

Container Transfer Logistics at Multimodal Container Terminals

Erhan Kozan

School of Mathematical Sciences, Queensland University of Technology
Brisbane Qld 4001 Australia
e.kozan@qut.edu.au

Abstract: Due to the dynamic nature of the environment a large number of timely decisions have to be continuously reviewed in accordance with the changing conditions of the multi-modal container terminal system. The development of a terminal to its optimum capacity with minimum investment is basically contingent upon the efficient loading and unloading of ships, trains and trucks using the terminal and the rapid movement of containers in and out of the terminal area. Such movements are in turn dependent primarily on re-sequencing and balancing of the multi-stage container transfer process; operating strategies; physical layout; and storage processes. The opportunity cost of ship time and variation from the desired level of service are compared in this paper.

Keywords: *multimodal container terminal; simulation; sea transportation.*

1. INTRODUCTION

The role of a multimodal container terminal (MMCT) is to ensure a smooth transfer of freight between the two nodes. The efficiency of the transfer between the nodes can have a significant effect on lateness and service times of ships. The system's steady-state performance is analysed as a function of the arrival and departure of import and export containers. An expected ship delay depends on the following parameters: number and types of cranes and other handling equipment and their ages; capacities and down-times; distribution of arrivals in a given time period; and overall length of the vessel.

The terminal's performance can be measured in terms of labour productivity, pick-up/delivery cycle times, equipment utilisation, ship service time, container throughput time. Achievement of a desirable level of customer service mainly depends on the length of the throughput time. Furthermore throughput time affects the stationary time and non-productive time of ships at the terminal. Long throughput times may cause congestion at the terminal.

Total throughput time of containers as a function of cranes, forklifts/highstackers and terminal transfer trucks should be used to measure the performance of the system (see Kozan and Preston (1999), Kozan (1997-1, 1997-2, and 2000), Preston and Kozan (2001 a and b)).

MMCT is very complex and due to the dynamic nature of the environment a large number of timely decisions have to be continuously reviewed in accordance with the changing conditions of the system Kozan (2000), Chung & Lin (2002), Kondratowicz (2000).

Investments in MMCT are very costly and the physical life time of the equipment much shorter 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. Investment in terminal infrastructure to allow faster loading/unloading of ships and trains is an example of an investment strategy. (Kozan (1994)).

This paper has analysed major activities in the container seaport. When a container vessel calls to a port, the containers on board must be unloaded

and stored at the port until they are transported further by rail or road. The containers must be stored in a manner so as to minimise the amount of handling needed to place a container in the storage area and to remove it when needed. A container terminal represents a point in a transportation system where containers are moved from one mode of transport to another. The model in this paper establishes the nature of the relationship between two or more significant factors and the options for increasing throughput by discovering the location of bottlenecks which restrict flow through the system. This model may be of use for long-term planning, for example, to help with the selection of a handling technology, site locations, or proposed service expansion.

2. MULTI-MODAL TERMINAL

As seen in Figure 1, after the import containers have been unloaded from the container vessel s and placed in the marshalling area i , they are transferred to the storage areas j , the multi-modal terminal truck area L or the road inter-modal terminal $ROIT$. The containers are transferred from L to rail intermodal terminals $RAIT$ for transferring to the hinterlands by terminal trucks. . If dealing with export containers the problem would be reversed, when a container arrives, for export, it is unloaded from the truck or train by gantry crane or yard machines (straddles, reach-stackers or fork lifts) and transferred to the storage area. In this process, the shore cranes, yard machines, terminal trucks and gantry crane cycles need to be synchronized.

When a container vessel arrives and its cargo is unloaded, the stevedoring company will receive information about where some of the containers are to be transported. The containers that are remaining must be placed in storage areas until they are needed. They stack the containers in a manner so as to minimise the time taken to retrieve a container by considering the storage area constraints. In the case of exports, the stevedoring company usually knows when a container arrives and when it will be scheduled to depart. The stevedoring company charges a penalty for containers that are delivered too early in respect to the departure time and after cut-off times no containers are received.

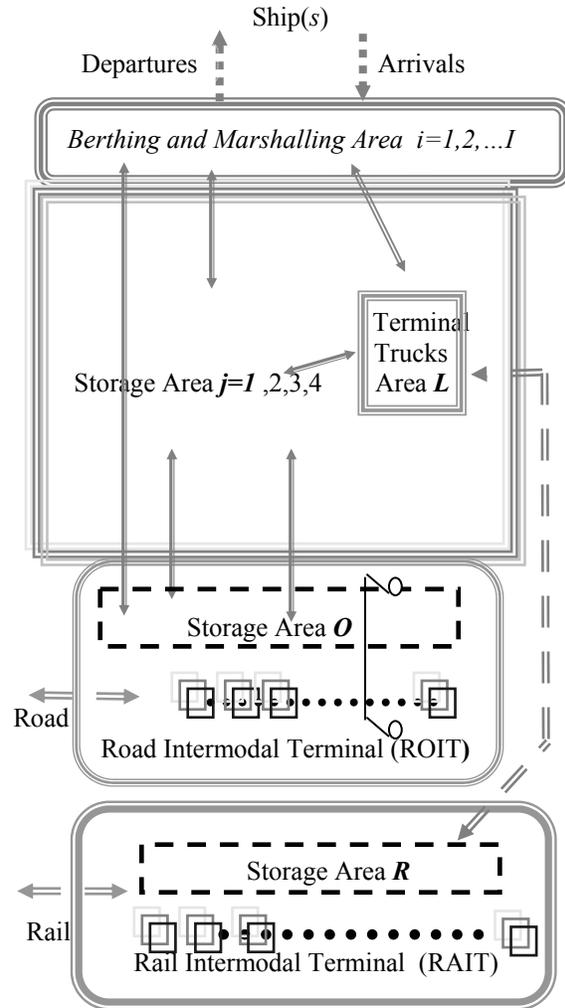


Figure 1. A Layout of a Multimodal Container Terminal

3. SIMULATION MODEL

Simulation is one of the most powerful analysis tools available for operation and the design of complex systems. The simulation model is developed for the purpose of understanding the behaviour of the MMCT terminal and/or evaluating various strategies for the operation of the systems. The relationships among system's elements and the manner in which they interact determine how the overall system behaves and how well it fulfils its overall purpose (Pidd, 1996). Analytical models cannot easily represent the complex interactions caused by random events. So, a simulation model is developed to describe container progress in the system to address a number of specific objectives of the research.

Some of the probability distributions may not be standard probability distributions like those used in queuing theory and other mathematical models; however, simulation allows us to include these non-standard distributions into the model. The potential for sensitivity analysis is almost limitless, so we investigate what improvements can be made to any bottlenecks if we have any and vary key parameters, such as the arrival times and handling times.

A simulation tool, Arena, is used for developing the model and analysing the results (Kelton et. al 1998). Simulation model statements of Arena are called blocks. Blocks define how the system operates. Each time a block is executed, the state of the system is changed. To execute a block, an object called an entity must pass through the block. Entities typically represent items moving through the system such as containers. Similarly, a block's function normally corresponds to an operation in the real system. For example, consider the resource block: equipment; when an entity executes this block, resource equipment is assigned to entity in much the same manner as a yard machine is assigned to a container transfer. The simulation model for multimodal container terminal with ARENA has the following characteristics:

Deliveries and pickups

The consequences of different delivery and pickup time policies can be examined by altering the variables Lead Time, Cutoff Time and Pickup Window. To change the number of yard machines, not only must the number of unit parameters in the transporter modules be altered, but corresponding changes must also be made to the capacity parameters of the resource modules.

Incoming Ships

The first loop of the simulation reads in the schedule, and creates an entity for each line of the schedule, assigning the attributes scheduled arrival, scheduled departure and crane allocations. The second loop repeats the schedule every day. Blocks assign the attributes which are respectively the number of import and export containers. Blocks also assign ships to berths and export and import containers to the storage areas (*j*), *terminal trucks area (L)*, *road intermodal terminal (ROIT)* or *rail intermodal terminal (RAIT)*.

Export Container Arrivals

When the container arrives, a block and its following assign block are used to assign a storage location within the area allocated to the ships.

Unloading and Loading Containers

A container on a ship can be unloaded by a shore-crane. Once a container has been unloaded by a shore-crane, it is then transferred by either a yard machine to area *j*, *L*, *ROIT* or *RAIT*. Containers are loaded onto ships by shore-cranes from berthing area.

Containers in the Yard

When the container reaches the intersection nearest to where it is to be stacked, it delays by the amount of time it takes the transporter to get to its assigned storage location and unload. The transporter is released, and the storage location is marked as occupied. If the container is an import container then it calls for a yard machine. If the container is an export container, it waits for its ship to be ready to load, and then it finds its berth number and works out where to load. If it is not at the top of its stack, it waits until it is

Ships Leaving the Terminal

When a ship leaves the terminal, it releases its berth resource.

Assumptions

An exact model of the system is usually very difficult to develop in a simulation. Firstly, – some approximations and simplifications should be made without disrupting the validity of the model. So, it is assumed that yard machines never get in each other's way. This ignores the effects of congestion. Secondly, – although Arena provides useful modules for some common simulation-related tasks, some situations, such as storage areas large enough that the position of an object matters, and yard machines that are partially interchangeable, must be handled by ad hoc methods, which are tedious, time-consuming, and error-prone. Furthermore, the workaround to allow partially interchangeable transporters requires bypassing some of Arena's transporter allocation logic. This forces the model to choose a type of transporter before actually allocating one, sometimes bypassing a nearby transporter of one type to allocate a more distant transporter of another type. It also means that requests for a

particular transporter type are handled on a first-come, first-served basis, which can be very inefficient, particularly for the shore crane, because parallel movements of a shore-crane are very time consuming and maximum available vertical transfers in a time frame should be done before horizontal movements.

4. AN APPLICATION

The Port of Brisbane can accommodate vessels with up to 33,000 dead weight tones and trades about 500,000 TEU/year. Currently there are seven container terminals at the Port of Brisbane. The terminals are owned by the Port of Brisbane Corporation but are leased to two stevedore companies: Patrick Terminals; and P & O Ports. Adjacent to the port at Fisherman's Island is the Brisbane Multimodal Terminal (BMT). Trains up to 900 metres long can be handled at this terminal. Containers are transferred to/from the marine container terminals by trucks to the BMT. Facilities at the Port of Brisbane are summarised in Table 1 to give an idea of the size of the MMCT.

Table 1. Facilities at the Port of Brisbane

Wharf & Operator	Length of berth	Shore-cranes	Yard Machines	Total Storage
1 Patrick	197	One twin-lift max lift 62t	13 straddle carriers;	14097 TEUs
2 Patrick	200	One twin-lift max lift:100t	6 heavy forklifts;	
3 Patrick	300	One twin-lift max lift 80t	2 prime movers	
7 Patrick	300	Two single -lift max lift: 40t 3 rubber-tyred gantries		
4 P&O	300	One single lift max lift 64t	11 reach stackers	7,100 TEUs &
5 P&O	250	One single lift max lift 64t		5500m ² storage shed
6 P&O	150	One twin-lift max lift 64t; one single-lift max lift 55t		

(See for details: <http://www.portbris.com.au>)

For this paper a trial data set was generated with 600 import and export containers. 30% of the containers are of 40 feet in length and the rest of containers are 20 feet in length. One or two shore-cranes can be assigned to a berth. Assignment of shore cranes to a container ship must be synchronized with an appropriate level of yard machines to move containers between the

marshalling area and the storage area. Otherwise, a bottle-neck can occur. This issue is further complicated by the fact that the transfer times depend on how far the container storage area is away from the ship.

When a ship arrives at a port, storage bays are set aside for the ship. Storage bays for export containers will be cleared when the ship departs, but import containers will remain there until being regrouped to other bays or taken away from the port.

Export containers may be delivered up to three days before the cutoff time, which is two hours before the ship's scheduled departure. Import containers may be picked up to transfer hinterland between 5am and 11pm and stay maximum two days after the ship's arrival at the storage area. Export containers enter the terminal by trucks and trains, and leaving the terminal by ships; and import containers enter the terminal by ships, and leaving the terminal by trucks and trains.

The trial data set used for the solution and subsequent sensitivity analysis is detailed below. Ships' entering and leaving the loading/unloading area are normally distributed with a mean of three hours and a standard deviation of one hour.

From the marshalling area, an average of 23% of all containers were transferred to the terminal truck area (L), an average 5% of containers transferred to the empty container storage area, 32 % containers transferred to ROIT and the remaining 40% of containers transferred to the four storage areas (j).

The storage area (j) is divided into 4 sections, and each section has a different transferring time. All sections have a capacity of 600 containers/stack. The maximum level of stack is three. The distribution of handling time of yard machines is Erlang (2.1). The distribution of handling time of a shore crane is Normal (2.6, 0.29). Its speed is normally distributed with (10 km/hr, 2 km/hr). Mean traveling times from the marshalling area to section 1 takes 3 minutes, to section 2 takes 3.5 minutes, to section 3 takes 4 minutes and to section 4 takes 6 minutes per container. To move a container from the marshalling area to L takes 3 minutes per container. The containers moved to L are transported to the rail terminal and each container takes on average 6 minutes. An average

of 71% containers use road and the remainder use rail. To move from the marshalling area to the empty container storage area takes 10 minutes per container.

Ship arrivals are scheduled weekly. However, late arrivals of ships are very common and actual arrival times of ships are determined as a triangular distribution with parameters (0,15,120).

5. ANALYSIS OF MACHINERY CONFIGURATIONS

The objective is to find an optimum balance between throughput time and leasing/operating costs so as to minimise the total costs of the system. The simulation results are examined for different numbers of yard machines, shore cranes, transfer trucks and gantry cranes to determine which configuration offered the lowest average throughput times.

The simulation runs comprised 20 replications of length 14 day each. The ‘warm-up’ period for the runs was 7 days; no statistics were gathered for these days (to allow the system to stabilise into its normal operation). After the replications, the expected throughput time of each ship $T(s,m,t,g)$ for different numbers of shorecranes (s), yard machines(m) transfer trucks (t) and gantry cranes (g) were collated.

The effect of gantry cranes at ROID to the throughput time was found very small because of the buffer storage area next to this terminal. Also, throughput time was not affected when the number of transfer trucks exceeds four. So the number of transfer trucks (t) and gantry cranes (g) were kept constant in the simulation and the simulation was run for values of $8 \leq m \leq 16$, $1 \leq s \leq 2$, $t=4$ and $g=1$.

The total throughput time affects the ship time at the berth and related berthing cost, and it can be expressed as $c_{bc} = c_h \times T(s,m,g,t)$ where c_h is the average ship cost/hour at the berth. The total leasing/operating cost of the machinery can be expressed as $c_{oc} = c_s \times s + c_m \times m$ where s and m represent number; and c_s and c_m represent leasing/operating cost of shore cranes and yard machines respectively. Then the total

cost is formed as $TC = c_{oc} + c_{bc}$ and it is converted to \overline{TC} for an easy cost analysis by the following assumptions:

- ratio between $[c_s : c_m]$ is assumed [12:1] ;
- ratio between $[c_h : c_m]$ is assumed [100:1]

Minimum average throughput (minaverage $T(s,m,t,g)$) is assumed as a base value (in our case it is $T(base)=T(2,16,4,1) =22$ hours) and ratio of the other $T(s,m,t,g)$ values to this base value are calculated (e.g. $T(s,m,t,g)/T(base)$) to determine relative cost values in terms of c_m .

Therefore,

$$\overline{TC} = c_s \times s + c_m \times m + c_h \times T(s,m,t,g) / T(base)$$

$$= 10 c_m \times s + c_m \times m + 100 c_m \times T(s,m,t,g) / T(base)$$

\overline{TC} values are calculated for all possible machinery configurations in terms of c_m and given in Figure 2.

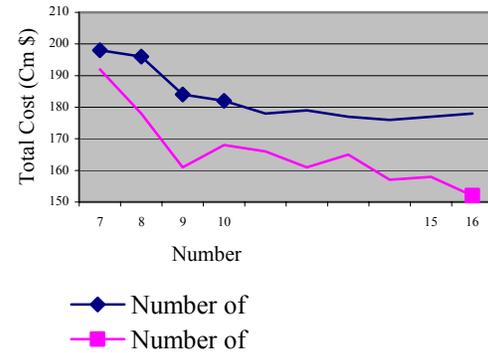


Figure 2. Total Cost for Different Machinery Configuration

\overline{TC} values are not definite for an optimal configuration because they depend on the accuracy of the cost ratio assumptions of the machinery. There also seems to be some inconsistencies in the results as well. However, they do give a general trend for the response of the variables being measured. It seems more beneficial to have a maximum allowable of 16 yard machine and two shore cranes.

6. CONCLUSION

In this paper, a simulation model is developed to analyse a typical multimodal container terminal. The simulation results are used to determine optimal machinery configurations, thus enabling the application of more efficient systems for the terminal.

The problem being investigated is the minimisation of ship delays, and handling and travelling time of containers from the time the ship arrives at port until all the containers from that ship leave the port. If dealing with export containers the problem would be reversed. That is, the handling and travelling time of the containers from when the first arrive to the port until the ship carrying the containers departs from the port. The model can be used to analyse and balance the container transfer process, thus saving costs, and improving the efficiency of the storage area and container transfer system. This model can be used as a decision tool in the context of investment appraisals of multimodal container terminals.

A cost benefit analysis of the ship berthing times is done to determine an optimal number of shore cranes, yard machines, transfer trucks and gantry cranes. The cost-benefit analysis must be performed before any implementation is considered. To make the cost-benefit analyses results more flexible an analysis should be carried out to determine the sensitivity of the best solution to changes in key variables. This would provide port planners with a mechanism for the continual updating of the optimal solutions based on any new estimates of these parameters.

The application of research results to multi-modal container terminals and operators in Australia has the potential to: reduce delays and costs by better planning of schedules of container transfer systems in Australia.

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.

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