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Agent based simulation architecture for evaluating operational policies in transshipping containers

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Abstract An agent based simulator for evaluating operational policies in the transshipment of containers in a container terminal is described. The simulation tool, called SimPort, is a decentralized approach to simulating managers and entities in a container terminal. Real data from two container terminals are used as input for evaluating eight transshipment policies. The policies concern the sequencing of ships, berth allocation, and stacking rule. They are evaluated with respect to a number of aspects, such as, turn-around time for ships and traveled distance of straddle carriers. The simulation results indicate that a good choice in yard stacking and berthing position policies can lead to faster ship turn-around times. For instance, in the terminal studied the Overall-Time-Shortening policy offers fast turn-around times when combined with a Shortest-Job-First sequencing of arriving ships.

Keywords Agent-based simulation · Container terminal management · Policy evaluation

1 Introduction

The growth in the use of containers for transporting goods has been profound from 39 million containers handled in 1980 to over 356 million in 2004 and the annual growth rate is projected at ten percent till 2020 [1]. Parallel with the increasing demands for transporting cargo in containers is the increasing importance in improving container terminal (CT) operations. As

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the primary function of CTs is to provide efficient, low-cost, inter- and intramodal transfer, inspection, storage, and control of cargo, the CT must be able to effectively act as an integral part of transport chain from origin to destination [2]. According to Frankel [2], port costs can be in excess of 50% of the total shipping costs of which 55% of these port costs are the result of poor ship turn-around times and low cargo handling speeds. The increasing demands on CTs is placing pressure on the management of CTs in finding ways to increase capacity and offer more efficient ship handling operations. De Monie [3] has identified several key parameters of CT capacity that can be improved through computerized planning, control and maintenance systems such as: scheduling the berthing of ships, scheduling the ship-to-shore handling, coordinating the terminal transfer, and managing the stacking/un-stacking of containers in the yard. In addition, De Monie has calculated that the cost per day of an 8,000 TEU (Twenty-foot Equivalent Units) ship to be on average $140,000.

Due to the challenges and complexity of managing CTs, there has been much research in CT effectiveness, capacity and technology. A literature survey overview on transshipment operations has been provided by Vis and Koster [4] and Meersmans and Dekker [5] followed by a rather comprehensive survey on container terminal logistics by Steenken et al. [6]. A classification of container terminal operations is provided by Henesey [7], which concludes that simulation models have been used extensively in understanding the behavior, experimenting and testing conditions and scenarios due to the cost and complexity of the CT domain.

This paper presents a multi-agent based simulator called SimPort (Simulated container Port) that is developed, as part of an IDSS (Intelligent Decision Support System) assisting human CT managers in evaluating and selecting policies to use for transshipment operations in a CT.

The remainder of the paper is organized as follows: in Sect. 2 a general description of the transshipment processes in a CT is presented. In Sect. 3, a research question is formulated and the methodology chosen as well as related work are described. The SimPort architecture and model is explained in Sect. 4. In Sect. 5, a description of simulation tests and the results are presented. In Sect. 6, a conclusion with pointers for future work .

2 Container terminal transshipment operations

Many shipping companies are trying to serve a geographic region, such as Europe, by establishing two or three main hubs from which smaller container ships will "feed" containers to and from other ports or CTs in the region. This 'hub and spoke' method of servicing ship line customers is similar to that used by the airline industry in transporting people in smaller aircrafts from a region via large international airports connecting with often larger airplanes to distant destinations or offering many destinations. The amount of transshipping is increasing and according to a study by OCS, [8] total transshipment throughput for Europe and the Mediterranean has increased by 58% over 2000–2004 to 22.5 million TEUs. Many CTs are fast becoming known as transshipment terminals in which they will be linked with 'feeder' ships and the containers from various ports and CTs are consolidated for loading on larger ships for transporting to another region. These transshipment terminals will have little or no land-side container transport. Specialized transshipment CTs that have been developed as a consequence to the large flow of containers being transshipped are for example; Malta, Gioia Tauro, Salalah, Algeciras, Singapore, Hong Kong, and Shanghai [9]. Notably, many transshipment CTs are located on islands with rather small population. Thus, much effort is concentrated on the marine side of the operations since there is very little land side operations.

In managing the CT, the transshipment operations in moving containers can be divided into four sub-processes: *ship arrival, loading/unloading, horizontal transport* and *yard stacking/unstacking* [4]. The four sub-processes in transshipment operations are described as follows:

Ship arrival: The arrival of a ship requires CT management to locate a berth position so that it can moor along the quay and to decide a service time in which to schedule operations in order to meet a desired departure time of the ship. This decision on choice of a berth policy has an impact on other decisions in the ship operations. The berth 'policy' is often formulated from choosing a sequence policy and a positioning policy. Main questions are *when* and *where* to place an arriving ship.

Loading and unloading: The loading and unloading sub-processes requires operational decisions by the CT management in allocating quay cranes (QC) and transport equipment such as straddle carriers (SC) or trucks and labor. Usually, the allocation of these resources is conducted in parallel with the ship arrival process. The container stowage planning in a ship is a rather complex problem to solve and according to a study by Wilson and Roach [10] it is found to be NP-hard. Obviously, solutions for loading and unloading a container ship are required fast and often heuristics are employed.

Horizontal Transport: An objective that many CT managers share is trying to keep the assigned QCs from being idle or avoiding interruption during operations so as to quickly service a ship. The availability, allocation and efficient use of terminal transport are very important to ensure that the QCs are productive. Henesey et al. [11] point out that many CT managers view the interface between the QCs and the yard to be a problem. Some problems in the horizontal transport process are: load sequence, routing, pickup sequencing and coordination with QCs. Additionally, the speeds and distances of the transporters are considered to have a major influence on the productivity of the QCs.

Yard stacking/unstacking: Containers are usually placed in different yard areas using a stacking policy which may consider, for example; type (export or import), and size (i.e. 40′ foot or 20′ foot), destination, or by ship line that owns the container, etc. Ideally in transshipment operations, the ship that is loading the containers should be serviced at the same time as the ship that is unloading the containers in order to avoid unnecessary stacking of containers. However, in reality the containers must often 'dwell' or be placed in a yard stack for a period of time while waiting to be loaded onto another arriving ship. Some problems or decisions affecting this process are: stacking density; yard stack configuration; container allocation to a stack according to rules of "policies"; and dwell times.

3 Research questions and methodology

In this paper, we pose the following research question; "how could multi agent based simulation (MABS) be used to study the impact of the different policies for sequencing of arriving ships, for berthing, and for container stacking on the performance of transshipment operations at a CT?"

This research question stemmed from discussions with CT managers and the results from the reviewed literature [7]. There often appeared to be a gap in understanding the complexity of the decisions made by the CT managers, such as berth assignment, between the theoretical perspectives and industry practice. Often mentioned in the interviews, is that existing tools are too cumbersome, do not accurately model the CT, are too expensive and do not provide results fast enough. In addition, some CT experts confided that berth allocation was conducted mostly by middle managers, who did not possess enough information in making the berth assignment decision. Of interest for many CT managers was an approach to assign a ship to a berth by considering: the distances traveled by the transporters, the daily costs of each ship, and the configuration of the yard.

Besides using simulation to solve the problem at hand, we considered other methods, such as, analytical approaches (e.g. queuing theory) and optimization. Since the problem includes stochastic processes and a multitude of process dependencies, e.g., a process may wait for another process to terminate, neither analytical approaches nor optimization approaches were found to be suitable for this study. MABS has been suggested by Wooldridge [12] to be applicable to domains that are distributed, complex, and heterogeneous, such as container terminals. Moreover, CTs possess many of the characteristics listed by Parunak et al. [13] that are deemed suitable for MABS, such as, random variables, large number of parameters, non-linear functions and behavior of a dynamic system.

Simulation in general can be used to study the dynamics of complex systems and how the various components of the system interact with each other [14]. The reason for simulation is that it is a good way for people to form cognition; *action or process of acquiring knowledge*.

The choice on using MABS specifically is based in the versatility in simulating complex systems and perceived simplicity from which modeling a CT can handle different levels of representation, such as real human managers in a management system. Parunak et al. [13] recently compared macro simulation and micro simulation approaches and pointed out their relative strengths and weaknesses. They concluded, "...agent-based modeling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision. Equation-based modeling is most naturally applied to systems that can be modeled centrally, and in which the dynamics are dominated by physical laws rather than information processing." As a CT has a high degree of localization and distribution and is dominated by discrete decision, we found agent-based modeling a promising approach worthy to investigate. Moreover, Davidsson et al. [15] and Henesey [16] conclude after reviewing a large number of papers applying agent-based approaches to transport systems, such as CTs, that the motivation for choosing an agent-based approach has been the straight-forward modeling of the entities in the domain, modifiability (single agent can be changed without changing the whole simulation architecture), and reusability.

3.1 Related work

A number of simulators and simulation models have been developed in studying CTs and they differ widely in objectives, complexity and details, but all seem to propose a centralized system for the management of the CT [17]. Distributed approaches have been investigated in a number of papers in solving scheduling or control problems that are related to shipping, ports, terminals and CTs using agent technology, such as [18–23]. Most of these papers have mainly focused on techniques for *automating* or *controlling* the operations in a CT, whereas, the contribution of this paper is on evaluating transshipment policies used (or to be used) by managers.

Several researchers have used general simulation packages to develop various models of CTs (cf. Vis and de Koster [3]). Such packages provide researchers a fast means to model the problems that they hope to understand. However, such packages are not flexible in modeling the characteristics of the CT in enough detail for many problems. A step towards more detailed and flexible modeling a CT have been investigated by Yun and Choi [24]. They used an object-oriented model approach to develop a series of simulation modules, which were used primarily to analyze different equipment types for handling the loading and unloading operations of a vessel. Thus, it included no modeling of managers and decision makers, just passive equipment.

Recently, a number of papers have been published on using multi agents systems for modeling CTs (cf. Henesey [16]). One example is Lee et al. [25], who simulated the PECT terminal in Busan, Korea. The study was primarily focused on the coordination between a number of different companies and how the resources (berths, QC, etc.) are allocated between them. The results indicated that the stronger the partnership relationships between shipper agents and CT operator agents, the faster the handling of containers. This study had a quite narrow purpose and did not model the containers, ships and stacks in any detail, which makes it unsuitable for the type policy evaluation we are looking for. Another example is provided by Lokuge et al. [26–28], which incorporates multi-agent systems for the decision tasks and an adaptive neuro-fuzzy inference system in making final decisions. However, they do not consider all the operations involved in transshipment operations, just the berth allocation. Moreover, Gambardella et al. [29] present an interesting approach, but the subject of their study is intermodal CT operations (thus not focusing on transshipment) in which a combination of operations research techniques with simulation using agents in a hierarchical order are applied. The problems they address are the scheduling, loading, and unloading operations. Decision support is divided into three modules: forecasting, planning, and simulation. The last module, simulation, employs agents that act in an agent simulator test bed to check for validity and robustness of policies. As their work focus on an intermodal terminal, transshipment operations unfortunately are not considered. Thus, from this perspective, one of the main contributions of this paper is that it covers all operations involved in the transshipment of containers in a CT.

From another perspective, the large body of research on dispatch rules in the context of job shop operations (cf. Blackstone et al. [30] and Green and Appel [31]) may be considered as related work. However, in such work assumptions are typically made that jobs are serially routed and that decision making is centralized. In our work we recognize that decision making is distributed and that decisions are made in parallel.

4 SimPort architecture

Based upon previous work [32], we have continued to use a knowledge engineering methodology known as MAS-CommonKADS [33]. A main reason for using this methodology is the support it provides for the knowledge acquisition process. For instance, there are templates and worksheets for understanding and specifying the system to be modeled. We model the CT managers by identifying the following: their tasks, how they are organized, methods for communication and coordination mechanisms. SimPort consists of two parts, the CT simulator that models the physical entities in the CT and a management simulator that models the actual decision makers. The management system simulator is based on the following managers that are modeled as agents: *port captain, ship agent, stevedore*, and *terminal manager*. Additional agents, which are modeled in the CT simulator, are the QCs and the SCs. The management model of the CT manager agents is illustrated in Fig. 1, which shows how the agents are organized. Communication and coordination are represented by arrows within the management model and interaction with the CT simulator is conducted by sending actions and receiving observations. The terminal agent is communicating with the stevedore agents. The stevedore agents are, in turn, coordinating activities with the ship captains, which are also communicating with the port captain. The stevedores are also issuing instructions to cranes and SC. As the purpose is to evaluate different policies, the autonomy of the agents

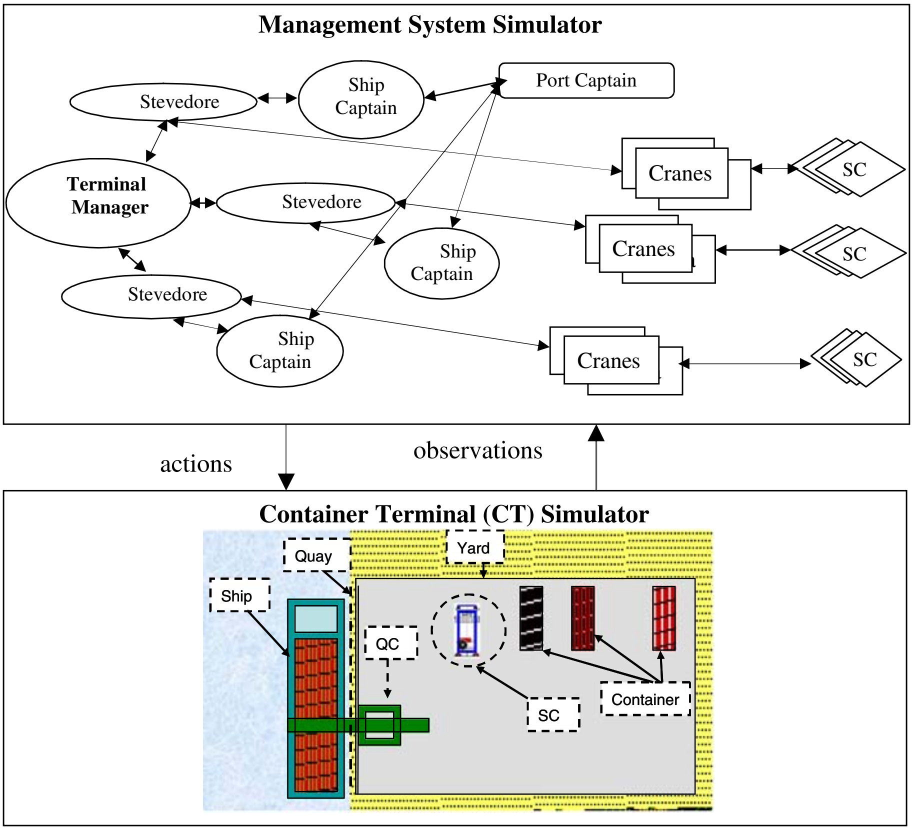

Fig. 1 Simplified view of the SIMPORT architecture

is quite limited. They make their decisions based on their state and on the information in the messages they receive from other agents. The agents' goals are only implicitly represented by the rules describing their behavior. As mentioned by Wooldridge [12] a merit of using reactive agents is that intelligent, rational behavior is that intelligent behavior emerge as a product of the interaction that the agent has with its environment. A more detailed description of the interaction between the agents is presented as an AUML diagram in Fig. 2.

4.1 The container terminal simulator model

The relevant entities of a CT described previously are modeled with the following characteristics (attached entities are marked in italic font):

Terminal: Length and width (m); Operating hours; *A yard*; and *A quay*.
Yard: Length and width (m); *A set of stacks* and *A set of paths* (where the SCs may drive).
Stack: Length and width (m); Maximal height (m); Position (x,y), e.g., the top left corner; Ship line or destination (optional); and *A set of containers* (variable).
Quay; Length (m); *A set of berth points*; Minimal distance between ships being worked at the quay (m); and *A set of QC*.
Berth point: Position (x,y).

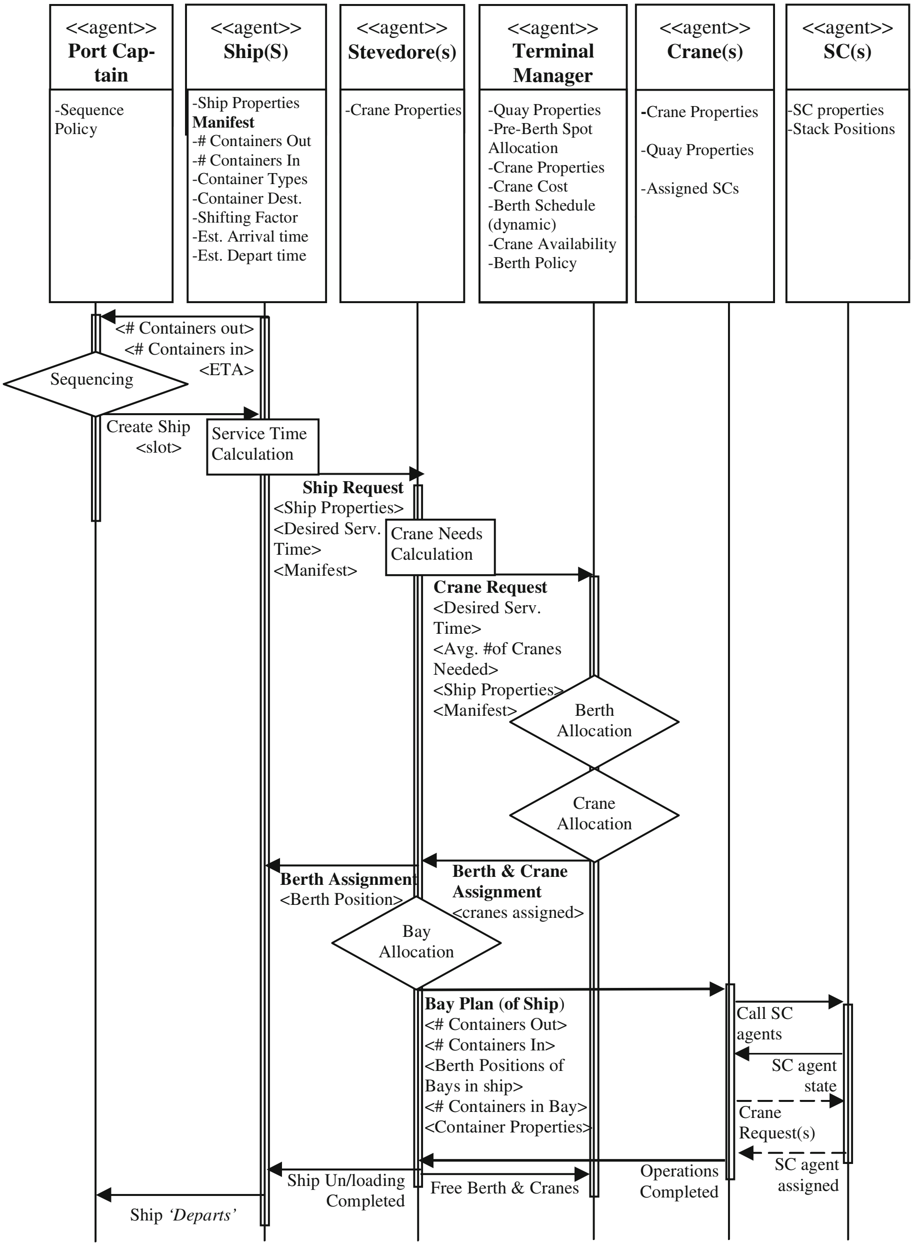

Fig. 2 AUML sequence diagram of agents in SimPort

Quay crane: Type of crane (regular, panamax, or postpanamax); Capacity (container moves per hour); *A set of SCs*; and *A buffer* (area for temporary storage of containers); and Crane speed.
Straddle carrier: Capacity (how many containers can it stack on top of each other); Position (x,y) (variable); and Maximum Speed (m/s).
Path: Start position (x_s,y_s); and End position (x_e,y_e).

Buffer: Capacity (number of containers).
Ship: Name; Type (regular, panamax or postpanamax); Length (m); Owner (Ship line); *A set of bays*; Estimated arrival time (variable); Desired departure time (variable); Actual arrival time (variable); and Position (x,y) (variable).
Bay: *A set of containers* (variable); A list of the containers to be loaded (variable); A list of the containers to be unloaded (variable); Capacity (number of containers); and Shifting factor (the percentage of container moves made by a crane for reshuffling containers which do not result in a container being loaded/unloaded).
Container: Type (TEU, FEU, hazardous, or refrigerated); Owner (Ship line); and Destination.

Once a ship is berthed it will remain berthed until the operations are completed, i.e., during the service time, which in practice is valid since the cost of interrupting or moving a ship during operations is expensive. When a ship is docked at a berth point, it will occupy the berth points corresponding to the length of the ship and the minimal distance between ships during the service time of the ship. As in a real CT, cranes cannot pass one over the other since they are fixed along tracks.

4.2 The management model

We modeled the CT managers as a set of agents by identifying the following: their tasks, how they are organized, methods for communication and coordination mechanisms [25]. The management simulator is based on the following managers that are modeled as agents: port captain, stevedore, ship agent, and terminal manager. In addition, the QCs and the SCs are modeled as agents. The agents make their decisions based on the information in the messages they receive.

4.2.1 Port captain agent

The port captain agent is constantly, once each day, searching for ships arriving to the port during the next 24 h period according to a schedule of arrivals. Based on their estimated arrival time and number of containers to be handled, the port captain decides in which order the ships will be served according to a sequence policy and its goal is to minimize the turn-around time.

From previous interviews and port visits, we have noticed that Port Captains may use three types of sequencing policies for arriving ships; first in first out (FIFO), highest earning first (HEF) and shortest job first (SJB). FIFO serves the ships according to the estimated time of arrival (ETA) on a first come and first out basis. Should the arriving ship deviate over 2 h from its expected ETA another arriving ship (that is arriving on time) may take its place. HEF implies the ship with the most containers to be loaded or unloaded will be given priority over all other ships that are scheduled. The HEF will sequence the ships with the higher number of containers first, given that there is a conflict, i.e. ships arrive <2 h from each others, otherwise according to FIFO. The more containers handled, the higher the earnings are for the terminal in serving the ship. Similarly, SJB assigns a ship to a berth with shortest service time first in order to turn-around a ship as fast as possible. The estimated service time is based on the amount of containers to be handled.

4.2.2 Ship agent

A unique agent represents each ship (i) arriving to the CT. The ship agent will possess the following information:

- Length of ship in meters (l_i).
- Type of ship.
- Estimated arrival time (t_i^{arriv}).
- Desired departure time (t_i^{dep}).
- The ship line that owns the ship.
- The number of bays in the ship.
- For each bay, the 'manifest' provides the following data; number of containers, container type, destination (from which we can infer it to be either an Export or Import container) and ship line (containers on board the ship may belong to other ship lines and this will affect in stack assignment).

When the ship is to be served, the ship agent sends its desired service time, t_i^{serv} to the stevedore agent, which is computed in the following way (where t_i^{wait} is the estimated waiting time);

$$t_i^{serv} = t_i^{dep} - t_i^{arriv} - t_i^{wait} \tag{1}$$

4.2.3 Stevedore agent

The goal of the Stevedore agent is to satisfy each ship agent's request, i.e., to be served within t_i^{serv}. It will request QC from the terminal agent that can handle the ship type, and a position of the cranes in order to serve the bays in a ship while trying to meet the estimated desired service time. The crane request is based on a calculation of the average number of cranes needed to work the ship. For example, if the number of containers to be loaded/unloaded, C_i is 400 and the desired service time corresponds to 4 h and the average capacity of the cranes, Q^s, is 25 moves per hour, then the number of cranes requested, Q is 4. (The reason for using the average capacity is to mirror the actual computations performed by actual stevedores.) The general formula used is:

$$Q = C_i/(Q^s * t_i^{serv}) \tag{2}$$

The second task of the Stevedore agent is to allocate the cranes provided by the Terminal manager agent to the different bays of the ship. It receives information from the ship agent regarding the number of containers in the bays, number of bays in the ship and the characteristics of the containers (size, type, destination and ship line). The bay allocation is done by assigning cranes to work an average number of containers (both to load and to unload) for all bays in a ship.

4.2.4 Terminal manager agent

The Terminal manager agent performs two tasks, allocation of berth points to a ship and allocating cranes to service a ship. Its goal is to berth the ships and allocate cranes in such a way that the service time and distance to the relevant stacks are minimized. It receives information from the stevedore agent on ship length (l_i) and will assign a set of berth points along the quay that the ship will occupy, which will include the spacing between two ships. From the 'request' sent by a stevedore agent, one for each ship, the terminal manager will allocate available cranes that can handle a ship type. In addition to the request, crane allocation is determined by crane type that can work a ship type and their distance to the berth spot. The number of cranes is limited and this may cause ships to either have slower service times or even wait.

The berth positions used by the terminal manager for the arriving ships will be determined by a *berth positioning policy*. From interviews with CT managers and collected data, two types of *berth positioning policies* have been identified that are actually used; berth closest to the stack (BCTS) policy and overall time shortening (OTS) policy.

The BCTS policy's objective is to place a ship closest to a 'target' stack which is the stack that will be the most visited by the SCs during the operations. That is, the one that has the largest sum of containers to be stored and containers to be fetched. The BCTS cause a ship to wait if a berth is occupied by another ship until that berth, which is closest to the stack, is available. The OTS policy, on the other hand, tries to place the ship to a berth position in order to minimize the turn-around-time for the arriving ship. In determining the berth position for an arriving ship the OTS policy is considering the sum of the estimated *Waiting Time and Service Time* at a potential set of berth points. The ship *Waiting Time* includes time left in serving another ship that is occupying a part of the quay. The estimation of the *Service Time* is based on the number of QCs and SCs employed, their performance, and the manifest. From the sum of the estimated *Service Time* and *Waiting Time*, i.e. the estimated turn-around time, the OTS policy will place a ship at the berth position with the shortest estimated ship turn-around-time.

4.2.5 Crane agent

The goal of a crane agent is to minimize (un)loading time as well as the distance traveled by the SCs. It receives a list from the stevedore agent which states all containers that should be unloaded/loaded from/to each bay. Based on this list, the Crane agent, will react by calling its three SC agents; an assumption based upon observations of real CTs where a number of transporters typically are 'bounded' to a specific crane. Based on SC agents' replies, it selects the SC agent most appropriate to pick up a particular container based on (a) availability (idle/busy) and (b) the distance between the SC and the container. The general objective for the crane agents is to load/unload containers as fast as possible and use the SCs to move the containers to and from the stacks in the most efficient way possible.

4.2.6 Straddle carrier (SC) agent

The SC agents are reacting to requests from their assigned crane agent. The SC agents have a map of the CT and their goal is just to satisfy the request of its crane agent.

If the stack that it has been ordered to put a container is full, the SC instead will go to the closest available stack. The SC agents move along one-way paths for safety reasons. The SC agents calculate the distance from the top left corner of a stack to the position of the crane working a ship's bay located at the berth point along the quay.

A SC agent determines its next destination through communication with the crane agent. The SC agent moves to a position in the yard that is generated by communication with the crane agent and subsequently establishes its next position by communicating back to crane agents that it has reached its assigned destination and is waiting for another task. The SC agent's function is to provide specific yard destinations rather than the container processing sequence. The model contains rules which determine an appropriate yard location based on current status of the stacks, stacking policy, and attributes of the SC agent.

4.3 Agent interaction

The communication between agents is implemented using a blackboard. The agents make decisions based on information in the messages they receive from each other. The intelligence level of the agents, such as stevedore, ship and crane agents can be considered reactive in that a specific action in the CT is executed upon a certain message. The major advantage in using reactive agents, according to Wooldridge [12], "*is that overall behaviour emerges from the interactions of the component behaviours when the agent is placed in its environment*". The interaction between the agents is summarized in Fig. 2, which adopts a pseudo AUML (Agent Unified Modeling Language) sequence diagram. The agent's goals are only implicitly represented by the rules describing the reactive behaviour, illustrated in Fig. 2.

5 Simulation experiments

SimPort was used in two series of experiments to evaluate stacking configurations and the transshipment operational policies.

5.1 Experiment I setup

A real CT (in India) was experiencing problems in serving arriving ships, which lead to ship waiting, often averaging three days. Ships were assigned to berths on a first-come-first-serve basis. The berth positioning was conducted on a more ad hoc basis. The stacks in the yard were organized between Imports and Exports. The managers were concerned that they would lose customers to competition and that more ships were planning to arrive at the CT. Therefore, the managers discussed ways of improving the operations without having to invest in equipment or extra labor. The managers in the terminal operations wanted to show or prove to the executives of the CT that by using different managing policies related to berthing of ships under some scenarios, the CT could handle the current arriving ships and even future demand. The managers at the CT provided data and layouts of their terminal for analysis. The following entities of the CT were modeled in SimPort:

- *Terminal*: The length and width of the terminal is 900 m and 1000 m; the operating hours are 07:00–20:00 from Monday to Friday.
- *Yard*: The length of the yard is 1000 m and width 890 m. Six large stacks that can store 180 containers each are defined. All stacks are assigned to a number of "ports of destinations", which are based on six different import and export destinations.
- *Quay*: The length of the quay that is able to serve docked container ships is 890 m. Four berth points are configured with a fixed length of 200 m between them along the quay. The minimal distance between ships is 20 m. Five QCs are assigned to work ships along a quay at the CT with a handling rate of 25 container moves per hour. The buffer size is three. Twenty SCs are employed during operations; four SCs are assigned to each crane. The SCs have a capacity of lifting one container over three and are set with a maximum speed of 30 km/h.
- *Ships*: The data was provided by CT managers at the real CT for developing the scenarios with three ships and the total number of containers for the each of three ships is 1100 for export and 1000 for import, which are identified as either reefer (5%), hazard (5%), and

standard (90%). In addition, each container is loaded (exported) or unloaded (imported) to/from a specific bay located on a ship. The arrival times for all 3 ships are randomly generated between the hours of 07:00–12:00.
- *Policies*: The berth positioning policies tested are the BCTS and OTS. Policies tested for sequencing arriving ships are FIFO, HEF, and SJB. Two container stacking policies are tested, Stacking by Ship Line and Stacking by Destination.

The output from the SimPort will be a berth assignment plan for scheduling, which includes the sequencing of arriving ships and the berth position that they will occupy along the quay. Terminal equipment will be assigned, e.g., QCs and SCs, to work ships. Finally, to compare performance levels of the various operational policies used, the following performance metrics are defined:

- *Total distance* — Total distances traveled for all the SCs used to serve the QCs for all three ships.
- *Average ship turn-around time* — Average time for turning-around a ship in a schedule (departure time — arrival time).
- *Average waiting time* — Average *Waiting Time* for a ship in a schedule.

Another possible metric is the cost for serving the ships (which is actually computed by SimPort). However, as this cost is mainly dependent of the ship turn-around time, and to some extent of the distance traveled by the SCs, we have chosen to focus on these. The same motivation can be applied to metrics such as the utilization rates for different types of CT equipment like the QCs, which in essence are captured by the turn-around time. The motivation for looking at distance traveled by SCs, is both related to cost, the more an SC travel the larger is the maintenance and fuel costs, and reliability and robustness, with increased slack time for the SCs the system would be better at handing disturbances.

5.2 Experiment I results

The simulation results of the evaluation of policy combinations are presented in Table 1. These are averages from 10 simulation runs and the low standard deviations indicate that these result are stable.

The shortest distances traveled by the SCs on average were found to be when applying the BCTS with the SJB policy, and where Stacking by Ship Line is outperformed by Stacking by Destination. Within the OTS position policy, there are slight differences in distances traveled, HEF caused the longest distances. In comparing stacking policies, Stacking by Destination yielded the shortest distances compared to Stacking by Ship Line. The shortest distance recorded for OTS was when using the SJB sequence policy and Stacking by Destination.

The average ship turn around per ship was found to be faster when using the OTS policy than the BCTS policy. For the OTS and Stacking by Ship Line policies, the fastest turn around times were achieved using SJB whereas the fastest turn around times for Stacking by Destination were achieved by using FIFO.

Also the average waiting times are longer for the BCTS than the OTS policy; more than 3 h for all policies, compared to less than half an hour for the OTS policy. Within the position policies the shortest waiting times are recorded when using the SJB policy. In comparing the average waiting times between stacking policies, Stacking by Ship Line on average had a longer waiting time.

For this CT achieving a reduction in waiting times by using the OTS berth policy seems preferable compared to achieving a minor reduction in distance traveled when using the

Table 1 Simulation results from experiment I. Average of 10 simulation runs and standard deviation (within parentheses) are presented

Simulation policy	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
	Stacking by ship line					
Total distance (km)	213.5 *(0.34)*	211.5 *(0.33)*	220.5 *(0.16)*	240.2 *(0.10)*	240.4 *(0.25)*	238.2 (0.14)
Ship turn around time	10:34:24 *(00:01:43)*	10:54:48 *(00:02:15)*	10:21:24 *(00:01:30)*	07:21:00 *(00:00:49)*	07:24:30 *(00:01:11)*	07:17:12 *(00:00:38)*
Waiting time	03:37:36 *(00:01:21)*	03:47:24 *(00:01:47)*	03:15:54 *(00:01:44)*	00:20:54 *(00:01:12)*	00:24:36 *(00:01:26)*	00:17:00 *(00:00:49)*
	Stacking by destination					
Total distance (km)	205.4 *(0.32)*	211.5 *(0.33)*	201.5 *(0.15)*	227.2 *(0.10)*	230.4 *(0.25)*	226.2 (0.14)
Ship turn around time	10:19:30 *(00:01:21)*	10:36:36 *(00:02:07)*	10:03:36 *(00:00:51)*	07:13:54 *(00:00:44)*	07:24:18 *(00:01:04)*	07:17:18 *(00:00:29)*
Waiting time	03:22:12 *(00:01:14)*	03:47:42 *(00:01:34)*	03:15:24 *(00:01:39)*	00:12:24 *(00:01:04)*	00:11:06 *(00:01:17)*	00:06:36 *(00:00:42)*

BCTS policy. Among the sequencing policies, the SJB policy nearly always yields the best results independently of what berth and stacking policies are used. Similarly, Stacking by Destination outperforms Stacking by Ship Line.

5.3 Experiment II setup

In the second series of experiments a more comprehensive set of scenario runs were performed on a model of a real CT located in Northern Europe that has a throughput capacity of 500,000 containers per year with the current operational equipment. The layout of the CT is presented in Fig. 3. We tested the same policies that were used in the first series of experiments. In the modeled terminal, export stacks, import stacks and stacks for hazardous and refrigerated containers are considered. The spacing between stacks is 40 m and the length of the stacks is 150 m and the width is 50 m. Each stack has a storage capacity of 180 containers (2 × TEU or 1 ×40′). The x and y coordinates of the top left corner of the stacks are used for positioning the stack in the yard and are used by the SCs for determining distances to the stacks in the yard. The SC paths follow a one-way direction as is commonly observed in real CTs for safety reasons. There are five QC and three SC assigned to each QC. Three of the QCs are normal sized with an average handling rate of 30 container moves per hour. The other two cranes are much larger so as to handle ships that are too wide to cross the Panama canal, which are called post-panamax, and able to handle 40 containers moves per hour. The buffer size is three for each QC.

The quay has a length of 800 m with a spacing of 20 m between ships and there are 800 berth points (one for each meter). The import container stacks are mostly located in the rear of the yard. The export container stacks are located closer to the cranes and berths. The hazardous container stacks are located in the middle of the yard.

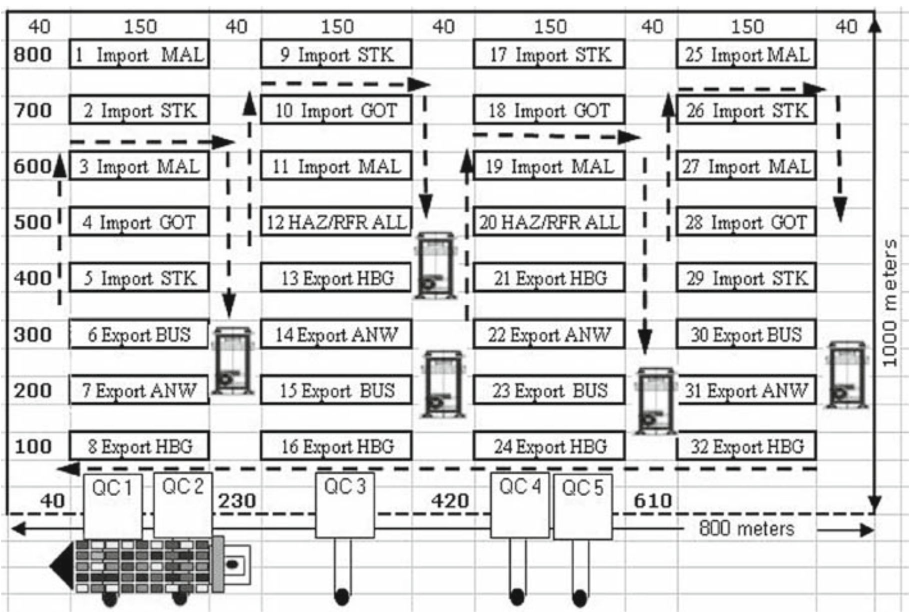

Fig. 3 Simulated CT layout

Two sets of ships were generated for studying two levels of number of arriving ships during a week, Low and High load volume. The Low load volume represents a schedule of ships with 14 ships of varying lengths between 140 and 340 m with in total 5000 containers to loaded or unloaded. This corresponds to an average load of 50% of the maximum capacity of the CT. The High volume represents a schedule of 21 ships (also varying between 140 and 340 m) with 7000 containers. The schedules of ships were generated with two different distributions of estimated ships arrivals, Peak or Even. The Peak distribution implies that there will be two peak arrival days during a week, whereas the Even distribution does not have any peak or 'low' arrival days. Thus, altogether four variants of schedules were considered; Peak and Low volume, Peak and High volume, Even and Low volume, and Even and High volume. The actual arrival times are randomly generated between −2 to 8 h with respect to the intended scheduled arrival time, so as to mimic the actual situations in a real CT in which ships are arriving late or early.

5.4 Experiment II results

The results are summarized in Table 2 (Stacking by Destination) and Table 3 (Stacking by Ship Line). For each performance indicator four different ship schedule scenarios are listed under the Distribution/Load Vol. heading. The figures are averages from 10 simulation runs. As in the first experiment, the standard deviations are low (<0.2% for the distance traveled and less than 1% for the turn around time). For reason of readability we do not include them in the tables.
The difference in distance traveled by the 15 SCs indicates, as expected, that the shortest distance is when BCTS positioning policy is used. When analyzing the sequence policies in relation to the positioning policies, little effect is viewed when using BCTS. There are differences in distances recorded between the sequence policies for OTS with HEF and SJB having less distance traveled when load is high. The shortest distances traveled by the SCs were found on average when using Stacking by Destination. For Stacking by Ship Line the results were almost similar for all positioning policies when using BCTS, whereas HEF was clearly best when using OTS.

As expected the average ship turn-around times for the OTS policy are lower than for the BCTS policy. Thus, there seems to be a trade-off between the distance traveled by the SC

Table 2 Results for the stacking by destination policy

Distribution/Load Vol.	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
	Total distance traveled by SCs (km)					
Even/Low	1438	1440	1440	1590	1465	1576
Peak/Low	1439	1439	1443	1484	1505	1450
Even/High	2042	2038	2044	2331	2132	2200
Peak/High	2049	2050	2048	2156	2123	2048
Total	6968	6967	6975	7561	7225	7274
	Average ship turn-around Time (hh:mm)					
Even/Low	08:54	09:08	08:40	06:57	08:30	07:04
Peak/Low	11:37	11:55	11:51	08:36	09:40	08:33
Even/High	10:12	11:26	09:39	08:03	08:10	07:20
Peak/High	15:12	15:24	13:41	12:02	13:41	12:34
Average	11:43	12:15	11:06	09:08	10:11	09:05

Table 3 Results for the stacking by ship line policy

Distribution/Load Vol.	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
	Total distance traveled by SCs (km)					
Even/Low	1446	1445	1441	1601	1476	1587
Peak/Low	1447	1446	1450	1495	1515	1460
Even/High	2052	2049	2054	2348	2147	2215
Peak/High	2059	2063	2059	2171	2138	2061
Total	7004	7003	7004	7614	7276	7323
	Average Ship turn-around time (hh:mm)					
Even/Low	08:55	09:10	08:41	06:59	08:33	07:07
Peak/Low	11:39	11:57	11:53	08:38	09:43	08:36
Even/High	10:15	11:28	09:40	08:06	08:12	07:22
Peak/High	15:14	15:26	13:43	12:06	13:45	12:38
Average	11:45	12:17	11:07	09:11	10:14	09:08

and the ship turn-around time. Regarding the sequence policies it seems as SJB often is the best choice. Regarding the differences between stacking policies, Stacking by Destination have on average a faster turn-around than Stacking by Ship Line.

Assuming that a fast turn-around time is the main objective, the best positioning policy seemed to be the OTS policy. If the objective is to minimize the total distance in meters traveled by SCs then the BCTS policy appears to be the best choice. Although transporter productivity may seem less important than turn-around time, it can have negative consequences such as forcing the QCs to wait for containers to be loaded or causing congestion at the yard. For unloading operations, a QC can land the container on the ground and keep landing containers to a maximum of three containers in the buffer area until they are picked by the SC. During the simulation there was zero QC idle time during unloading operations. However, during the loading operations some QC idle time was witnessed. The sequence policies of arriving ships such as FIFO, HEF, or SJB can affect the performance as well. The most common sequence policy and the most 'fair' is the FIFO policy. The SJB policy when used with both BCTS policy and OTS policy resulted in turn around times that were on average faster than the FIFO or HEF policies. The use of the HEF policy yielded longer turn-around around times. The experiments indicated that choice of stacking policy could lead to shorter distances traveled by the SCs. In certain situations when the QCs are not the bottleneck, the stacking policy can affect the performance of the SCs.

5.5 Validation

Validation determines to which extent a simulation model is an accurate representation of the real system. In validating the SimPort model, we followed Law and Kelton [24] and performed a sensitivity analysis of the programmed model. Several sensitivity analysis experiments were conducted in which one ship with nine bays was simulated with combinations of one container or two containers positioned in different bays of the ship. We tested different input data, such as crane moves per hour, position of target stacks and containers in a ship, for its effects on the crane allocation to a bay on a ship, distances traveled by the SCs and the ship turn-around time by increasing or decreasing the values for the input data. The simulation results were consistent both with calculations and with our perceptions of the CT system. Thus, according to Law and Kelton [14], we can infer a *face validity* of the SimPort model.

In further seeking to validate SimPort, a series of interviews and questionnaires were conducted. The collected initial results suggested that the Operations Directors and managers of several CTs found the SimPort model and results to be credible. The relative merits and the actual values (e.g. turn-around times) of the different policies, as indicated by the simulation results, were in line with what managers were expecting. Often mentioned by the interviewees was that not enough attention on the decision making was made when a ship arrives at a container terminal. Additionally, the prospect of evaluating strategies that consider the coupling of operations policies with the stacking of containers in the yard, the distances to be traveled by the transporters with berth positioning and QC allocation to be enticing in order to serve customer and lower costs. Current software tools do not consider such parameters or variables as SimPort does and analytical tools, which are the most used are often viewed to be cumbersome for deeper analysis. Further details about the validation of SimPort can be found in Henesey [16].

6 Conclusion and future work

The experiments have shown that MABS can be used to study the impact of different policies for sequencing, berthing, and stacking on the performance of CTs. We have analyzed which CT management policies could be best considered in relation to: ship arrival patterns, number of containers to be handled during a time period, changes in container stack layout in the yard and berth. SimPort has proven able to capture many of these types of changes. In addition, we found that MABS offered a more natural (i.e., structure preserving) way of modeling the decision making entities. This was very useful in the discussions with the different CT stakeholders, e.g., when validating the behaviour of SimPort, as well as making the simulator easy to modify. Moreover, it is relatively easy to capture any degree of detail of the system, as well as parallel and distributed decision making, which can be quite difficult when using e.g., traditional queuing models.

The agent-based manager system which assigns berth schedules using the various management policies has indicated that some policies have faster ship turn-around times and lower SCs usage than other policies for certain scenarios. In addition, other performances measures can be computed such as costs, which depends on turn-around times and the number of containers handled, etc. However, the main contribution of the paper is not that a particular policy is better than another policy, because this may differ between container terminals (depending on the layout, the number and capacity of equipment, the load in terms of ships and containers to be handled etc.). The main contribution was rather to show how MABS can be used to evaluate policies in a specific context or situation.

Future work would be to include other performances measures and developing more policies for testing; distribution of arriving ships, number of containers to be handled, characteristics of the containers and yard stacking policies. CT operators have shown interest in evaluating candidate policies for their CTs using SimPort. The case study in experiment I coupled with the tests conducted in experiment II suggests many tantalizing opportunities to further improve SimPort. Additional decision making capabilities for the manager agents could be used for enhancing the decisions made. Often mentioned by CT managers is to incorporate economic or cost indicators into the simulation, such as cost per hours for groups employed to work a ship, cost for fuel consumed by SCs, number of containers handled during a specific period and profit or loss made.

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