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An Analysis on the Modeling of Container Terminal Operations

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Abstract

Objectives: Container terminals are essential intermodal interfaces in the global transportation network. Efficient container handling at terminals is important in reducing transportation costs and keeping shipping schedules. The present analysis describes these problems within the scope of container terminal modeling. **Methods/Statistical Analysis:** Basic formulation of the problem is stated as two-machine flow shop problem. The well-known maximum travelling salesman problem (Max TSP) has been applied in this study. Max TSP can be solved as a TSP by replacing each edge cost by its additive inverse, since, there is a different value for unloading stack i while loading stack j and loading stack i while unloading stack j; this model corresponds to the Asymmetric Travelling Salesman Problem (ATSP). **Findings:** It is found that, there is an essential need for improvements and optimization of all aspects in the container transportation chains. For the real life systems of this type, this problem has been solved optimally. Significant possibilities for time savings have been arrived in this study. For real life case, where the reloading is performed on two barges placed side by side (8 stacks in the bay, 11 bays, 4 containers in the stack) time savings as a function of the terminal length are presented. The time saving with respect to number of rows inside the container yard is presented. Simulation models of container cranes demonstrate significant time savings, if double cycling is applied. It is showed that application of the double cycling can result in time savings of 12 to 27 % depending on the system parameters. This analysis is based on discrete event simulation and analytical optimization methods. **Application/Improvement:** Good planning of container terminal operations reduces waiting time for liner ships. Reducing the waiting time increases customer satisfaction and improves the terminal productivity which gives the container terminal an advantage over its competitors.

Keywords: Container Terminals, Modeling, Mathematical Models, Optimization, Scheduling, Simulations

1. Introduction

Over the last years, international sea freight container transportation has grown dramatically and container terminals play a key role within the global shipping network. Terminal's operations have received increasing interest in the scientific literature and operations research techniques are more and more used to improve efficiency and productivity[1]. Port efficiency is an important requirement in order to survive in the competitive world of shipping industry.

Seaports are complex dynamic systems consisting of numerous interacting elements, influenced by random factors. Hence, full utilization of the available resources and efficient management of operations are two major goals. Under these two goals many objectives will be achieved such as increasing the port throughput and utilization of resources (berths, cranes, quay, yards, etc), reducing handling time, minimizing port congestion, minimizing disruptions, demurrage and operating costs[2].

A container terminal is the zone of the port where vessels dock on a berth and containers are loaded, unloaded and stored in a buffer area called yard. In import-export terminals the flow of containers continues inland and containers are picked-up and delivered by trucks and trains in an area called gate, whereas in transhipment terminals, containers are exchanged between ships commonly referred to as mother vessels and feeders,

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according to a hub-and-spoke system. Figure 1 illustrates the main subsystems and operations in a container terminal[1]. Import, export and transshipment containers constitute yard components.

In a container yard, the most commonly used cranes are, Rubber-Tired Gantry (RTG) cranes, Rail-Mounted Gantry (RMG) cranes, reach stackers, chassis-based transporters and straddle carriers. RMG cranes are the only one suited for fully automated container handling[5]. A typical container terminal is presented in Figure 2.

2. A Review on Existing Problems

A review of several literatures shows that many scientific papers are dealing with optimization of operations in container terminal. Comprehensive overviews are presented in[5-7]. The classification of main logistic processes and operations in container terminal are given in[5-7]. Additional references are,[8–11]. A detailed analysis using Permutation Block Algorithm (PBA) has been made in[12] to get the maximum utilized space inside the container by reducing the unused space, by obtaining the coordinates of the container and coordinates of the box. However, it is applicable only for the Equal Dimension Boxes.

Most of the studies have been focused on optimization of specific process alone and not on the whole container terminal as a system. The prime logistic processes inside container terminal are: berth allocation, stowage planning, quay crane assignment, scheduling of quay crane, yard crane scheduling, storage and stacking police, rail operations, truck operations and internal

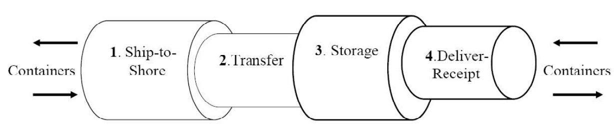

Figure 1. The main subsystems in a container terminal[3].

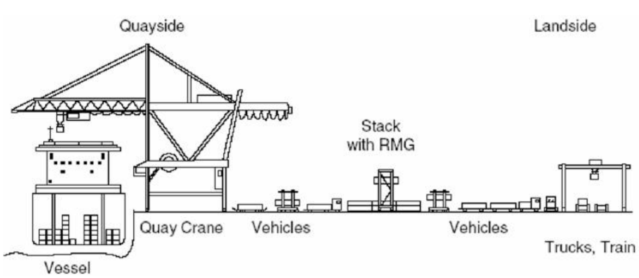

Figure 2. Transportation and handling chain of container[5].

transports[13]. Based on the process, models are classified as deterministic, stochastic, static and dynamic.

The complexity of the terminal processes arises from several interactions between the operations and from the variety of stochastic processes(e.g., ship arrival rates, times required for each step of container's movement, equipment repair times, equipment failure times, number of containers loaded and un-loaded)[14]. Using simulation models, it is possible to fully describe the system and they are long-lasting. On the other hand, analytical modelling of container terminal consists of setting up mathematical models and equations which describe certain stages in the functioning of the system. The main problem of container terminal analytical models relates to the fact that they lose in detail and flexibility, so they simplify the real situation. Therefore, simulation modelling is better than analytical one in representing the random and complex environment of a container terminal. Analytical or simulation models can also be used for workload balancing, for defining work rules and work crew schedules within short and long periods[14].

3. Optimization and Simulation in Container Terminals

The most difficult terminal management problem is optimizing the balance between the ship-owners who are in need of quick service of their ships and economical use of allocated resources. Both container ships and container port facilities are very expensive; hence, it is most desirable to utilize them as intensively as possible.

The manager can trust the computer-generated solutions only by validating them by means of a simulation model of the complex environment of container terminal. Hence, the simulation tool also becomes a means to introduce new approaches into traditional settings. A simulation model of a container terminal is basically a computer program written in a general purpose language (C/C++) or in a special simulation-oriented language – simulator (Arena, MES CTMS, Petri Nets, MODSIM)[15].

The simulation models are used to analyze bottle-neck and deadlock problems, conflicts, container handling techniques, vehicle and vessel scheduling (departure and arrival rates), equipment utilization and operational efficiency (yard, gate and berth). So, a simulation implements the most important aspects of the processes at the container terminal. The advantage of simulation modelling over analytical modelling of container terminals is that it allows for a greater level of detail and avoids too many simplifications[15].

4. Risks and Challenges in Modelling

The reviewed literature shows that there are different models for the same processes. One of the major examples for this is container quay crane scheduling. In this study, the tasks are defined by container group, bay and bay area. The difference between bay and bay area is presented in Figure 3. These models are developed simultaneously over a relatively long period, but[11] proposed a comprehensive method for evaluation of this model. Significant analysis of this problem has been presented. Quay cranes are the most expensive reloading equipment in container terminals; hence, the container quay crane is always the leading element of the system. This is validated from the fact that, by enhancing quay-crane efficiency, the ship turn-around time can be reduced which leads to improved port productivity and improved throughput in fright transportation systems[16].

Double cycling is an operating reloading technique that reduces empty moves of reloading mechanization, by combination of two or more separate tasks; while single cycling is more common used technique, because the organization and monitoring of the process is[13].

For quay cranes cycle is a complete round-trip of the crane trolley from ship to shore and back, or from shore to ship and back[16]. Main advantage of this method of double cycling is low cost of investments. There are no requirements for terminal expansions or buying of new equipment, so this is a good way to increase terminal capacity and improve level of consumer services without large costs.

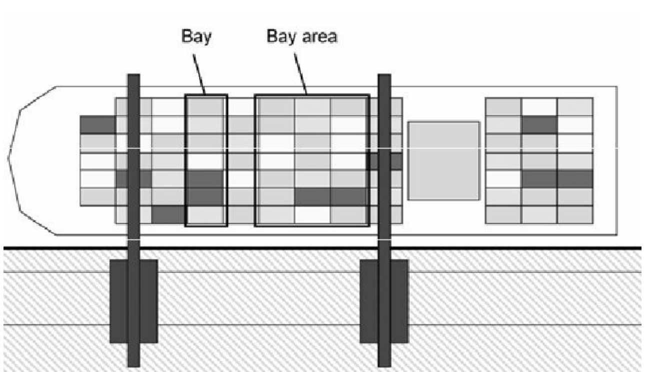

Figure 3. Container quay crane scheduling models.

Relatively small numbers of papers dealt with the problem of container crane double cycling. A method for double cycling with a goal of reducing the number of operations necessary to turn around the bay in the ship has been proposed as per[16]. The amount of work in every stack is defined by number of containers to load/unload. The problem is solved optimally by using Johnson's rule, and greedy strategy is proposed in addition. Basic formulation of the problem is stated as two-machine flow shop problem[16].

u_c - Number of containers to unload in stack $c \in S$.
l_c - Number of containers to load in stack $c \in S$.
FU_c - Completion time of unloading $c \in S$.
FL_c - Completion time of loading $c \in S$.
ω - Maximum completion time.
X_{kj} - Binary variable to for ordering of unloading jobs (1 if $j \in S$ is unloaded after $k \in S$ and 0 otherwise).
Y_{kj} - Binary variable to for ordering of loading jobs (1 if $j \in S$ is loaded after $k \in S$ and 0 otherwise).
M - A large number.

The formulation is:

(SP) minimize ω

$$\text{subject to } \omega \ge FL_c \forall c \in S, \tag{1a}$$

$$FL_c - FU_c \ge l_c \forall c \in S, \tag{1b}$$

$$FU_k - FU_j + MX_{kj} \ge u_k \forall j,k \in S, \tag{1c}$$

$$FU_j - FU_k + M(1 - X_{kj}) \ge u_j \forall j, k \in S, \tag{1d}$$

$$FL_k - FL_j + MY_{kj} \ge l_k \quad \forall j,k \in S, \tag{1e}$$

$$FL_j - FL_k + M(1 - Y_{kj}) \ge l_j \quad \forall j, k \in S, \tag{1f}$$

$$FU_c \ge u_c \forall c \in S, \tag{1g}$$

$$X_{kj}, Y_{kj} = 1,0 \forall j, k \in S. \tag{1h}$$

The QC double cycling method as mixed integer program has been reformulated[17]. As a first step, analysis on sequencing of all stacks in every hatch has been performed and then sequences all the hatches. Heuristic method is combined with the Johnson's rule for solving this problem. A formulation in QC scheduling problems is proposed as a mixed integer programming model[18]. A hybrid heuristic approach is proposed to solve this model.

The algorithm applied in this study takes two types of sequencing into account, i.e., inter-stage sequencing (hatch sequencing) and intra-stage sequencing (stack sequencing in the same hatch). This approach hybridizes a certain reconstructive Johnson's rule with an effective local search method. Finally, certain data in real cases are used to evaluate the effectiveness of the proposed approach. The literature in sea terminals demonstrates that increased efficiency is achieved in crane productivity through double cycling, by reducing the number of cycles to approximately 20% and operational time to about 10% when double cycling only below deck[15].

At container yard, containers are grouped so that containers of a certain operator get grouped in the same bay; the containers are also divided according to the container height and destination. The groupings are applied for the purpose of simplifying the organization and tracing container locations at the container yard. The observed examples analyzed the reloading of 1 ship/barge or 2 barges aligned one beside another at berth.

Figure 4 shows the containers that are to be unloaded or loaded, inside the bay. Once the first stack is unloaded, then the loading of that stack is combined with an unloading of the next stack, and so on. It is assumed that barge/ship is unloaded stack by stack because by combining more than two stacks, hence, there is a possibility of endangering barge/ship stability. The optimization aim is to minimize barge/ship turn-around time. The problem is divided into two phases. The first phase of the problem is to determine the optimal scheduling for every pair of stacks, and the second phase is to schedule all the stacks. The model used for stack reload scheduling corresponds to the well-known maximum travelling salesman problem (Max TSP)[19]. Max TSP can be solved as a TSP by replacing each edge cost by its additive inverse. And since, there is a different value for unloading stack i while loading stack j and loading stack i while unloading stack j; this model corresponds to the Asymmetric Travelling Salesman Problem (ATSP).

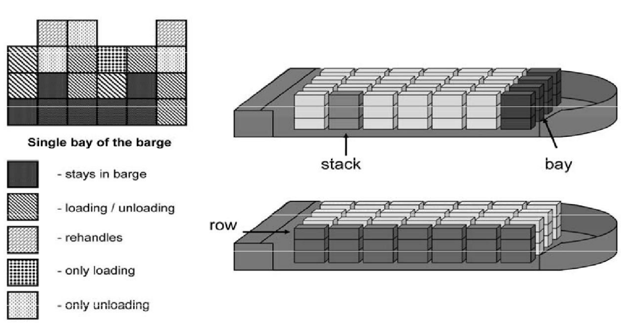

Figure 4. **Bay inside barge/ship**[20]

ATSP is described: Let G = (V, H) be a given complete digraph, where V = {1,K*d*} is the vertex set and *H* = {(*e*, *l*): *e*, *l* ∈ *V* } is the arc set; let t_{el} be the cost associated with arc(e, l) ∈ *H* (with t_{ee} = +∞ for each *e*∈ *V*). A Hamiltonian directed cycle (tour) of G is a directed cycle visiting each vertex of *V*exactly once, i.e., a spanning subdigraph $\widetilde{G}$ = (*V*,*H*) of G such that $|\widetilde{H}|$ = d (the number of elements in finite set $\widetilde{H}$ is denoted by $|\widetilde{H}|$), and $\widetilde{G}$ is strongly connected, i.e. for each pair of distinct vertices, (e, l) ∈ *V*, e < l, both paths from e to l and from l to e exist in *G*. The ATSP is used to find a Hamiltonian direct cycle G* = (V, H*) of G with minimum cost $\sum_{(e,l)\in} H^{t_d}$. Without loss of generality, we assume $t_{el} \geq 0$ for any arc(*e*, *l*) ∈ H. The integer linear programming formulation of the ATSP is formulated as:

$$\upsilon(ATSP) = \min \sum_{(e,l)\in H} t_{el} Z_{el} \quad (2a)$$

Subject to

$$\sum_{e\in H} Z_{el} = 1 \qquad l \in V \quad (2b)$$

$$\sum_{l\in V} Z_{el} = 1 \qquad e \in V \quad (2c)$$

$$\sum_{e\in Q} \sum_{l\in V\setminus Q} Z_{el} \geq 1 \qquad Q \subset V : Q \neq \theta \quad (2d)$$

$$Z_{el} \geq 0 \qquad e, l \in V \quad (2e)$$

$$Z_{el} \text{ integer} \qquad e, l \in V \quad (2f)$$

Where, Z_{el}=1, if and only if arc (*e, l*), is in the optimal tour.

If optimization is performed for only one part of the system, in this study, barge reloading, influence on other operations is neglected. Due to the complexity of whole system, exact algorithms usually could not be implemented. Simulations are commonly used tool to optimize the material flow systems.

Basic characteristic for every material flow system is its dynamic behaviour. Hence, every static analysis of these systems implies smaller or larger neglects. Material flows are highly complex processes with several variables. These include transport of material, its transformation, material handling and multiplex interaction of inner and external factors. Designing a new system demands analysis of all processes and system state variables.

Three types of simulations can be distinguished: Strategically, operational and tactical simulations[20]. Simulations are mostly applied in the case study researches. Simulations of the whole system and the methods for the optimization of individual processes having integrated together in the analysis of the whole system have been presented[21].

5. Discussions and Conclusions

An analysis on the technical problems on modeling of container terminal operations have been presented. This study has been performed based on the need for an improvement in all aspects of container transport due to the global increase in the volume of containerized goods. For the real life systems of this type, this problem has been solved optimally. Significant possibilities for time savings have been arrived. Table 1 shows time savings as the function of terminal length, for real life case, in which the reloading is performed on two barges placed side by side. Number of containers that needs to be loaded and unloaded in every stack is assumed to be ranges from n to 0 with uniform distribution, where n is the maximum number of containers in the stack.

Largest barges usually have only 4 stacks in one bay, but as mentioned earlier, investigations have been performed on cases, where there are two barges aligned one beside another at the berth and Table 2 shows the effect of number of stacks inside the bay.

The system performance is also depends on terminal layout, significantly. In this simulation, the barge is assumed to be centered on the quay. The influence of bay position on the time saving has been demonstrated in Figure 5.

The time saving with respect to the number of rows inside the container yard is presented in Figure 6. Influence of the number of row is smaller than number of bays. This has been expected, because of the movement of gantry is dominant in comparison to the trolley movement, for this type of operations and this type of movement. For double cycling application, the simulation models of container cranes demonstrate significant time savings. It is showed that application of the double cycling can result in time savings of 12 to 27 % depending on the system parameters.

Table 1. Effect of yard length on time savings

Container yard Length (m)	400	1000	1400
Time savings (s)	16927	74012	134667

Table 2. Effect of yard length on time savings

Number of stacks in bay	8	12	16
Time savings (s)	22703	39728	57370

Figure 5. Influence of bay position on the time saving.

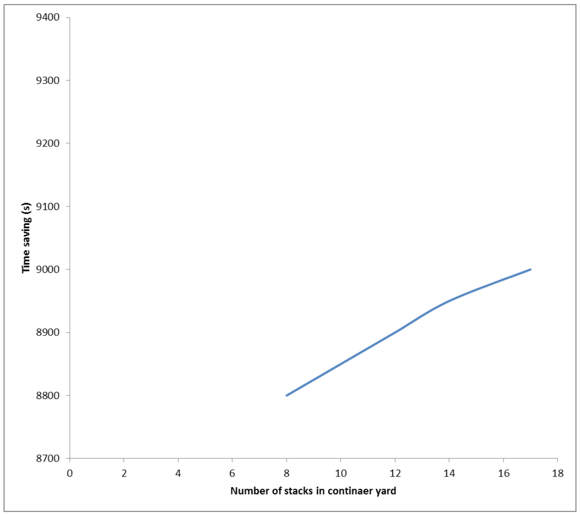

Figure 6. Influence of number rows in container yard.

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