Intermodal Terminals

Luis Ferreira
Lecturer
School of Civil Engineering
Queensland University of Technology

Erhan Kozan
Lecturer
School of Mathematics
Queensland University of Technology

Abstract:

This paper discusses the major factors influencing operating performance of an intermodal terminal, namely: operating strategies; train operations; track layout; lifting equipment; and management information systems.

A methodology is put forward which enables operating strategies to be evaluated. Computer simulation is used in order to arrive at the strategy which minimises operating and capital costs and satisfies customer service requirements. The simulation model outputs include performance measures related to customer service such as mean waiting times required for loading and unloading of containers; as well as productivity measures of terminal operations such as lifting equipment utilisation.

Contact Author:

Luis Ferreira
Queensland University of Technology
GPO Box 2434
BRISBANE QLD 4001

Telephone: (07) 864 1542 Fax: (07) 864 1515

Introduction

Freight transport has a critical role to play in improving the competitiveness of the trade exposed sectors of the Australian economy. An efficient and effective freight transportation system is one of the major objectives of the Federal Government's micro-economic reform programme. An efficient land transport network requires that interfaces between different modes of transport are provided which minimise costs, whilst meeting customer requirements for reliability of service delivery. It is those interfaces, in the form of container transfer facilities by road to/from rail, which are the subject of this paper.

Ogden has undertaken considerable research into freight modelling and analysis, Ogden (1990). However, there has been little systematic analysis into the operation of container transfer facilities in order to provide a means by which several operating strategies can be evaluated.

The problems associated with inefficiencies and congestion in container transfer facilities have been addressed by a number of Australian government sponsored investigations including the Inter-State Commission (1989) and Industry Commission (1991). Terminal costs, as well as delays in pick-up and delivery, have a significant detrimental impact on rail's ability to compete with road, particularly on the Melbourne - Sydney -Brisbane corridors (National Freight Initiative, 1990)).

In 1990/91 intermodal freight, mainly in the form of container traffic, made up 5.5 million tonnes out of a total 8.4 million tonnes of interstate freight carried by Australia's rail systems. The movement of containers by rail has seen rapid growth in the last five years. The five rail terminals handling intermodal freight, namely Acacia Ridge (Brisbane), Chullora (Sydney), Dynon (Melbourne), Islington (Adelaide) and Kewdale (Perth), handled over 500,000 containers in 1990/91.

Most of these terminals were ill-equipped to deal with the rapid growth in demand through the 1980's. As a result, a number of terminal redevelopment programs were recently put in place throughout Australia. The latest of such projects is the construction of a new rail terminal at Enfield in Sydney at an estimated cost of $20 million.

Demand on rail terminals is likely to continue to increase at a fast rate given the current relatively low market share in most of the main interstate rail corridors, and hence rail's potential to attract road based container movements. Rail's share of the general freight market on the eastern seaboard corridors ranges from around 25 percent to 35 percent. Recent decisions regarding infrastructure investment and organisational changes should increase rail performance levels and hence its market share, Ferreira (1992).

The 'One Nation' statement by the Federal Government earlier in 1992 focused investment in rail mainly in track related projects. The latter account for all but $20 million of the total $454 million allocated to the national rail network. This level of funding represents around 27 percent of the $1.7 billion identified by the National Rail Corporation (NRC) as its capital requirements over the coming decade.

Structure of this paper

The next section deals with the main factors which influence intermodal terminal performance, namely operating strategies, train plans, lifting equipment, and customer requirements. This is followed by a description of the simulation techniques which are being developed to evaluate terminal operating performance. The methodology used is discussed and some of the results obtained are presented. Finally, some conclusions regarding the applicability of the methodology are offered.

Terminal operating performance

The role of a road/rail freight intermodal terminal is to ensure a smooth transfer of freight between the two modes. Such freight may be in containers, flat trays, piggyback (trailer on flat wagon) or roadrailers (trailers capable of road and rail movement without requiring rail wagons). Figure 1 shows the main factors influencing terminal operating performance, (Ferreira and Sigut, 1992). Some of these factors will now be discussed in turn.

Figure 1 : Terminal Performance Factors

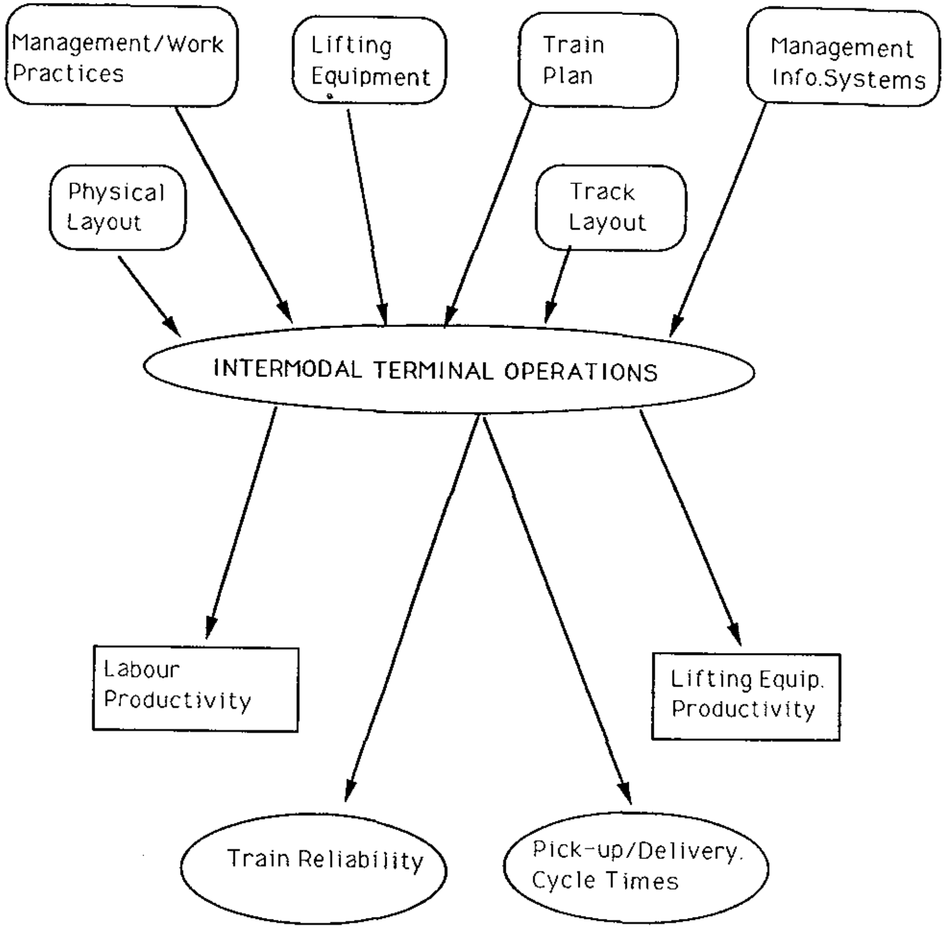
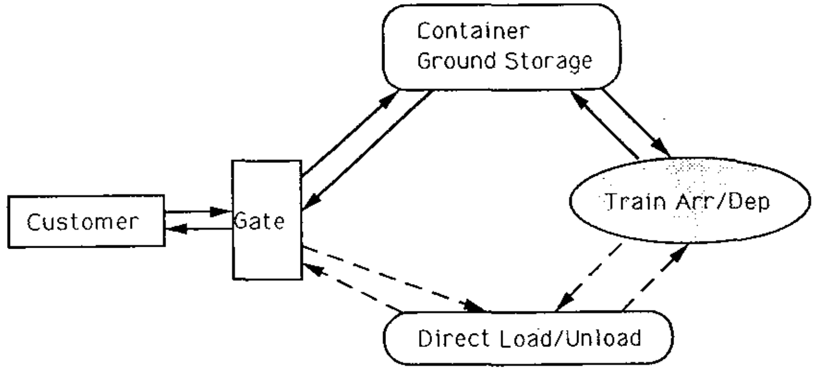
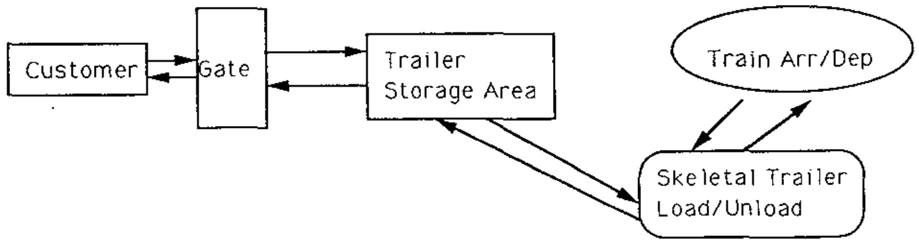


Figure 2 : Terminal Operating Strategies

Random Acess Loading/Unloading



Skeletal Trailer Loading/Unloading



Operating strategies

As shown in Figure 2, two main operating strategies for the loading and unloading of containers may be adopted, namely: random access and the use of skeletal trailers. Under the random access system, customers pick-up/deliver containers directly from/to a train or from/to ground storage. This is the method commonly used in Australian and in European terminals. The skeletal trailer system is mainly used in North America. It is based on the use of a dedicated fleet of skeletal trailers which are used to pick-up containers directly from a train. Those trailers are then moved to a trailer storage area ready to be picked-up by individual customers. The reverse process is followed when loading containers on to trains.

The main advantages of the skeletal trailer approach are related to lifting equipment productivity - it avoids double handling of containers; track productivity - trains can be quickly loaded/unloaded; customer service - customers are removed from the train loading/unloading area and are provided with a dedicated trailer storage area thus reducing customer turnaround times within the terminal. The main disadvantages of this system are the capital cost requirements - dedicated fleets of skeletal trailers compatible with container types; and the need to provide a storage area for skeletal trailers. Skeletal trailer operation is ideally suitable for conditions where trains are required to have low unloading/loading cycles, and containers are mainly of a standard type.

Train planning

Efficient operations require a train operating plan which is both disciplined and as simple as possible. Trains should not be shunted or split in any way. This requires tracks of sufficient length to accommodate current and expected future train sizes.

Lifting equipment

The equipment available to load/unload containers onto/from rail wagons is of two main types, namely: gantry cranes (rail mounted or rubber tyre), and side-loaders (forklifts and reachstackers). Most road/rail terminals in Australia use a combination of these two types of equipment. A third type of equipment, straddle carriers, are used in seaport terminals to move containers within the terminal from loading/unloading area to storage areas.

The choice of equipment will depend on container throughput, operating strategy, physical operating space, track layout and degree of standardisation in container sizes and types. Each type of equipment has different capital costs (ranging from over $2 million for a rubber tyre gantry crane to around $0.4 million for a forklift); as well as different land requirements for operating purposes, and pavement strength requirements.

Customer requirements

Overall transit times, reliability of delivery times and cost are the main factors influencing mode choice in the freight transport sector, Industry Commission (1991), Fowkes et al (1991), Jeffs and Hills (1990). Users of intermodal terminals have as their main requirements reliability of delivery times; container pick-up and delivery cycles which are delay free, and the ability to monitor progress of their consignments (i.e. real time information regarding container location and estimated arrival times. Efficient and timely interchange of data between the rail system and its customers is critical to the efficient operation of a terminal as highlighted by Zimmer (1989).

The simulation model described below uses queueing theory under steady state conditions.

Simulation of terminal operations

Queueing theory offers one of the most powerful analytical tools to find the optimum capacity of facilities providing a service under random conditions. Queueing theory provides a large number of alternative mathematical models for describing a queue. Most mathematical models of queueing phenomenon are solved for steady state conditions, while only a few are analysed in time dependent form.

Daganzo (1990) has analysed the effect of crane operations on ship service at port terminals. He first proposed a simple, approximate approach to calculate the maximum berth throughput during periods of congestion. This was followed by an examination of the effect on ship delay, when the traffic level does not exceed the maximum throughput.

The simulation model

Peak demand periods are critical in determining maximum resource requirements and customer service levels achieved. Therefore, it was decided to simulate two periods of peak demand on a terminal, namely:

(a) A train unloading period, which typically takes place in the morning with several trains arriving within the space of four to five hours; and
(b) A train loading period when containers arrive by road to be loaded onto rail wagons for departures late in the afternoon.

Simulating train unloading operations

The operations to be simulated can be viewed in two steps, namely:

(i) the allocation of incoming trains to rail tracks within the terminal; and
(ii) the unloading of containers to the ground or a waiting truck once each train 'arrives' at its allocated track.

(i) Assignment of trains to rail storage tracks

The problem is one of assigning a train to a rail track within the terminal given the train size and arrival time; the lifting equipment available at each track; and a minimum 'tolerable' delay to the availability of containers after arrival (e.g. customers should have access to their containers no more than a specified time period after the train's arrival).
It is normal operating practice for each incoming train to be allocated a 'home' track, and for that train to regularly arrive and depart from that same track. The current version of the model assumes this to be the case. However, it is envisaged that a train assignment module will be developed at a later stage.

(ii) Unloading containers from train to ground and/or road vehicles

The model assumes that several trains arrive during the simulation period and that a number of container lifting machines are available for the unloading task. Some machines are only available for specific trains (e.g. a gantry crane may be the only equipment available to unload trains which are 'stored' on the middle track of a three track straddle configuration).

The following data is required as input:

- Train scheduled arrival times
- Probability distribution of train delays
- Mean number of containers per train
- Probability distribution of number of containers per train
- Number of container lifting machines
- Service times for each machine and their distributions
- Queueing discipline

Table 1 shows details of the input data used for a simulation run. These inputs are used for illustration purposes and do not reflect actual conditions at any specific terminal. The model is currently being used to simulate conditions at the Acacia Ridge terminal in Brisbane and the results will be reported on at the conference.

TABLE 1 : Input Date - Container Unloading Simulation (Base Case)

Number of Trains	5
Inter-arrival Times	60 mins.
Average No. Containers/Train	80 (normally distributed with s.d. = 15)
Lifting Equipment	4 Machines
Service Times	2.5 mins./container for 2 machines and 4.5 mins./container for the other 2 machines
Service Time Distribution	Exponential
Queueing Discipline	Random access

Currently, the outputs available for each simulated period include:

- Mean unloading waiting time per container
- Mean and maximum length of queue (number of containers waiting to be unloaded)
- Number of containers handled by each lifting machine
- Percentage utilisation time for each lifting machine
- Number of containers in queue at the end of the simulation period.

Table 2 summarises the main results using as inputs the data shown in Table 1. Table 2 also shows the effect of sensitivity tests carried out to quantify the effect of changes in lifting equipment service times; number of machines available; and train arrival pattern.

TABLE 2 : Simulation Results - Train Unloading

	Base Case[1]	Run Number[2]					
		1	2	3	4	5	6
Mean Container Waiting Time (mins.)	24	23	21	18	29	29	18
Mean Queue Length (No. Containers)	29	27	25	20	35	37	23
Mean Machine Utilisation (%)	89	84	77	70	94	100	78

NOTES: (1) Using input data as shown in Table 1

(2) Run 1 - Machine service times reduced by 10%
Run 2 - Machine service times reduced by 20%
Run 3 - Number of machines increased to 5
Run 4 - Machine service times increased by 10%
Run 5 - Train inter-arrival times reduced from 60 mins. to 50 mins.
Run 6 - As in Run 5 with number of machines increased from 4 to 5

A reduction in machine service times of 20 percent (run 2) results in a 13 percent reduction in the mean time required for a container to become available (mean container waiting time). At the same time, mean machine utilisation is reduced from 89 percent to 77 percent. If an additional machine is made available (run 3) the mean container waiting time is reduced by 25 percent and the mean machine utilisation is reduced to 70 percent.

Simulating train loading operations

In this case, we are interested in simulating peak conditions when containers arrive at the terminal by road vehicle to be loaded into rail wagons. A queueing model was used to simulate road truck arrivals with conditions as set out in Table 3.

TABLE 3 : Input Data - Train Loading Simulation (Base Case)	
Number of containers to be loaded	120
Number of available lifting machines	4 with service times as in Table 1
Inter-arrival times (mins.)	1 minute
Inter-arrival times distribution	Exponential

Table 4 summarises the results of several simulation runs to quantify the significance of changing inter-arrival times; number of lifting machines; and machine service times. The results shown for mean waiting time per container do not include the road vehicle processing time and travelling time within the terminal.

TABLE 4 : Simulation Results - Train Loading

	Base Case[1]	Run Number[2]		
		1	2	3
Mean container waiting time (mins.)	2	8	15	13
Mean queue length (no. containers)	2	9	13	12
Mean machine utilisation (%)	78	94	93	94

NOTES: (1) Using input data as shown in Table 3

(2) Run 1 - Container intermodal times reduced by 20%
Run 2 - Machine service times increased by 30 percent
Run 3 - Number of machines reduced from 4 to 3

As shown in Table 4, if the machine service times increase by 30 percent, the mean waiting time per container rises from 2 to 15 minutes (Run 2). A similar effect is produced when the number of machines is reduced from 4 to 3 (Run 3).

Terminal operating costs

The results of a simulation model can be used to determine total terminal operating costs under several operating scenarios. The total operating costs can be expressed as a function of the work undertaken by each container lifting machine and the unit cost of operating that machine.

The total cost, C, can be expressed as:

$$C = \Sigma_k \ \Sigma_j \ \Sigma_i \ c_{kj} \ x_{ki} \ t_{ki} \text{ .... (1)}$$

Where: i = lifting task to be performed (e.g. rail to ground; rail to truck; rail to skeletal trailer)

k = type of lifting equipment (e.g. forklift, crane)

j = cost component to be considered (e.g. labour, maintenance, capital, paving)

c_{kj} = cost per unit time of operating equipment type k, for cost component j

t_{ki} = time required to perform lifting task i by equipment type k

x_{ki} = number of lifting tasks of type i performed by equipment k

Equation (1) when used in conjunction with simulation results can be used to cost the trade-offs between customer service and operating costs. For example, operating strategies designed to minimise pick-up and delivery of container from and to a terminal, will mean higher costs through higher handling equipment availability. The effects of changing train schedules and train sizes can also be assessed.

Conclusions

The 'One Nation' statement from the Federal Government earlier in 1992 alocated $454 million to the national rail network. The 'One Nation' funded projects by themselves are unlikely to result in significant freight modal shifts. At best, there will be slight increases in rail's market share on some corridors. However, the set of conditions attached to the release of funds has the potential to help change management and work related practices, which could lead to significant cost reductions and container service improvements. Therefore, it is likely that there will be added pressure on existing intermodal terminal infrastructure to cope with increased demand.

A methodology designed to measure the performance of road/rail container transfer facilities has been put forward by Ferreira and Sigut (1992). Currently there are a number of operating philosophies for such facilities but there is no systematic analytical tool to assess the cost effectiveness of a given operating strategy.

Using simulation based on queueing theory, two types of terminal operations were modelled, namely unloading and loading of containers from and to rail wagons. Model outputs include mean loading/unloading times per container; mean and maximum container queue lengths; and handling equipment utilisation.

Data from Acacia Ridge intermodal terminal in Brisbane is currently being collected to test the models and the results will be reported on at the Conference.

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