Simulation of Operational Policies for Transhipment in a Container Terminal

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Abstract: - A simulation approach utilizing agent technology is applied to the problem of analysing operational policies for transhipping containers in a port container terminal. The managers involved in transhipment operations, i.e., the terminal manager, the port captain, the stevedores and the ship captains, as well as some of the operators of the physical resources, such as cranes and straddle carriers, are modelled as agents. To illustrate the approach, the simulator, called SimPort, has been configured based on real data from container terminals and used for comparing six transhipment policies in several scenarios. The policies concern the sequencing of ships and berth allocation. The policies are evaluated with respect to a number of aspects, such as, turn-around time for ships, and travelled distance of straddle carriers.

Key-Words: - Container Terminals, Decision Support Systems, Multi Agent Based Simulation, Transhipment Operations, Berth Allocation,

1 Introduction
The number of Twenty-foot Equivalent Unit containers (TEUs) shipped world-wide has increased from 39 million in 1980 to 356 million in 2004 and growth is still projected at an annual growth rate of 10% till 2020 [1]. Ports and container terminals (CTs) are trying to meet increasing demand by creating additional capacity. According to Drewry consultants, the cost for planning for container terminals in Northern Europe for 2004 is €549 million with total project costs reaching €6081 million [1, 2]. Many of the solutions considered can be classified as either physical expansion or increasing terminal performance. Some types of physical expansion solutions are purchase of new or additional equipment, hiring more labour, development and purchase of IT systems. Solutions that can be classified as increasing terminal performance are optimisation, use of simulation to use resources more efficiently.

This paper presents a multi-agent based simulation (MABS) approach to evaluating different ways of increasing terminal performance. A simulator called SimPort has been developed to show the viability of this approach. The agent based approach offers the power of modeling the decision making processes of different actors. An application that may benefit in using an agent based approach is the operations of transhipping containers in a CT.

The remainder of the paper is organized in the following way; first a general description of the CT transhipment processes is provided, then the agent-based simulator is presented. The design of the experiments is explained in section 4 which is followed by a description of the results that are analyzed and discussed. Finally, some conclusions are presented together with pointers to future work.

2 Container Terminal Description
Container handling activities in CT are shown to be dependent on various related subsystems [3]. The managers involved are generally referred to as terminal managers, ship planners, yard planners, ship line agents, and resource planners. To satisfy the management goals for all the managers is difficult because they often have conflicting interests, i.e. the discharging of containers at a fast rate may lead to sub-optimal conditions for the stacking and positioning of containers in the yard. Ideally, the owners of arriving ships would like to ensure that when their ships arrive to a CT the berths are empty so there are no delays. On the other hand, CT management would like to reduce the capital outlay so that berths are always utilized. Sometimes one ship line can become dominant and its demands can take excessive importance, e.g. one ship requiring preferential service. The management of a CT can be a complex problem for CT managers to
solve because of the following reasons: performance is determined by a variety of inputs and outputs; the size and number of actors often having conflicting objectives; intrinsic characteristics of the CT; and uncertain external influences such as government or international policies, weather, politics, etc. The processes involved in the transshipment of containers can be divided into sub-processes [4]. Some of these sub-processes are identified and the form of decision making required for the CT management to consider are illustrated in Figure 1.

Fig. 1 Decision Types & Policies for a Simulated CT

The arrival of a ship requires the CT management to locate a berth position and a service time to schedule operations. This choice of a berth policy has an impact on other decisions in the ship operations. The berth policy is composed of a sequencing policy and a positioning policy. The loading and unloading sub-processes would require an operational decision by the CT management in allocating quay cranes (QC) and straddle carriers (SC). Usually, the allocation of these resources is conducted in parallel. The operations concerning container stacking in the yard is influenced by the stacking policy used by the CT management.

The containers are usually sorted using a stacking policy which considers; type (export or import), size (a 40’foot or 20’foot), destination, or by ship line that owns the container. The positioning policy and the stacking policy are viewed as either tactical or strategic depending on how flexible the CT can configure the berths and stacks. The flow of containers is bi-directional, which means that the containers are placed into stacks and then pulled out.

Ideally, in transshipment operations the ship that is unloading the containers to be loaded by another ship will be serviced at the same time with the other ship in order to avoid the problems of stacking containers and thus provide a faster service. However, in reality the containers must often ‘dwell’ or be placed in a yard stack for a period waiting to be loaded onto another ship.

Often mentioned by CT managers during port visits is that existing tools for simulation of CT transhipment policies, are too cumbersome, do not accurately model the CT, are too expensive and not fast. In addition, some CT experts confided that berth allocation was conducted mostly by middle managers, whom did not possess enough information in making the berth assignment decision.

In this paper we study how MABS can be used to analyze the impact of the different policies for sequencing and berthing on the performance of CTs under various conditions.

3 SimPort Simulation Model

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.

3.1 The Container Terminal Model

The relevant entities of a CT terminal described previously are modelled in the following way (entities are marked in italic font):

**Terminal:** Length and width (meters); Operating hours, e.g., 07:00 – 18:00 from Monday to Friday; The terminal handling charge (THC), a cost paid by the ship lines for handling each container unit (dollars per container); A “penalty” cost, an extra cost for handling containers out of operating hours (dollars per container); A yard; and A quay.

**Yard:** Length and width (m); A set of stacks and A set of paths.

**Stacks:** Length and width (m); Maximal height (m); Position (x,y); Ship line or destination (optional); and A set of containers (variable).

**Quay:** Length and width (m); The position of the berth points along the quay that can be assigned to arriving ships (x,y); Minimal distance between ships being worked at the quay (m); and A set of quay cranes.

**Quay cranes:** Type of crane (regular, panamax, or postpanamax); Capacity (container moves per hour); A set of straddle carriers (always three); and A...
**buffer** (with room for three containers and Crane speed).

**Straddle carriers**: Capacity (how many containers can it stack on top of each other); Position (x,y) (variable); and Maximum Speed (m/s).

**Ships**: Name; Type (regular, panamax or postpanamax); Length (m); Owner (Ship line); Cost of operation (dollars per hour); A set of bays; Estimated arrival time; Desired departure time; and Position (x,y) (variable).

**Bays**: 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 moves that made by a crane for reshuffling containers which do not result in a container being loaded/unloaded).

**Containers**: Type (TEU, FEU, hazardous, or refrigerated); Owner (Ship line); and Destination.

The berth points in SimPort are segmented in increments of 1 meter. Once a ship is berthed it will remain berthed until the operations are completed, which in practice is valid since the cost of interrupting or moving a ship during operations is expensive. When ship i is docked at berth point b and at time t, the ship will occupy so that means not other ships can use berth points between b-10 and b + l_i + 10, from time t to t + (l_i / v), where l_i is the length of the ship and v is the service time. As in a real CT, in the modelled CT, cranes can not pass one over the other since they are fixed along tracks. The yard of the CT has stacks for container storage. Stacks store containers under various management policies such as; if they have the same type, etc.

3.2 The Management Model

By using a knowledge engineering methodology known as MAS-commonKADS, 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 [14]. The management simulator is based on the following managers that are modelled as agents: port captain, stevedore, ship agent, and terminal manager. In addition, the quay cranes and the straddle carriers are modelled as agents. The agents make their decisions based on the information in the messages they receive.

### 3.2.1 Port Captain Agent

The port captain agent is constantly, once each day, searching for ships arriving to port during the next 24 hour period. Based on their estimated arrival time (and sometimes size), the port captain decides in which order the ships will be served according to a sequence policy.

In this work we focus on three sequencing policies; First In First Out (FIFO), Highest Earning First (HEF) and Shortest Job First (SJF). FIFO serves the ships mainly according to the estimated time of arrival (ETA). Should the arriving ship deviate over 2 hours from its expected ETA another arriving ship (that is arriving on time) may take its place. HEF sequence the ships according to the number of containers to be handled (given that there is a conflict, otherwise according to FIFO). The more containers handled, the higher the earnings are for the terminal in serving the ship. The order is determined from a list of ships that are expected to arrive during a 24 hour period. Similarly, SJF assigns a ship from a schedule of ships that are to arrive during a 24 hour period to a berth according to the fastest service time required to turn-around a ship based on amount of containers to be handled.

### 3.2.2 Ship Agent

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

- Length of ship in meters (l_i).
- Type of ship (v_i) which is regular, panamax or post panamax,
- Desired service time (t_i^serv ) is based on the schedule, from the ship line perspective, listing estimated arrival time (t_i ^arriv ) and estimated departure time (t_i ^dep ).
- The Ship line that owns the ship
- The number of bays in the ship (j_i).
- For each bay, the ‘manifest’ provides the following data; number of containers, and for each container type (whether a 40’, 20’, Refrigerated or Hazardous), 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).
- The hourly operating cost.

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 waiting time);

\[
(1) \quad t_i^serv = t_i^dep - t_i^arriv - t_i^wait
\]
3.2.3 Stevedore Agent
The Stevedore agent will try to satisfy each ship agent's request, i.e., to be served before $t_{serv}$. It will request quay cranes from the terminal agent that can handle the ship type, $v_i$ 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 hours and the average capacity of the cranes, $Q'$, 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:

$$Q = \frac{C_i}{Q'} \ast t_{serv}$$

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 load and unload) for all bays in a ship.

3.2.4 Terminal Manager Agent
The Terminal manager agent performs two tasks, allocation of berth points to a ship and allocating cranes to service a ship. It receives information from the stevedore agent on ship length ($l$) and will assign a sequence of berth points ($b_i$) 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. Crane allocation is determined by crane type(s) that can work a ship type, $v_i$ 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. Cranes are assigned by the average number of crane moves per hour $Q'_v$, and dividing to the number of containers, $C_i$ to be worked for ship $v_i$.

The berth positions used by the terminal manger 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 (i) containers to be stored and (ii) containers to be fetched. The BCTS will 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 ships to berth positions in order to minimize the total ship turn-around-time for all arriving ships in a scheduled period of time. In determining the berth position for an arriving ship the OTS policy is considering the Waiting Time during the simulation from a potential set of berth points. The number of possible berth points depends on the berth spacing as well as a ship’s length plus a buffer distance. 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 SCs employed, the routes covered by SCs and their average speed. The estimated sums of all the routes travelled by each SC are totalled to provide the distance being covered by the SCs for each ship. From the sum of the estimated Service Time and Waiting Time, i.e. the turn-around time of the OTS policy will place a ship wherever the shortest estimated ship turn-around-time is achieved.

3.2.5 Crane Agent
The crane agents are coordinated by a stevedore agent during operations. 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 and based on their replies, select the SC agent most appropriate to pick up a particular container based on a) availability (idle/busy) and b) that 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.

3.2.6 Straddle Carrier (SC) Agent
The SC agents are reacting to requests from their assigned crane agent, an assumption is based upon observations of real CTSs where a number of transporters typically are ‘bounded’ to a specific crane. 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 and stacking policy, and attributes of the SC agent.

4 Design of Simulation Experiments
Simulated scenario runs are performed on a model of a real CT locate in Northern Europe that has a throughput capacity of 500,000 containers per year with the current operational equipment. In the layout of the CT presented in Fig. 2, the stacks, the berths, and the SC paths were considered in the model, whereas the inland interface of the CT, i.e., the rail connection and the gate for truck interchange, was not modelled. The stacking policy used is, stack by Line. In the modeled terminal export stacks, import stacks and stacks for hazardous and refrigerated containers are considered. The spacing between stacks is 40 meters and the length of the stacks is 150 meters and the width is 50 meters. Each stack has a storage capacity of 180 containers (2 x TEU or 1 x 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 SCs follow a one-way direction for safety reasons. In the layout, there are five quay cranes (QC) that are assigned to work ships along a quay. There are 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.

The handling rates of the two ‘post-panamax’ cranes are averaging 40 containers moves per hour. The quay has a length of 800 meters with a spacing of 20 meters between ships. There are 800 position points (range from 1 meter to 800 meters) that can be used to assign an arriving ship. 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 located in the middle of the yard. Finally, there are 15 terminal transporters called SCs that are assigned to the 5 quay cranes.

4.1 Scenarios
For the simulation experiments, two sets of ships were generated for two levels of berth utilization for arriving ships, Low and High. The Low volume represents a schedule of ships with a number of containers to be handled for the week to be set at 5,000 containers with 14 ships representing an average load of 50% of the maximum that the CT can handle physically. A High volume of ships is a schedule of ships with 7,000 containers and 21 ships, representing an average load of 70% that can be handled at the CT. The schedules of ships were generated with a distribution of ships during the schedules that can be considered to be Peak or Even. A Peak distribution implies that there will be at least two peak arrival days during a time period and an even distribution represents a number of arriving ships scheduled to arrive during a time period without peak or ‘low’ arrival days. Altogether four variants of schedules were considered; Peak and Low volume, Peak and High volume, Even and Low volume and Even and High volume.

4.2 Performance Indicators
The main production measures in a real CT are mostly based on ship productivity, which is container moves/ship-hour at berth. The SimPort model is designed to evaluate proposed policies for
yard layouts, sequence of ships, berthing assignments (sequence and positioning) and container handling strategies. To compare proposed alternatives for a given terminal, the following measures of performance are defined:

- Average Turn-Around Time: Average time for turning-around a ship in a schedule.
- Maximum Turn-Around Time
- Average Distance (m): Total distances travelled in meters for each of the SCs used to serve cranes assigned to ships in a schedule.

5 Results

The simulation experiments lead to the following preliminary results summarized in Table 1.

<table>
<thead>
<tr>
<th>Distribution / Load Vol.</th>
<th>Average Distance Traveled by SCs (m)</th>
<th>Average Ship Turn-Around Time (hh:mm)</th>
<th>Max Turn-Around Time for a Ship (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BCTS</td>
<td>HEF</td>
<td>SJB</td>
</tr>
<tr>
<td></td>
<td>102 739</td>
<td>102 831</td>
<td>102 831</td>
</tr>
<tr>
<td></td>
<td>Peak / Low</td>
<td>102 767</td>
<td>102 767</td>
</tr>
<tr>
<td></td>
<td>Even / High</td>
<td>97 225</td>
<td>97 064</td>
</tr>
<tr>
<td></td>
<td>Peak / High</td>
<td>97 580</td>
<td>97 618</td>
</tr>
<tr>
<td></td>
<td>Average Ship Turn-Around Time (hh:mm)</td>
<td>Even / Low</td>
<td>15:24</td>
</tr>
<tr>
<td></td>
<td>Peak / Low</td>
<td>23:02</td>
<td>23:02</td>
</tr>
</tbody>
</table>

Average Distance Traveled by SC — the difference in meters travelled by the 15 SCs indicates, as expected, that the shortest distance is when BCTS is used. When analysing 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 travelled when load is high.

Average Ship Turn-Around Time — 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 travelled by the SC and the ship turn-around time. Regarding the sequence policies it seems as SJB often is the best choice.

Max Turn-Around Time for a Ship — indicates that the longest times for turning-around a single ship are when applying the BCTS and using the HEF sequence policy. The OTS using the FIFO or the SJB show similar results.

6 Conclusion and Future Work

The objective of using MABS such as SIMPORT was to analyze 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 layout in the yard and berth. SIMPORT is able to reflect many of these types of changes into the model for simulation.

The agent-based manager system has indicated that some policies have faster ship turn-around times and lower distances travelled by SCs over other polices for certain scenarios.

Future work would be to evaluate other performances measures and developing more polices for testing; distribution of arriving ships, number of containers to be handled, characteristics of the containers and yard stacking policies.

References: