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**An optimisation model for export and import container process
in seaport terminals**

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Abstract

The use of containers has greatly reduced handling operations at ports and at all other transfer points, along with increase in efficiency and speed of transportation. This was done in an attempt to cut down the cost of maritime transport, mainly by reducing cargo handling costs and ships' time in port by speeding up handling operations. Since a container ship involves major capital investment and significant daily operating costs, customer service has become an important issue for container port terminals. So, major factors influencing container transfer efficiency should be analysed to optimise resource usage resulting in lower operating costs while achieving a desired level of customer service. In this paper, a mathematical model is designed to analyse export and import container progress in intermodal container terminals taking into account factors such as container handling and transfer equipment, storage capacities, terminal layout and the consequences of changed scheduled throughput time. The model presented here can be seen as a decision support system for container terminal logistics. Further research continues into the investigation of the solution of the larger real life problem.

Key words: Seaport, project scheduling, container terminal logistics

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Introduction

World container port traffic continues to grow and is currently about 200 million TEUs (twenty-foot equivalent units) a year (UNCTAD 2001). Because of the huge investment in container ships and port infrastructures, port operators consistently attempt to find ways to reduce ships' time in port and container handling costs.

When a container ship berths at a port, import containers are unloaded to the marshalling area and they are then moved to the yard storage area for further in-land transport by road or by rail. Export containers, which are stored in the storage area first, are moved to marshalling area and are then loaded to the ship. Ship loading or unloading is either by shore cranes or by derricks. Between marshalling and yard storage area, containers are handled and transferred by forklifts, straddle-carriers, and/or gentry-cranes. The ship time is affected by the physical layout of the terminal; storage location; the number and type of yard machines available to use, as well as the operation strategies.

Therefore the problem being investigated is to minimise total expected throughput time of containers which is the sum of the handling and travelling times for moving containers into different sections in the terminal. When dealing with export containers the process would be reversed. That is, the handling time of the containers from when it first arrives at the port until the ship carrying the containers departs from the port. Total throughput time of containers as a function of cranes, forklifts and reachstackers and terminal transfer trucks at the terminal should be determined to measure the performance of the system. (See Kozan and Preston (1999), Kozan (1997a)). Taleb-Ibrahimi et al. (1993) has analysed the effect of handling and storage strategies for seaport terminals for long-term planning. At the operational level, the paper describes how to minimise and predict the amount of handling work.

Kozan (1997b) gives a review on recent analytical and simulation models. In a later study, Kozan (2000) proposes a network model for container transfer at multimodal terminal. This network model aims at minimising the total throughput time of handling and travelling times of container, taking into account of port storage area, and a variety of handling equipment. Preston & Kozan (2001a) suggest a container location model and apply tabu search to analyse different storage policy. While optimising the transfer schedule for a given storage location assignment they reduce loading time in their paper. Similarly Preston & Kozan (2001b) optimise the storage location to match a particular transfer schedule. Lai and Lam (1994) apply queuing theory and simulation to investigate the throughput and utilisation of yard equipment under various allocation strategies. Kim and Kim (1999) have analysed the optimal number of bays and the number of stacking levels in a container terminal.

The analysis in this paper can be used for long-term planning, for example, to help with the selection of handling technology, site location, or proposed service expansion. The system's steadystate performance is analysed as a function of the arrival and departure of import and export containers.

The Model

Before a container ship arrives at a port, the terminal operator would have already received the list of import containers, and their location on the ship. An unloading sequence is worked out according to the location of containers and the number of cranes assigned. After all import containers have been unloaded to the marshalling area, they are handled and transferred to the storage area by yard machines (forklifts, reachstackers, etc). Different type of yard machine has different handling and transfer speed. The complete time for a particular container to be moved to the storage area depends on when a yard machine is available; what type of yard machine is available; and the storage location of containers. The reverse process applies to export containers.

Parameters and Variables

s	*1, 2, ..,S ships*
m	*1, 2, ..,M yard machines (fork-lifts, straddle-carriers, reach-stackers or frontloaders)*
$N_{s,c}^{imp}$	*Total number of import containers to be unloaded from ship s by shore crane c*
$N_{s,c}^{exp}$	*Total number of export containers to be loaded to ship s by crane c*
$n_{s,c}^{imp}$	*Import containers 1, 2, …,$N_{s,c}^{imp}$*
$n_{s,c}^{exp}$	*Export containers 1, 2, …,$N_{s,c}^{exp}$*
R_o	*Road transfer storage bay*
R_a	*Rail transfer storage bay*
t	*Time 0, 1, 2, ..,T*
b	*Storage bays 1, 2, ..,R_o,.., R_a,..,B*
$b_{n_{s,c}^{imp}}$	*Storage bay for the $n_{s,c}^{imp}$ the import container*
$b_{n_{s,c}^{exp}}$	*Storage bay for the $n_{s,c}^{exp}$ th export container*
A_s	*Scheduled arrival time of ship s*
D_s	*Scheduled departure time of ship s*
$\mathbf{s}_s$	*Maximum allowable lateness in ship departure (this value is used to limit the search space)*
w_s	*Delay penalty of ship s per unit time*
$\mathbf{m}_{n_{s,c}^{imp}}$	*Unloading time of container $n_{s,c}^{imp}$ from ship s by a shore crane c.*
	This would include side-way crane movement as a set-up time.
	These values could be determined from the container loading sequence.

$\mathbf{m}_{n_{s,c}^{exp}}$ *Loading time of container $n_{s,c}^{exp}$ to ship s by shore crane c.*

This would include side-way crane movement as set-up time.
These values could be determined from the container loading sequence.

$\mathbf{l}_{n_{s,c}^{imp},m}$ *The expected moving time of an import container of ship s from the marshalling area to bay $b_{n_{s,c}^{imp}}$ by yard machine m.*

$\mathbf{l}_{n_{s,c}^{exp},m}$ *The expected moving time of an export container of ship s from bay $b_{n_{s,c}^{exp}}$ to the marshalling area by yard machine m.*

$E_{n_{s,c}^{imp},m}$ *Initial calculated earliest finishing time to move the import container $n_{s,c}^{imp}$ from the marshalling area to bay $b_{n_{s,c}^{imp}}$ by yard machine m.*

$$E_{n_{s,c}^{imp},m} = A_s + \sum_{k=1}^{k=n_{s,c}^{imp}} \mathbf{m}_k + \mathbf{l}_{n_{s,c}^{imp},m} \qquad \text{for } s=1,2,..,S; \; c=1,2,..,C \; ; \; m=1,2,\ldots M;$$

$$n_{s,c}^{imp} = 1,2,.., \; N_{s,c}^{imp}$$

$L_{n_{s,c}^{imp},m}$ *Initial calculated latest finishing time to move the import container $n_{s,c}^{imp}$ from the marshalling area to the storage bay $b_{n_{s,c}^{imp}}$ by yard machine m.*

$$L_{n_{s,c}^{imp},m} = \mathbf{s}_s + D_s - \sum_{k=1}^{N_{s,c}^{exp}} \mathbf{m}_k \qquad \text{for } s=1,2,..,S; \; c=1,2,..,C \; ; \; m=1,2,\ldots M;$$

$$n_{s,c}^{imp} = 1,2,.., \; N_{s,c}^{imp}$$

$E_{n_{s,c}^{exp},m}$ *Initial calculated earliest finishing time to move the export container $n_{s,c}^{exp}$ from the marshalling area to the storage bay $b_{n_{s,c}^{exp}}$ by yard machine m.*

$$E_{n_{s,c}^{exp},m} = A_s + \left(\sum_{k=1}^{N_{s,c}^{imp}} \mathbf{m}_k \right) + \left(\sum_{k=1}^{n_{s,c}^{exp}} \mathbf{m}_k \right) + \mathbf{l}_{b_{s,c}^{exp},m} \qquad \text{for } s=1,2,..,S; \; c=1,2,..,C; \; m=1,2,\ldots M;$$

$$n_{s,c}^{exp} = 1,2,.., \; N_{s,c}^{exp}$$

$L_{n_{s,c}^{exp},m}$ *Initial calculated latest finishing time to move the export container $n_{s,c}^{exp}$ from the marshalling area to the storage bay $b_{n_{s,c}^{exp}}$ by yard machine m.*

$$L_{n_{s,c}^{exp},m} = \mathbf{s} + D_s - \sum_{k=n_{s,c}^{exp}}^{N_{s,c}^{exp}} \mathbf{m}_k \qquad \text{for } s=1,2,..,S; \; c=1,2,..,C; \; m=1,2,\ldots M;$$

$$n_{s,c}^{exp} = 1,2,.., \; N_{s,c}^{exp}$$

d_s *Actual departure time of ship s.*

$$X_{n_{s,c}^{imp},m,t} = \begin{cases} 1 & \text{if yard machine } m \text{ completes the moving of import container } n_{s,c}^{imp} \text{ to storage} \\ & \text{bay b at time } t. \\ 0 & \text{otherwise} \end{cases}$$

$$X_{n_{s,c}^{exp},m,t} = \begin{cases} 1 & \text{if yard machine } m \text{ completes the moving of export container } n_{s,c}^{exp} \text{ to storage} \\ & \text{bay b at time } t. \\ 0 & \text{otherwise} \end{cases}$$

Objective function

The objective is to minimise the total cost of ship delay at port:

$$Z_1 = Min \sum_{s=1}^{S} w_s g \left(d_s - D_s \right)^+ \tag{1}$$

Constraints

The model is subject to the following constraints:

Ship departs after yard machines complete moving all export containers to marshalling area and the last container is loaded to ship s by shore cranes

$$d_s = \underset{n_{s,c}^{exp}}{Max} \left[\boldsymbol{m}_{n_{s,c}^{exp}} + \sum_{m=1}^{M} \sum_{t=E_{n_{s,c}^{exp},m}}^{L_{n_{s,c}^{exp},m}} t g X_{n_{s,c}^{exp},m,t} \right] \quad \text{for } s=1,2..,\, S;\ c=1,2,..,C \tag{2}$$

All import containers must be moved to the storage area by a yard machine.

$$\sum_{m=1}^{M} \sum_{t=E_{n_{s,c}^{imp},m}}^{L_{n_{s,c}^{imp},m}} X_{n_{s,c}^{imp},m,t} = 1 \qquad \text{for } s=1,2,..,S;\ n_{s,c}^{imp} = 1,2,..,\, N_{s,c}^{imp} \tag{3}$$

All exports containers must be moved from the storage area by a yard machine.

$$\sum_{m=1}^{M} \sum_{t=E_{n_{s,c}^{exp},m}}^{L_{n_{s,c}^{exp},m}} X_{n_{s,c}^{exp},m,t} = 1 \qquad \text{for } s=1,2,..S;\ n_{s,c}^{exp} = 1,2,..,\, N_{s,c}^{exp} \tag{4}$$

All import containers from ship s must be moved to the storage area first before the handling and transfer of export containers:

$$\underset{n_{s,c}^{imp}}{Max} \left\{ \sum_{m=1}^{M} \sum_{t=E_{n_{s,c}^{imp}}}^{L_{n_{s,c}^{imp}}} t g X_{n_{s,c}^{imp},m,t} \right\} \le \underset{n_{s,c}^{exp}}{Min} \left\{ \sum_{m=1}^{M} \sum_{t=E_{n_{s,c}^{exp},m}}^{L_{n_{s,c}^{exp},m}} \left(t - I_{n_{s,c}^{exp},m} \right) g X_{n_{s,c}^{exp},m,t} \right\}$$
$$\text{for } s=1,2,..,S;\ c=1,2,..,C\ ;\ n_{s,c}^{imp} = 1,2,..,\, N_{s,c}^{imp}\ ;\ n_{s,c}^{exp} = 1,2,..,\, N_{s,c}^{exp} \tag{5}$$

Yard machine as renewal resources:

$$\sum_{s} \sum_{c} \left[\sum_{n=1}^{N_{s,c}^{imp}} \sum_{t=\max\left(h,E_{n_{s,c}^{imp},m}\right)}^{\min\left(h-1+I_{s,b,m}^{imp}, L_{n_{s,c}^{imp},m}\right)} X n_{s,c}^{imp} + \sum_{n=1}^{N_{s,c}^{exp}} \sum_{t=\max\left(h,E_{n_{s,c}^{exp},m}\right)}^{\min\left(h-1+I_{s,b,m}^{exp}, L_{n_{s,c}^{exp},m}\right)} X n_{s,c}^{exp} \right] \le 1$$
$$\text{for } h = 1,2,..,T;\ m=1,2,..M \tag{6}$$

The objective function $Z_1 = \min \sum\limits_{s=1}^{S} w_s g(d_s - D_s)^+$ is effectively similar to minimising

the weighted cost of ships staying at a port $Z_2 = \min \sum\limits_{s=1}^{S} w_s g(d_s - A_s)$. The following two possible cases proves the statement:

for $d_s > D_s$

d_s - D_s = (d_s - A_s) + (A_s - D_s) = (d_s - A_s) + *(constant).*

Therefore Z_1 and Z_2 give the same optimal values.

for d_s £ D_s

(d_s-D_s)⁺ = 0 and minimisation of *(d_s - A_s)* does not change the scheduled departure time and total utilisation of the port.

Using the objective function Z_1 (equation 1) has the following advantages:

- D_s can be adjusted during the planning stage;
- using Z_1 as an objective function enables slightly quicker search for optimal or near optimal solution with heuristic techniques; and
- the windows of ship movements may also be adjusted accordingly during the planning stage to increase the utilisation of the port and its infrastructure.

Solution Techniques

A mixed Integer programming model for export and import container process in seaport terminals has been developed in this paper and tested with a small size problem using the Generalised Algebraic Modelling System, GAMS (1998). The small size problem formed from one ship, two cranes, two yard machines, eight exports and eight import containers. GAMS found a relax solution of the problem very quickly and shown by a Gantt chart in Figure 1, but GAMS could not confirm the results as an optimal solution after 1 million iterations. As the linear programming relaxation is not very tight, the mix integer linear programming solver (OSL) spends a lot of time in the branch and bound before finding a good solution.

The solution of the problem is NP-Hard because more containers, ships and equipment are involved for a longer time period. Research continues into the investigation of the solution by meta-heuristic techniques namely tabu search, ant algorithm and genetic algorithm. Heuristic techniques normally yield good solutions to this type NP-Hard problems, but cannot be guaranteed to produce an optimum. Long time real-life data collection has been started at a Brisbane port and research continues into the investigation of the solution of the problem with real–life data by heuristic techniques.
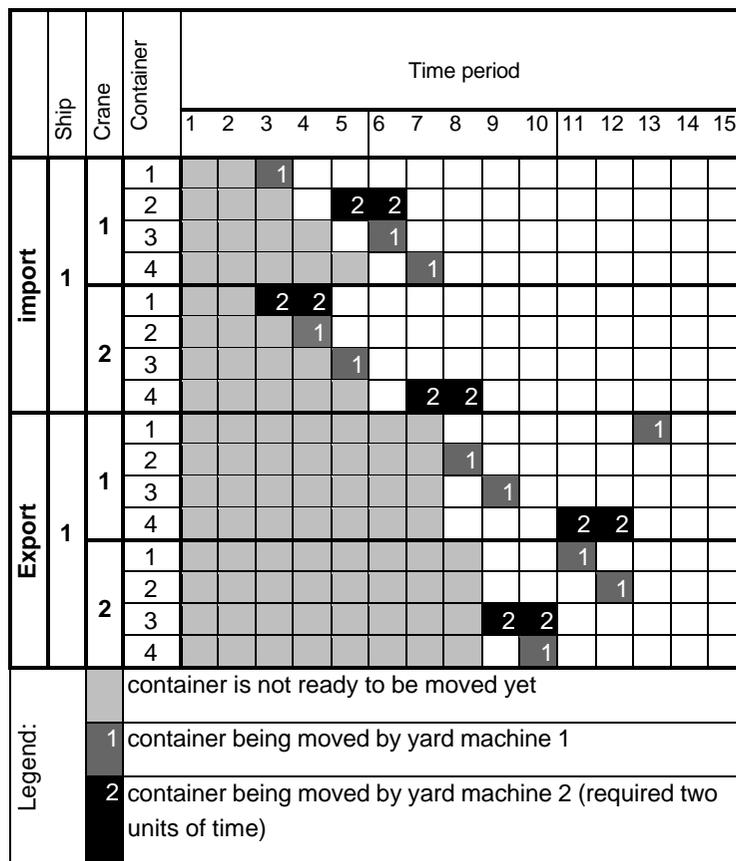
Ship	Crane	Container	Time period
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
import / 1	1	1			1												
		2					2	2									
		3						1									
		4							1								
	2	1			2	2											
		2				1											
		3					1										
		4							2	2							
Export / 1	1	1													1		
		2								1							
		3									1						
		4											2	2			
	2	1											1				
		2												1			
		3									2	2					
		4										1					

Legend:		
		container is not ready to be moved yet
	1	container being moved by yard machine 1
	2	container being moved by yard machine 2 (required two units of time)

Figure 1 A relax solution of the sample problem

Conclusion

The problem being investigated is the minimisation of handling and travelling time of containers from the time the ship arrives at port until all the containers from that ship leave the port. This mathematical model can be used as a decision tool in the context of investment appraisals of multimodal container terminals. Long-time data collection should be carried out before the implementation of the model. In the optimisation of the port system through these type of mathematical models, several parameters are involved in the phenomena which influences the optimisation results. A more detailed study may be undertaken to analyse the effect of these parameters on the improvement of port capacity in the long-term. The model assumes that equipment is available every time it is needed. This study has been confined to the basic elements of the overall investment planning problem related to the expansion of the system. Improvements in operational methods are beyond the scope of this study. The complexity of the current model is very high, so the inclusion of other terminal activities is left out of this study.

Investments in multimodal terminals are very costly and the technical progress of the equipment used gives them a much shorter life than they had in the past.

In order to obtain maximum benefits it is usually necessary to combine a number of investment strategies into a coherent and complementary package of capital expenditure projects. For example, the investment in terminal infrastructure to allow faster loading/unloading of ships and trains (see Kozan (1994)).

In addition, a comprehensive hinterland analysis within the national context will provide more comprehensive data for estimating the future demand on any seaport system. Future studies are needed on the alternative means of increasing seaport efficiency by improving utilisation of the present capacity. Such a study might cover better port planning methods, investments for increasing the capacity of the lagging segments of the seaport system, and means of better utilisation of present facilities.

Therefore, the model can be used to:
• analyse and balancing of the container transfer process, cost savings and performance improvements;
• improve efficiency of the storage area and container transfer system;
• improve different plant layout methodologies to increase efficiency of containers management and minimise total container throughput time.

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