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A SIMULATION MODEL FOR STRADDLE CARRIER OPERATIONAL ASSESSMENT IN A MARINE CONTAINER TERMINAL

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ABSTRACT

The globalization combined with the success of containerization has brought about tremendous increases in the transportation of containers across the world. This leads to an increasing size of container ships which causes higher demands on seaport container terminals and their equipment. In this situation, the success of a seaport container terminal resides in a fast transshipment process with reduced costs. For these reasons it is necessary to optimize the terminal's processes. The aim of this paper is to optimize the internal transport cycle in a marine container terminal managed by straddle carriers. Three sub-systems are analyzed in detail: the landside and the quayside transportation and the storage of containers in the yard. The conflicts and decisions that arise from these three subsystems are analytically investigated. Moreover, a decision support system (DSS) is developed in order to obtain valid results for the whole transport chain. Simulation has been used to compare different straddle carrier's operation strategies, such as single-cycle versus double-cycle, and different dimensions in the handling equipment fleet. The simulation model is explained in detail and the main decision-making algorithms from the model are presented and formulated.

Key words: Port operations, straddle carrier, container terminal optimization, simulation, operational research.

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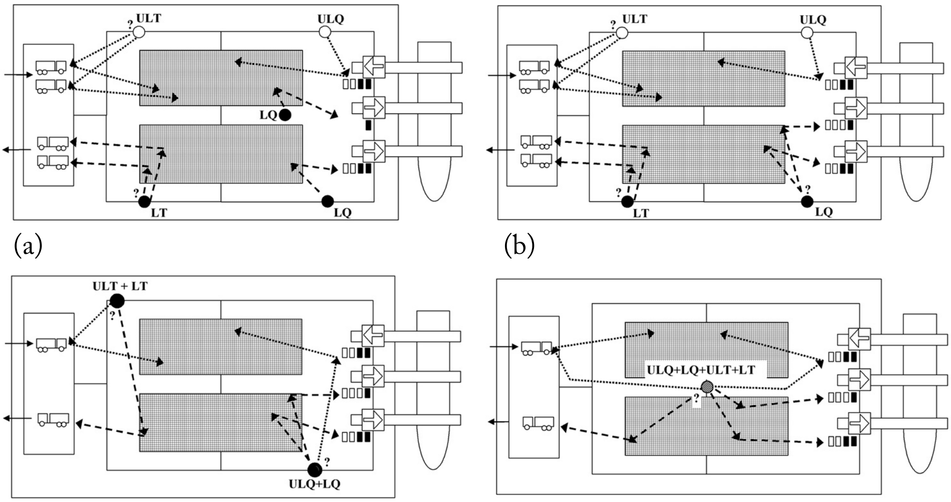
INTRODUCTION

The purpose of this paper is to compare at operational level different strategies to assign straddle carriers (SC) to concrete tasks in a marine container terminal. There are four types of tasks for straddle carriers: to transport a container to the quay crane to be loaded in the ship (LQ), to pick up an unloaded container from the quay zone and deliver it to the storage yard (ULQ), to pick up a container from the storage yard to dispatch it through the truck gates (LT) and to receive a container from a truck and transport it to the storage yard (ULT).

According to the types of task that a particular SC can be assigned to, three assigning strategies can be defined. The single-cycle strategy, where a SC can only be assigned to one type of task, the double-cycle strategy where a SC can be assigned to both of the available type of tasks (L-loading and UL-unloading) but only in one zone (Q-quay zone or T-truck gates area) and the quadruple-cycle where a particular SC can be assigned to all types of task in any zone.



(a) (b) (c) (d)

Figure 1. Available jobs depending on the SCs assignment strategy. (a) Single cycle. (b) Single cycle with quayside pooling strategy. (c) Double cycle. (d) Quadruple cycle.

The performances of these three assigning strategies are compared using a simulation model. Moreover, heuristic algorithms for the straddle carrier job assignment and for the allocation of containers in the storage yard have been developed.

ASSIGNMENT AND ALLOCATION ALGORITHMS

The optimum location of containers in the storage yard and the optimum assignment of tasks to straddle carriers are defined as NP-hard problems (1). For this reason, analytical solutions require a lot of constraints and do not consider the interaction of more than one subsystem. For example (2) analyses the berth allocation to ships, (3, 4) study the crane split (i.e. the allocation of quay cranes to ships and the ships' sections), (5, 6) analyze gantry crane productivity, (7, 8, 9) focus on storage and stacking logistics and (10, 11) use queuing theory to optimize quayside interconnection.

The goal of this research is to find an integrated solution for the three subsystems. For this reason, simulation is used as a tool to solve together all these problems and obtain an integrated solution. However, the simulation model needs three heuristic algorithms in order to support decisions in the following areas:

— Assigning jobs to straddle carriers and routing them.
— Allocating inbound containers in the yard.
— Allocating outbound containers in the yard.

The simulation model does not make decisions in allocating quay cranes to vessels and allocating vessels to berths neither.

In the next lines of the paper these three algorithms are presented.

Assigning jobs to straddle carriers

The algorithm has two main parts: identification of available jobs and assignment to SC of the best job.

In the berth area, there are two possible jobs to assign to straddle carriers, depending on which type of operation has to be performed: to pick up a container in the quay crane to bring it to the yard (ULQ - the quay crane is unloading a vessel) or to pick up a container in the yard to bring it to a quay crane (LQ - the quay crane is loading a vessel). In the truck gates area, there are two more possible jobs: to pick up a container in the yard to bring it to a truck gate (LT - loading an empty truck) and to pick up a container in a truck gate to bring it to the yard (ULT - unloading a truck).

The total number of available jobs to assign to a particular SC, depends on the straddle carrier's assignment strategy (simple, double or quadruple cycle). For example when a SC is operating in simple cycle in the berth area, only one job type is available as long as the SC is assigned to a quay crane performing only loading or only unloading operations (ULQ or LQ). It can happen that the SCs operate in pooling strategy; and they are not assigned to a particular quay crane, in order to achieve greater productivities (11). In this situation, for simple cycle, each SC is assigned to one process (ULQ or LQ) and the number of available jobs depends on the number of quay cranes that are performing this process. On the other hand, for landside operations each SC is only assigned to one process (ULT or LT) in simple cycle strategy. Then, the number of available jobs is the number of truck doors where this process (ULT or LT) will be carried out.

When the SCs are performing landside operations in double cycle, the number of available jobs is the total number of operative truck doors. The same happens at quayside interconnection in double cycle strategy, when the total number of jobs is the total number of quay cranes operating at the moment. Finally, in quadruple cycle the total number of jobs is the total number of operating trucks doors and quay cranes in the terminal.

<table>
<tr><th rowspan="2">Terminal Area</th><th rowspan="2">Type of operation</th><th colspan="2">Number of available jobs in Single Cycle strategy</th><th rowspan="2">Double Cycle</th><th rowspan="2">Quadruple Cycle</th></tr>
<tr><th>No Pooling</th><th>Pooling</th></tr>
<tr><td rowspan="2">Berth Area</td><td>LQ</td><td>Only 1: transfer the next container of the crane's loading sequence from the storage yard to the under crane buffer.</td><td>1 to 5: equal to the number of cranes loading the same ship. Transfer the next container of the one of these cranes' loading sequence from the storage yard to the under crane buffer.</td><td rowspan="2">LQ +ULQ both in Pooling strategy</td><td>(LQ +ULQ both in Pooling strategy) + LT + ULT</td></tr>
<tr><td>ULQ</td><td>1 to 4: equal to the number of containers unloaded and buffered under the crane.</td><td>1 to 20: equal to the number of containers unloaded and buffered under all the cranes that are unloading the ship.</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Tuck Gates Area</td><td>LT</td><td colspan="2">Equal to the number of trucks waiting to be loaded</td><td rowspan="2">LT + ULT</td></tr>
<tr><td>ULT</td><td colspan="2">Equal to the number of trucks waiting to be unloaded</td></tr>
</table>

Table 1. Number of Available Jobs depending on the SCs Assignment Strategy.

Once the available jobs, depending on the strategy (simple, double or quadruple cycle), are identified, the next step is to evaluate an objective function for each one of these available jobs. Afterwards, the job which minimizes the objective function will be selected. Moreover, it has to be taken into account that a minimum service level has to be provided to quay cranes and trucks. Then, there is a minimum level of service for every job to be started that can not be exceeded. This minimum level of service depends on the operation to be performed. For example, loading quay crane is a more strict process than loading trucks, because a quay crane should never be waiting for a container. On the other hand, a truck can wait for the container to be loaded.

The objective in assigning jobs to SCs is to increase the service level by reducing the total time to perform the job. In order to reduce this total time it is essential to reduce the empty travel time between the ending of one job and the beginning of the next job. Another important parameter to minimize is the number of reshuffles, because more reshuffles implies more time to perform the job.

Operation	Acceptable level of service
LQ (loading quay crane)	Always one container waiting to be loaded.
ULQ (unloading quay crane)	Always one empty slot in the buffer capacity under the crane.
LT (loading truck)	Maximum waiting time to start the job 20 minutes.
ULT (unloading truck)	Maximum waiting time to start the job 20 minutes.

Table 2. Minimum level of service of different operations.

The objective function consists in minimizing the total cost of unproductive operations. If it is considered that a particular task "*j*" could be satisfied by several containers "*k*" of the same class, then:

$$u_{ijk} = C \cdot \left(r_{jk} + e_{ijk}\right) \tag{1}$$

Where: u_{ijk} is the unproductive cost for SC "*i*" performing task "*j*" with container "*k*".
C is the cost of SCs per unit time.
r_{jk} is the reshuffling time for task "*j*" with container "*k*".
e_{ijk} is the empty travel time from SC "*i*" location to task "*j*" and container "*k*" slot position.

The reshuffling time can be expressed as:

$$r_{jk} = \left(1 - z_{jk}\right) \cdot \left(L + 2 \cdot M + U\right) \tag{2}$$

Where: z_{jk} is the position in the stack of the container "*k*" required in task "*j*"
$z_{jk} = 1$ implies top position in the stack. No reshuffles required.
L is the time required by the SC to load one container.
M is the traveling time required for the SC to move to an adjoining position.
U is the time required by the SC to unload one container.

Finally, e_{ijk} is the travel time of the empty straddle carrier "*i*" from its position after finishing his last job "*j-1*" to the correct position to start the job "*j*" with container "*k*". The travel time includes the increase of time due to enter and exit to/from a container bay-yard.

$$e_{ijk} = \frac{\left\| \vec{C}_{jk}(x_{jk}, y_{jk}) - \vec{S}_{i,j-1}(x_{i,j-1}, y_{i,j-1}) \right\|_{dist}}{V_e} + q \cdot T \tag{3}$$

Where: C_{jk} is the location of container "*k*" selected for task "*j*".
$S_{i,j-1}$ is the location of SC "*i*" after finishing task "*j-1*".
V_e is the speed of the SC when traveling empty.
q is the number of direction changes in the itinerary.
T is the extra time required for each turn of the SC.

The objective function in equation 1 is restricted to some constraints:

— Only one job can be done at the same time for each straddle carrier.
— Each straddle carrier can carry only one container.
— The number of available jobs to assign to each SC depends on the strategy used (simple, double o quadruple cycle).
— Each straddle carrier makes the decision to choose one job independently from the others, even though the jobs are shared by all the straddle carriers every moment.
— Between the available jobs, it is chosen the one that minimize the objective function. It has to take into account that there is a minimum service level that has to be provided to trucks and quay cranes.

The LT and LQ processes, both require a container class "*l*" from the stacking yard. But, there can be more than one container class "*l*" in the yard. Then, the container "*k*" with less empty travel time and less reshuffling time is chosen.

To solve this objective function (equation 1) in the simulation, a heuristic algorithm is used. The algorithm is a very simple mixed integer programming model, following logical decisions rules as branch algorithms.

First of all, the available jobs are identified: pick up a container from the quay crane (ULQ), pick up a container from the yard and bring to the quay crane (LQ), pick up a container from the truck door (ULT), pick up a container from the yard and bring it to the truck door (LT). As explained before, the number of available jobs depends on which strategy is used (simple, double or quadruple cycle) and on the total number of quay cranes operating "*n*" and the total number of operating truck gates "*m*".

Afterwards, the possible slots in the yard "*k*" that contains the required container class "*l*" to pick up in order to perform the job "*j*", are determined. Finally, the objective function is evaluated for each job and for each slot "*k*". The job which minimizes the objective function is selected. Sometimes is not possible to choose between all the available jobs because it is required to perform a particular job in order to provide the minimum service level.

Allocating outbound and inbound containers in the yard

There are three main strategies for allocating inbound and outbound containers in the yard. The container yard can be divided in two main parts: one only for outbound containers (waiting to be shipped) and the other for inbound containers (waiting to be delivered by truck or rail). One strategy could be to stack the inbound containers close to the quay cranes (quayside) and the outbound containers close to the truck gates (landside). This strategy is advisable when gantry cranes unloading rates are higher than loading rates (11) or when the terminal has a high transshipment percentage. If both flows are unbalanced, it is necessary to assign more bay yards to the biggest flow. The second strategy could be the opposite of the first one: inbound (landside) and outbound (quayside). Finally, all the containers could also be stacked everywhere in the container yard. There is no division in the container yard for stacking inbound and outbound containers in this last strategy.

Once one strategy is selected, it is needed to determine an allocating algorithm for inbound and outbound containers flow.

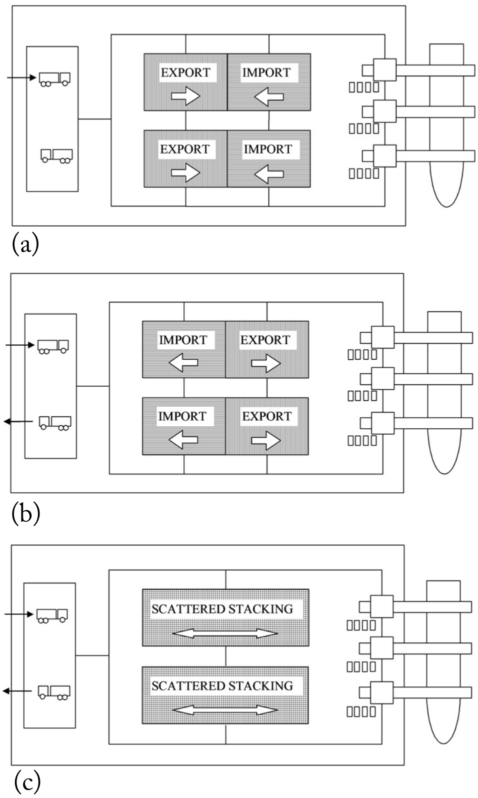


Figure 2. Main allocation strategies for import and export containers in the yard. (a) Import – quayside, Export - landside. (b) Import – landside, Export - quayside. (c) Scattered stacking.

Allocating outbound containers

The outbound containers enter the terminal through the truck gates. The objective is to find an optimum slot "*k*" that minimizes the unproductive operational cost of equipment (i.e. empty travel time and reshuffles). Equation 1 can be used to determine this unproductive cost, taking into account that the empty traveling time for a slot "*k*" is the distance from the slot location to the scheduled berthing place of the outgoing vessel.

To evaluate the objective function it is necessary to allocate every container in a particular "*k*" slot position. For this purpose a DoS (duration of stance) technique is used. The main parameter to allocated outbound containers is the accessibility of this container for future operations. The

DoS technique is used to assign the higher accessibility container slots in the yard to containers with lower dwell time.

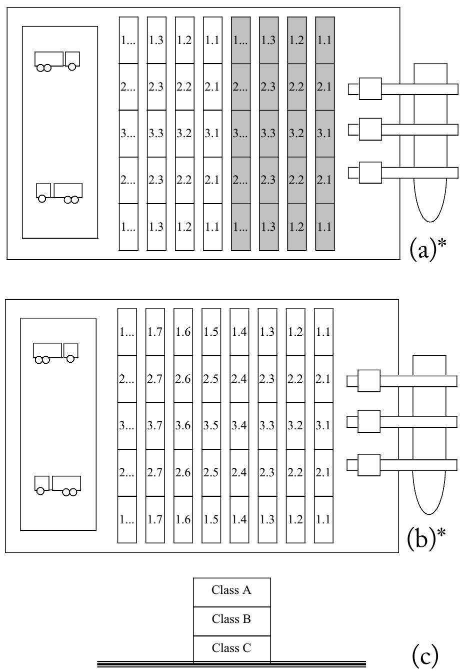
The allocating algorithm for outbound containers will have the following steps:

— Depending on the allocating strategy, the number of possible bay yards to stack the containers is defined.
— The accessibility determines the decision-making process. Depending on the dwell time of the container, the algorithm assigns the most suitable slot. The DoS rule works as follows: as lower is the dwell time better accessibility is needed. Then, the container with lowest dwell time will be allocated in the slot position with the best accessibility at this moment and vice-versa, for highest dwell time worst positions.

However, there is a big variance in container's dwell time and it is impossible to keep empty container slots waiting for the arrival of a particular container with lower dwell time, because it is impossible to know, for sure, that this container will arrive. For this reason three range of containers dwell times (A, B, C) are defined, depending on the range in dwell times. According to the dwell time class of a particular container, different starting point locations for the container are defined. The algorithm checks the best starting slot position depending on dwell tine container class. If this position is full, the second best one is checked and so on until an empty position is found.

For the A class containers, the best slot positions are reserved. These best positions are the most accessible slots of the container yard (i. e. the top positions of each stack). Among these top positions, the best are the ones located more closely to the transportation network of the yard (beginning and ending positions of a bay-yard) and located more closely to the quay-side. For the class B containers, the medium stack slots positions are the starting point. In this case, a container can be placed on the top of them, needing a reshuffle to reach it. Finally, class C containers are stacked in the bottom slot positions. Two reshuffle operations could be needed in this case.

Figure 3. Accessibility of storage yard slot positions. (a) Different areas for import and export containers (b) Scattered stacking. (c) Elevation view.



*Note: The order of slot positions from higher to lower accessibility is 1.1, 1.2, 1.3, 1..., 2.1, 2.2, 2.., 3.1, 3..., ...

Allocating inbound containers

The objective is finding an optimum position for these containers in the yard, once unloaded from the ship. Again the objective is to reduce the empty traveling time of the straddle carriers and reduce the reshuffling in next operations (i.e. loading trucks operation). The problem in most of the world's terminals is the lack of previous knowledge of truck's arrival (only known few hours before). Then, it is very difficult to store containers minimizing reshuffle operations. The same DoS technique is applied in this case.

THE SIMULATION MODEL

The purpose of the simulation model is to compare different dispatching strategies for straddle carriers and to evaluate the suitability of the allocating algorithms proposed. This allows finding which are the best strategies to improve the service levels reducing transshipment costs.

The model is based on TCB (Barcelona Container Terminal). The model is a reduced-size model, due to the time costly developing process. Two blocks from the TCB are represented in the model. That supposes a total of 2700 slots positions instead of the 8.738 real slots positions.

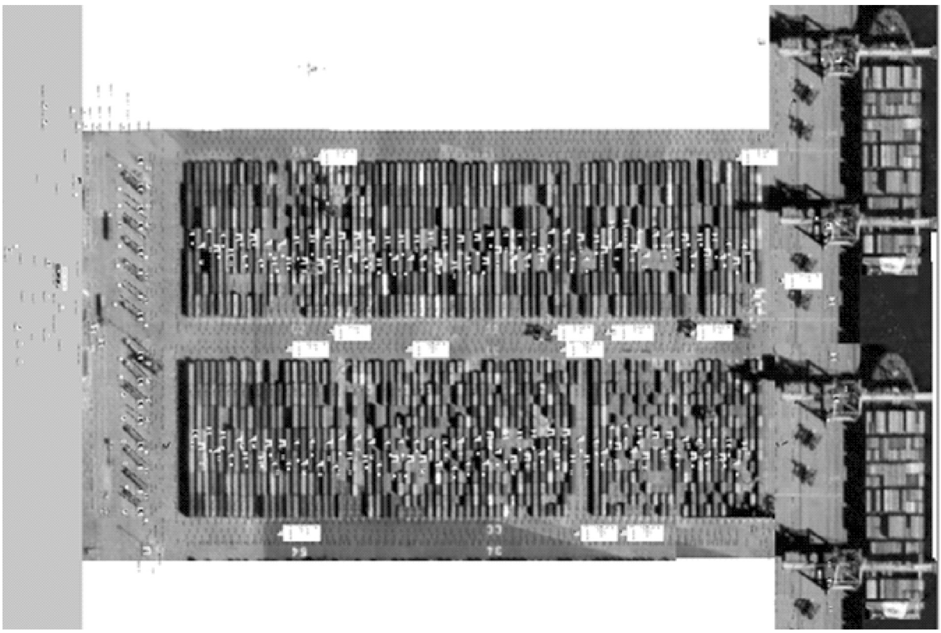


Figure 4. The simulation model layout.

Main	Quantity	Performance indicators
Ships	2	Unloading sequence of 250 containers. Loading sequence of 230 containers.
Containers	20 feet	Only general purpose 20 feet containers are considered in the simulation.
Quay cranes	4	Service time follows a triangular distribution. Loading rate: 23 cont/hour, σ=4 cont/hour. Unloading rate: 30 cont/hour., σ=6 cont/hour. 4 buffer slot positions under each quay crane.
Straddle Carriers	Variable to optimize	Stacking 3 containers in height. Loaded speed = 12 Km/h. Unloaded Speed = 16 Km/h. Speed inside a bay = 7 Km/h. Time to load/unload a truck: triangular distribution, μ=60s σ=20s. Time to load/unload a container from ground: triangular distribution, μ=30s σ=10s. Time to enter/exit a bay: triangular distribution, μ=5s σ=2s.
Storage yard	2700 slots	Stacking area of 4.74 Ha divided in two blocks o 2.37 Ha each. 75 bays per block, 7 rows per bay and 3 tier.
Trucks	Infinite queue	An infinite queue of alternative loaded and empty trucks is simulated in the entrance of the truck gates. Actually, the arrivals frequency of trucks depends on day hours. There are peak hours when trucks queue very long to enter the terminal. This assumption allows the simulation of the worst scenario.

Table 3. Physical configuration of the simulation model.

The simulation model is built following the QBM (quality-based modeling) technique (12). The main simplifications of the model are the following ones:

— Only one size of containers (40 feet) is considered.
— The weight of the containers is not considered. Neither IMO class nor voyage number (13), are considered.
— Only a general purpose container type is considered.
— The destination and the shipper are included in a new parameter: batch shipper's cargo.
— The number of containers in each shipper's batch is generated random between 1 to 50 containers.
— The dwell time of each container is divided in three main groups (A, B, C) and to all the containers from the same shipper's cargo is assigned one of these three possible dwell time classes.
— Each bay-yard of containers is accessible from both sides: left and right. Once the SC enters to the desired bay-yard from one side, it has to go out from the same side. This is a simplification in order to avoid possible physical contradictions and to give stability to the simulation model. However, in reshuffling operations all the container slots from the same container bay-yard are accessible by the same straddle carrier and furthermore, the SC does not have to exit the bay-yard through the same side that entered.
— When is needed to perform a reshuffle operation, the loaded container will be unloaded to the closest position to the container slot where the reshuffle started.
— The trucks have only simple cycle (they only unload or load a container). There is not double-cycle. Then, a truck that comes to unload a container afterwards cannot pick up another container.

During the simulation time there is an undefined queue of empty and full trucks waiting to enter the terminal. Actually, the arrival frequency of trucks depends on the day hours. There are peak hours where the trucks can make long queues to enter to terminal. The objective of this hypothesis is to study the worst scenario in peak circumstances (100% resources used: all trucks doors are full and all quay cranes operative).

The average of a vessel cycle in TCB is of about 18 hours. It is assumed that only the 60% of the vessel's stance time in the port corresponds to unloading and loading operations (i.e. 10 hours). The total duration of the simulation is 20 hours and 30 minutes hours. The objective is to create a time lag between vessels in order that all the operations coexist in a certain period of time. Table 4 shows the scheduling of operations for each vessel.

<table>
<tr><th>Time of simulation</th><th>Berth 1</th><th>Berth 2</th></tr>
<tr><td>0-2:30</td><td rowspan="2">Mooring
Administrative tasks</td><td>No vessel</td></tr>
<tr><td>2:30-4:00</td><td rowspan="2">Mooring
Administrative tasks</td></tr>
<tr><td>4:00-6:30</td><td>Unloading</td></tr>
<tr><td>6:30-9:00</td><td>Unloading</td><td>Unloading</td></tr>
<tr><td>9:00-11:30</td><td>Loading</td><td>Unloading</td></tr>
<tr><td>11:30-14:00</td><td>Loading</td><td>Loading</td></tr>
<tr><td>14:00-16:30</td><td rowspan="2">Administrative tasks
Exit</td><td>Loading</td></tr>
<tr><td>16:30-18:00</td><td rowspan="2">Administrative tasks
Exit</td></tr>
<tr><td>18:00-20:30</td><td>No vessel</td></tr>
</table>

Table 4. Loading and unloading operations for both vessels.

Considering this schedule of operations, and taking into account the average operational rates of the quay cranes, the number of containers to be loaded or unloaded in each phase is determined. This allows for considering the total time to complete each phase as a performance parameter for each simulation scenario.

This model is a practical tool able to compare different straddle carrier's operation strategies, such as single-cycle versus double-cycle or quadruple cycle. Besides, all these operation strategies could be also compared to different allocation strategies, such as half yard restricted to stack inbound containers and the other half to outbound, vice-versa or stacking in the entire yard without flow restrictions. From each one of these simulation scenarios, the number of straddle carriers needed to ensure an optimum service level it can be determined.

CONCLUSIONS

A particular container terminal can be very different from another due to the physical configuration and the handling equipment used. Furthermore, a container terminal is a complex system, since several operations have to be performed and a good coordination between operations is required. Simulation models can be a very efficient tool to compare, optimize or synchronize terminal's operations. On the other hand, simulation models are a time-consuming job to develop and validate. Nowadays a new concept, emulation, is growing fast. Emulation it can be seen as a simulation in real time with the real data from the terminal's system every moment. This new concept is available due to the technical advances in TOS (terminal operating systems) which supports terminal planning, scheduling and equipment control, creating a virtual. Emulation can be integrated in this TOS.

In the present research project, a simulation model is created in order to compare different allocating, dispatching and assigning strategies for a maritime container managed by straddle carriers. A good understanding of the simulation model and the algorithms used are necessary for a correct evaluating of the simulation results. Numerical results of the application of the algorithms in TCB (Barcelona Container Terminal) are not available yet.

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UN MODELO DE SIMULACIÓN PARA LA EVALUACIÓN OPERACIONAL DE STRADDLE CARRIER EN UNA TERMINAL PORTUARIA DE CONTENEDORES

Resumen

El fenómeno de la globalización, juntamente con el éxito de la contenerización ha propiciado un enorme incremento en el transporte de contenedores en todo el mundo. Esta situación ha llevado a un incremento en el tamaño de los buques portacontenedores, lo que supone unas exigencias mayores a las terminales y sus equipos.

En este contexto, el éxito de las terminales de contenedores reside en un rápido proceso de carga/descarga con unos costes reducidos. Por estos motivos cada día se considera más necesaria la optimización de los procesos de la terminal.

El presente artículo trata la optimización del subsistema de transporte interno en una terminal marítima de contenedores operada mediante straddle carriers (SC), uno de los equipos tecnológicos más ampliamente utilizados en las grandes terminales del mundo. Se analizan tres subsistemas en detalle: la interconexión lado tierra, el almacenaje de contenedores en la campa y la interconexión lado mar. Los conflictos y decisiones que conllevan las operaciones en estos subsistemas se tratan de manera analítica y se proponen algoritmos de optimización. Adicionalmente, se ha desarrollado un modelo de simulación para contrastar los algoritmos propuestos y para comparar las distintas configuraciones operacionales de la flota de SCs. El modelo de simulación se explica en detalle y los algoritmos de toma de decisiones se presentan y formulan.

METODOLOGÍA

En una terminal marítima de contenedores existen básicamente 3 procesos logísticos: la carga/descarga de buques portacontenedores, el almacenaje en la campa y la recepción/entrega terrestre de los contenedores. Adicionalmente, es necesario un cuarto proceso que asegure el transporte horizontal de los contenedores entre los tres subsistemas anteriores: el subsistema de interconexión. La operativa del subsistema de interconexión está estrechamente ligada al tipo de equipo utilizado, en este caso los SCs.

La configuración de las operaciones de los SCs en una terminal marítima de contenedores, depende de lo que se denomina "estrategia de asignación", que consiste en el proceso de asignación de las tareas concretas a las distintas unidades que conforman la flota de equipos de interconexión. En el lado mar existen dos tipos de tareas: recoger un contenedor que ha sido descargado por la grúa de muelle y llevarlo a la campa de almacenaje (tarea tipo ULQ), o la tarea inversa (LQ). A su vez en el lado tierra existen dos tipos más de tareas: recibir un contenedor y almacenarlo en la campa (tarea tipo ULT) o recoger un contenedor de la campa para entregarlo a un camión o ferrocarril (tarea tipo LT). Se pueden diferenciar tres tipos de estrategias en función de las tareas que están disponibles para un SC concreto: ciclo simple, ciclo doble y ciclo cuádruple (ver Fig. 1). Cuando una terminal opera en ciclo simple, solo un tipo de tarea está disponible para el SC. Por ejemplo, en el lado mar, un grupo de SCs están asignados a una sola grúa operando en carga o en descarga. Igualmente en ciclo simple los SC pueden trabajar en equipo. En este caso los SCs están asignados a un grupo de grúas, pero todas ellas operando en el mismo tipo de operación, ya sea carga del buque o descarga. En el caso de trabajar en doble ciclo los dos tipos de tareas (UL o L) están disponibles para un SC, pero en una sola área de la terminal (lado mar o lado tierra, pero no ambos). Finalmente en el ciclo cuádruple, todas las tareas puede ser asignadas a cualquier SC.

Para analizar en funcionamiento en términos de productividad y eficiencia de cada una de estas estrategias, se ha desarrollado un modelo de simulación basado en una simplificación de la Terminal de Contenedores de Barcelona (ver Fig. 4). Este modelo de simulación requiere algoritmos que le permitan tomar decisiones en dos aspectos:

— Asignación de tareas a los equipos.
— Selección de la posición de almacenaje del contenedor en la campa.

El algoritmo de asignación, trata de minimizar el tiempo improductivo de cada SC, mediante la reducción de las distancias de viaje en vacío y la reducción del número de remociones (ver ecuación 1).

A su vez, el algoritmo de almacenaje, está basado en incrementar la eficiencia en la rotación de contenedores, almacenando aquellos con un tiempo de estancia menor en las posiciones más accesibles de la campa (ver Figera 3). El algoritmo, considera las estrategias básicas de almacenaje habitualmente utilizadas en las mayores terminales del mundo (ver Figura 2).

CONCLUSIONES

Una terminal de contenedores puede ser muy diferente de otra debido a su configuración física y a la tipología de los equipos de interconexión utilizados. Por otro lado, una terminal de contenedores es un sistema complejo, donde distintas actividades deben coordinarse entre si. Los modelos de simulación pueden ser una herramienta muy potente para comparar, optimizar y sincronizar las operaciones de la terminal. Sin embargo, los modelos de simulación requieren un gran esfuerzo de desarrollo y validación.

En el presente artículo se ha presentado un modelo de simulación que compara distintas estrategias de asignación de tareas y de almacenaje de contenedores. Un buen conocimiento del modelo es necesario para la correcta interpretación de los resultados. Los resultados numéricos de la aplicación del modelo a la Terminal de Contenedores de Barcelona (TCB), aún no están disponibles.