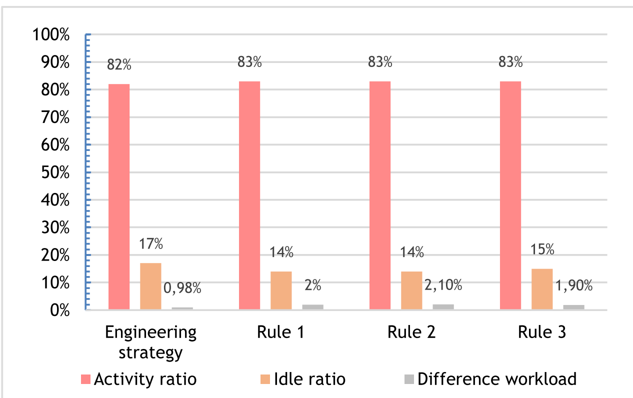

FIGURE 15. Gantry cranes utilization.

behavior of the proposed system architecture components plays a significant role in reducing situations in which cranes stop working. Moreover, the distance traveled by cranes is minimized (Fig. 13), because their moves are restricted by Constraint 5; thus, they move if and only if allowed, and they look for a sequence of tasks that can diminish unproductive times and moves, (formulas 7 and 9), that is, the best path on the graph. This better usage of cranes is confirmed by Fig. 15, particularly with regard to the idle time and workload balancing. In our model, cranes have almost the same workload and are able to perform more tasks during the working day, i.e. they have more idle time.

Additionally, the simulation showed that the gantry cranes subjected to our rules were faster during the first half of the working day (between 8 and 14 h), performing 63% of their assigned workload. In the other models only 50% of the workload was completed. Thus, the faster a crane worked, the faster it finished its workload. In addition, cost and energy savings can be achieved, since container processing in both areas is done without the need for reach stackers (see the first paragraph of Section V) due to the new configuration of operating areas. Cranes move along the rail yard simply by redesigning the dynamic components. The following table summarizes the simulation results of all involved simulation days (see, Table 4).

VIII. CONCLUSION AND FUTURE WORK

This paper focused on minimizing waiting situations and unproductive movements in order to improve the productivity of gantry cranes and to speed up container processing at the rail yard of the multimodal terminal of Le Havre seaport. In the Section IV, the proposed multi-agent based simulation model was detailed. In the section V, problems under focus was introduced and an improving solution for gantry cranes scheduling was designed. This solution is a novel approach that allows cranes to adapt the working area to their needs. Following this, the implementation and verification of the model were described, and description of the drawbacks of the existing handling rules [15] and a discussion of the simulation results were presented. We reported that the proposed system architecture has a strong effect on minimizing the occurrence of waiting situations. The results obtained show that using this improved rail yard partition mechanism, containers can be evacuated more rapidly to their destinations.

The authors' future research will try to address some of the limitations of this research: disturbance events are not taken into consideration, and the arrival date of import containers at the MMT is ignored, thus causing a poor scheduling of all-day intra-port container transfer.

REFERENCES

[1] *Container Port Traffic (TEU: 20 Foot Equivalent Units)|Data|Table*, accessed on Nov. 18, 2015. [Online]. Available: http://data.worldbank.org/indicator/is.shp.good.tu
[2] A. Frémont and P. Franc, "Hinterland transportation in Europe: Combined transport versus road transport," *J. Transp. Geogr.*, vol. 18, no. 4, pp. 548–556, Jul. 2010.
[3] "Keep europe moving—Sustainable mobility for our continent. Mid-term review of the European commission's 2001 transport," Eur. Commission, Final, Brussels, White Paper. COM 314, 2006.
[4] *Modal Share of Freight Transport to and From EU Ports—Think Tank*, accessed on Nov. 18, 2015. [Online]. Available: http://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_STU(2015)540350
[5] C. Bierwirth and F. Meisel, "A survey of berth allocation and quay crane scheduling problems in container terminals," *Eur. J. Oper. Res.*, vol. 202, no. 3, pp. 615–627, May 2010.

[6] C. Bierwirth and F. Meisel, "A follow-up survey of berth allocation and quay crane scheduling problems in container terminals," *Eur. J. Oper. Res.*, vol. 244, no. 3, pp. 675–689, Aug. 2015.
[7] P. Kroll and P. Kruchten, *The Rational Unified Process Made Easy: A Practitioner's Guide to the RUP*. Reading, MA, USA: Addison-Wesley, 2003.
[8] L. E. Henesey, *Multi-Agent Systems for Container Terminal Management*. Karlskrona, Sweden: Blekinge Institute of Technology, 2006.
[9] M. Bielli, A. Boulmakoul, and M. Rida, "Object oriented model for container terminal distributed simulation," *Eur. J. Oper. Res.*, vol. 175, no. 3, pp. 1731–1751, 2006.
[10] B. W. Wiegmans, D. T. Stekelenburg, C. Versteegt, and Y. M. Bontekoning, "Modeling rail-rail exchange operations: An analysis of conventional and new-generation terminals," *Transp. J.*, pp. 5–20, 2007.
[11] J. A. Ottjes, H. P. M. Veeke, M. B. Duinkerken, J. C. Rijsenbrij, and G. Lodewijks, "Simulation of a multiterminal system for container handling," in *Container Terminals and Cargo Systems*, K. H. Kim and H.-O. Günther, Eds. Berlin, Germany: Springer, 2007, pp. 15–36.
[12] A. Benghalia, M. Oudani, J. Boukachour, D. Boudebous, and A. E. H. Alaoui, "Optimization-simulation for maritime containers transfer," *Int. J. Appl. Logistics*, vol. 5, no. 2, pp. 50–61, 2014.
[13] J. Dubreuil, "La logistique des terminaux portuaires de conteneurs," in *Centre Interuniversitaire de Recherche sur les Réseaux d'Entreprise, la Logistique et le Transport*. Quebec, Canada: Library and National Archives of Quebec, 2008.
[14] A. Cartenì and S. de Luca, "Tactical and strategic planning for a container terminal: Modelling issues within a discrete event simulation approach," *Simul. Model. Pract. Theory*, vol. 21, no. 1, pp. 123–145, 2012.
[15] D. Leriche *et al.*, "Simulating new logistics system of Le Havre Port," *IFAC-PapersOnLine*, vol. 48, no. 3, pp. 418–423, 2015.
[16] Z. Sun, L. H. Lee, E. P. Chew, and K. C. Tan, "MicroPort: A general simulation platform for seaport container terminals," *Adv. Eng. Inform.*, vol. 26, no. 1, pp. 80–89, 2012.
[17] M. Najib, A. El Fazziki, and J. Boukachour, "A container terminal management system," in *Proc. Int. Conf. Harbour Maritime Multimodal Logistics M&S*, 2012, pp. 118–127.
[18] M. Najib, J. Boukachour, and A. El Fazziki, "A multi agent framework for risk management in container terminal: Suspect containers targeting," *Int. J. Comput. Sci. Appl.*, vol. 10, no. 2, pp. 33–52, 2013.
[19] F. Fotuhi, N. Huynh, J. M. Vidal, and Y. Xie, "Modeling yard crane operators as reinforcement learning agents," *Res. Transp. Econ.*, vol. 42, no. 1, pp. 3–12, 2013.
[20] G. Maione and M. Ottomanelli, "A preliminary Petri net model of the transshipment processes in the Taranto container terminal," in *Proc. 10th IEEE Conf. Emerg. Technol. Factory Autom. (ETFA)*, vol. 1. Sep. 2005, pp. 165–171.
[21] A. Gudelj, M. Krčum, and E. Twrdy, "Models and methods for operations in port container terminals," *PROMET-Traffic&Transp.*, vol. 22, no. 1, pp. 43–51, 2010.
[22] N. Boysen, M. Fliedner, and M. Kellner, "Determining fixed crane areas in rail–rail transshipment yards," *Transp. Res. E, Logistics Transp. Rev.*, vol. 46, no. 6, pp. 1005–1016, 2010.
[23] M. Wooldridge, *An Introduction to Multiagent Systems*. Hoboken, NJ, USA: Wiley, 2009.
[24] K. Cooper, S. P. Abraham, R. S. Unnithan, L. Chung, and S. Courtney, "Integrating visual goal models into the rational unified process," *J. Vis. Lang. Comput.*, vol. 17, no. 6, pp. 551–583, 2006.
[25] A. Garro and W. Russo, "*easyABMS*: A domain-expert oriented methodology for agent-based modeling and simulation," *Simul. Model. Pract. Theory*, vol. 18, no. 10, pp. 1453–1467, 2010.
[26] M. Dorigo and C. Blum, "Ant colony optimization theory: A survey," *Theor. Comput. Sci.*, vol. 344, nos. 2–3, pp. 243–278, 2005.
[27] *Multimethod Simulation Software and Solutions*, accessed on Nov. 22, 2015. [Online]. Available: http://www.anylogic.com/
[28] *Help—AnyLogic Simulation Software*, accessed on Feb. 18, 2017. [Online]. Available: https://help.anylogic.com/index.jsp?topic=/com.xj.anylogic.help/html/experiments/Parameter%20Variation.html
[29] K. Hoad, S. Robinson, and R. Davies, "Automating DES output analysis: How many replications to run," in *Proc. 39th Conf. Winter Simul.*, 2007, pp. 505–512.
[30] M. D. Petty, "Calculating and using confidence intervals for model validation," in *Proc. Fall Simul. Interoperability Workshop*, 2012, pp. 10–14.
[31] *Minitab*, accessed on Mar. 7, 2017. [Online]. Available: https://www.minitab.com/fr-fr/

MOHAMED NEZAR ABOURRAJA received the M.S. degree from the Faculty of Sciences Semlaila of Marrakech, Morocco, in 2013, where he is currently pursuing the Ph.D. degree with the Computer Science Sciences Department. His research interests are in simulation of containers terminals, multi-agent modeling, and supply chain management.

MUSTAPHA OUDANI received the Ph.D. degree in operational research and computer science from the University of Le Havre in 2014. He is currently an Associate Professor of mathematics with Marrakech Private University. His research interests are in operational research, optimization, simulation, and supply chain management.

MOHAMED YASSINE SAMIRI received the M.S. degree from the Faculty of Sciences Semlaila of Marrakech, Morocco, in 2013, where he is currently pursuing the Ph.D. degree with the Computer Science Sciences Department. His research interests are in software engineering, focusing on containers terminal and supply chain risk management.

DALILA BOUDEBOUS has been an Associate Professor of computer science with the University of Le Havre, France, since 1992. She has supervised two Ph.D. dissertations in supply chain performance and currently one Ph.D. dissertation in robust optimization. Her research interests involve simulation and optimization applied especially to port logistics and transportation.

ABDELAZIZ EL FAZZIKI received the M.S. degree from the University of Nancy, France, in 1985, and the Ph.D. degree in computer science from the University of Marrakech in 2002. He has been a Professor of computer science with Marrakech University since 1985. He has authored over 50 papers on software engineering. His research interests are in software engineering, focusing on information system development.

MEHDI NAJIB received the M.S. degree from the Faculty of Sciences Semlalia of Marrakech, Morocco, in 2009, and the Ph.D. degree in computer science from the University of Le Havre in 2014. He is currently an Associate Professor of computer science with Marrakech Private University. His research interests are in risk management, containers terminal management, and workflow management.

ABDELHADI BOUAIN received the M.S. degree from the Faculty of Sciences Semlaila of Marrakech, Morocco, in 2012, where he is currently pursuing the Ph.D. degree at the Computer Science Sciences Department. His research interests are in ubiquitous systems, sensors network, and simulation.

NAOUFAL ROUKY is currently pursuing the Ph.D. degree at the Department of Computer Sciences, University of Normandie, Le Havre, France. His research interests are in operational research, optimization, simulation, and supply chain management.