Establishing Relationships Between Port Capacity, Throughput and Performance by Simulation Studies

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Abstract The use of port simulation models as a decision support tool has been well-established. For over three decades, simulation models have been used for port planning and evaluating proposed operational changes as well as investment alternatives. The outputs which have included ship's turnaround time, queuing delay, queue length, as well as economic measures such as unit costs or despatch/demurrage, have enabled managers to make decisions to improve the operations of their ports. In one instance, a number of simulation studies were carried out using a Port Simulation Model developed for the planning and management of operations of a bulk coal loading facility. The simulation model was used over twenty times to simulate a variety of configurations, operating procedures and system capacities. The results obtained from these studies have been verified by actual data over a period of time. With the richness of results obtained over a number of years, it was decided to synthesise the results of all simulations and to develop relationships between capacity parameters, throughput and performance. The systematic procedure for developing the relationships has involved tabulating and graphing the queuing delay and demurrage for various throughput levels with different capacity parameters. Discrete changes in capacity parameters have been isolated and their effect on performance parameters was separated and used for the development of the relationships.

1. INTRODUCTION

Port simulation models have been commonly used to simulate the performance of ports. The simulation models have been found useful in evaluating proposed operational changes as well as investment alternatives. The outputs have included ship's turnaround time, queuing delay, queue length, as well as economic measures such as unit costs or despatch/demurrage. These results have enabled managers to make decisions to improve the operations of their ports. The use of port simulation models as a decision support tool has been well-established. However, each simulation study is usually an end in itself. Having served the purpose, for which the simulation is carried out, the study becomes the part of a collection.

In providing decision support to one port authority for almost ten years, a number of simulation studies were carried out. The simulations were undertaken by using a Port Simulation Model developed for the planning and management of operations of this bulk coal loading facility. The simulation model was used over twenty times to simulate a variety of configurations, operating procedures and system capacities. The results obtained from simulation studies have been verified by actual data over a period of time. With the richness of results obtained over a number of years, it was decided to synthesise the results of all simulations and use it to develop relationships between capacity parameters, actual throughput and performance.

The systematic procedure for developing the relationships has involved tabulating and graphing the performance indicators such as queuing delay and demurrage for various throughput levels with different sets of capacity parameters. Discrete changes in capacity parameters have been isolated. The effect on performance parameters for various throughput caused by a discrete specific capacity parameter change was able to be separated and used for the development of the relationships.

1.1 The Port's Operational Structure

There are two major subsystems in a bulk export terminal: the inloading subsystem where the bulk commodity from the sources (mines) is received and unloaded, and the outloading subsystem which deals with loading the commodity onto ships for export. The two subsystems are interfaced through the stockyard which comprises of stockpiles and yard machinery. The yard machinery may be dual purpose (e.g. stacker-reclaimer) or specifically designed to either stack the commodity onto stockpiles or to reclaim the material from stockpiles for loading onto the outloading string. Both the inloading and outloading capacities can be influenced by the interface Equipment capacity is expressed in tonnes per hour (tph) and the port capacity in million tonnes per annum (MTPA). A simplified structure of the overall operations is given in Figure 1.

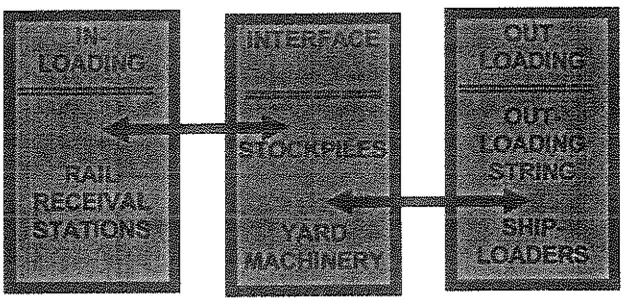

Figure 1: The Overall Structure

This paper deals specifically with the determination of the outloading capacity. However, some discussion of inloading capacity parameters is provided for obtaining an overall picture of port capacity considerations.

2. THE INLOADING CAPACITY

2.1 Factors Affecting Inloading Capacity

The key determinant of the capacity of inloading system is the number and design capacity of rail receival stations. Other major considerations include the number and payload of the consists; average distance (or time) travelled by trains from mines to the rail receival stations; the number, capacity and availability of stacking machinery; operational practices etc.

2.2 Infrastructure

The terminal has two rail receival stations, each with a design unloading rate of 4000 tph. However, a delay of approximately 20 minutes before the commencement of unloading and 5 minutes at the completion of unloading are incurred. These delays are due to the positioning of wagons and other safety considerations.

2.3 Inloading Rate

Assuming a payload of 7,700 tonnes per consist, it takes 1.925 hours to unload the train. With 25 minutes of total delay per consist , the gross time taken to service one consist is 2.34 hours giving a gross rate of 3,300 tonnes per hour. This is obtained by dividing the payload of 7,700 tonnes by gross unloading time.

2.4 Operational Hours Available

The rail receival station is available for 24 hours a day for 365 days a year except for the following interruptions:

(a) Maintenance downtime of 12 hours every two weeks, a total of 312 hours in a year
(b) Queensland rail holidays of 3 days per year, i.e. for 72 hours a year
(c) Shutdown due to weather, averaging about 72 hours in a year

This leaves an available time of (8760 - 312 - 72 - 72) or 8304 hours in one year's operations.

2.5 Saturated Capacity of Rail Receival Station

Saturated capacity is defined as the throughput that can be handled if inloading was carried out for 100% of the available hours. This yields a value of 27.4 MTPA, as shown below:

Saturated capacity = 8304 * 3300 = 27.4 MTPA

As the throughput increases, trains may have to queue at the rail receival station. The relationship between average queueing time and throughput is expected to follow the commonly observed behaviour of waiting line systems.

2.6 Economic Capacity of Rail Receival Station

The economic capacity of inloading operations is given by the throughput at which the queueing delay exhibits an exponential increase with increase in throughput, and approaches infinity.

The rail receival station utilisation rate (or commitment rate) is also expected to vary with throughput in a manner similar to the queueing time. In fact a linear relationship between average queueing time and rail receival station utilisation rate is anticipated. It is premised that economic capacity will be reached when the rail receival station utilisation reaches around 85-87% . Other criteria may be introduced.

The inloading capacity has undergone a step jump with the addition of a second rail receival station, doubling its capacity from about 24 MTPA to 48 MTPA. No interaction or synergy resulting from the addition of the second RR station, has been modelled.

3. THE OUTLOADING CAPACITY

3.1 Factors Affecting Outloading Capacity

The key determinant of the capacity of the outloading subsystem is the number of shiploaders and their design capacities. Other factors include the number of berths; speed and capacity of the outloading conveyor system which determine the outloading string capacity; maintenance schedules and breakdowns; stockpile situation, availability of yard machinery; operational practices etc. Note that the design outloading rate for the shiploader is 7,200 tonnes per hour

3.2 Capacity Estimation Criteria

Port capacity, expressed in million tonnes per annum (MTPA), is the amount of coal that can be loaded on to ships over one year without excessive delays to ships or excessive demurrage. Commonly used criteria in port performance analysis include berth occupancy rate, maximum or average queue length, waiting or queueing time, ship turnaround time and demurrage. The capacity estimation principles are similar irrespective of the criteria used. In this study, maximum acceptable demurrage is used for capacity analysis. The port authority is of the opinion that additional expenditure on facilities may be justified only when demurrage exceeds 25.¢ per tonne. This is taken to represent the acceptable level of this operational parameter. Hence, the throughput achieved at this level of demurrage is taken as a measure of port capacity. This is detailed in the next section.

3.3 Port Capacity under Various Configurations

The following configurations (Figure 2) have been identified with a view to estimating the port outloading capacity under different scenarios. The results of simulating the port performance with different scenarios are used to determine the throughput for similar values of selected performance criteria. This is premised to be the logical and rational estimation of port capacity.

- Single berth, single shiploader, low loading rate
- Single berth, single shiploader, high loading rate
- Two berths, single shiploader, low loading rate
- Two berth single shiploader, high loading rate
- Two berths, two shiploaders, low loading rate
- Two berths, two shiploaders, high loading rate

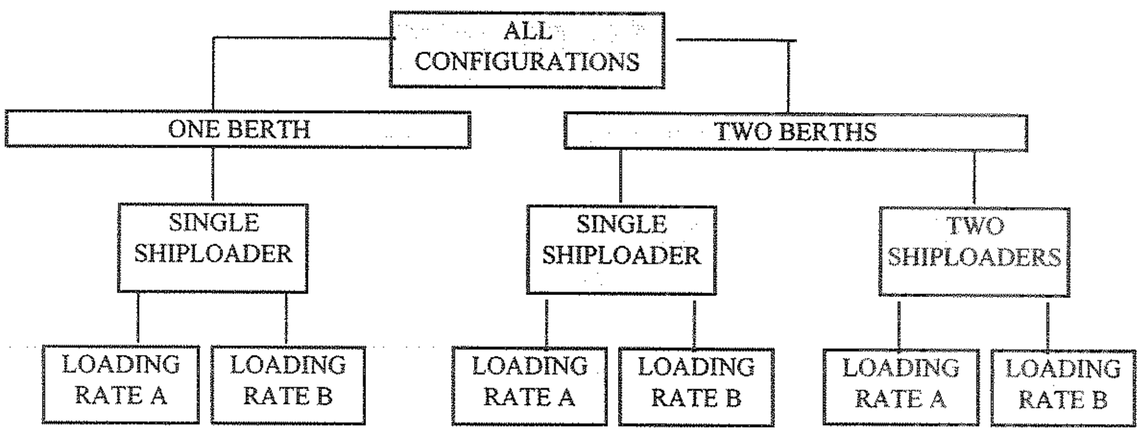

Figure 2: Infrastructural Combinations used in Model Simulations

4. CAPACITY ESTIMATION UNDER ALTERNATIVE SCENARIOS

4.1 One Berth, One Shiploader, Low Loading Rate

Figure 3 shows that under this scenario, the operational capacity of the port is 20.00 MTPA. Recall that the capacity has been defined as the throughput at which the demurrage is 25.¢ per tonne.

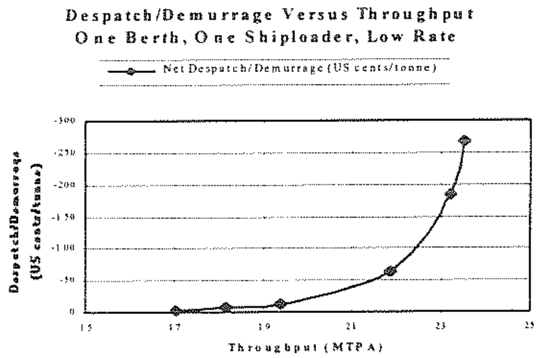

Figure 3: One Berth, One Shiploader, Low Loading Rate

4.2 One Berth, One Shiploader, High Loading Rate

Figure 4 shows the variation of despatch/demurrage with throughput for this system configuration. The port capacity is estimated at 21.4 MTPA.

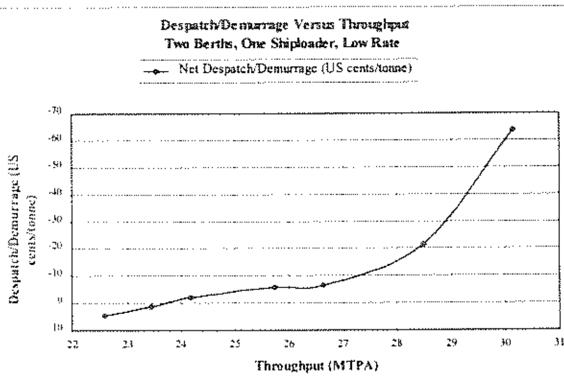

Figure 4: One Berth, One Shiploader, High Loading Rate

4.3 Two Berths, One Shiploader, Low Loading Rate

Figure 5 shows the variation of despatch/demurrage with throughput for this system configuration. The port capacity is estimated at 28.50 MTPA.

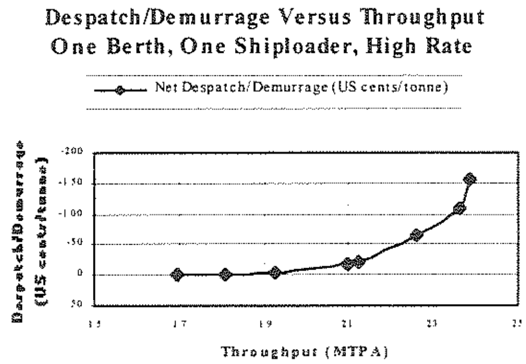

Figure 5: Two Berths, One Shiploader, Low Loading Rate

4.4 Two Berth, One Shiploader, High Loading Rate

Figure 6 shows the variation of despatch/demurrage with throughput for this system configuration. The port capacity is estimated at 30.65 MTPA.

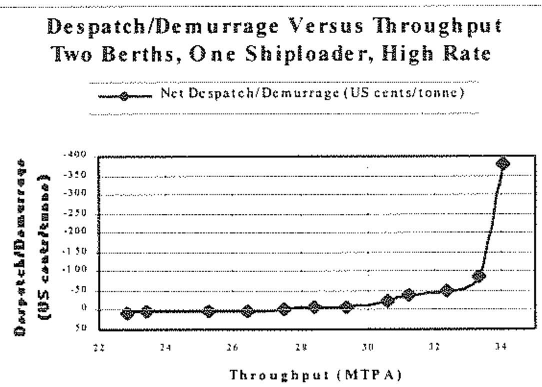

Figure 6: Two Berths, One Shiploader, High Loading Rate

4.5 Two Berths, Two Shiploaders, Low Loading Rate

Figure 7 shows the variation of despatch/demurrage with throughput for this system configuration. The port capacity is shown to increase to 44.5 MTPA.

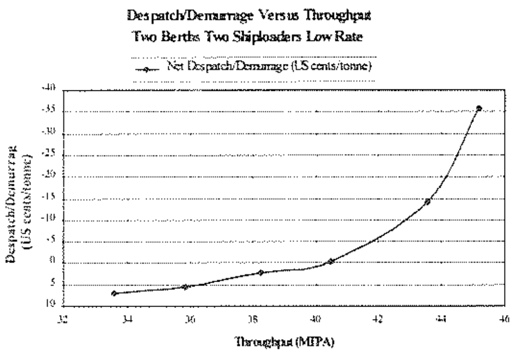

Figure 7: Two Berths, Two Shiploaders, Low Loading Rate

4.6 Two Berths, Two Shiploaders, High Loading Rate

Figure 8 shows the variation of despatch/demurrage with throughput for this system configuration. The port capacity is highest under this scenario and is estimated at 46 MTPA.

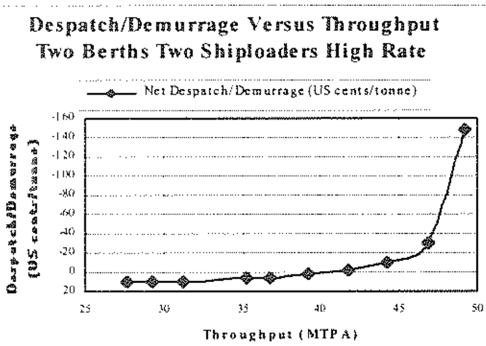

Figure 8: Two Berths, Two Shiploaders, High Loading Rate

5. INFRASTRUCTURAL CONTRIBUTION TO CAPACITY

5.1 Effect of Loading Rates

Three sets of values were obtained representing two different loading rates.

Table 1: Effect of Higher Loading Rate

Fixed Port Parameters	Low Loading Rate	High Loading Rate
One berth, one shiploader	20.00	21.40
Two berths, one shiploader	28.80	30.65
Two berths, two shiploaders	44.50	46.00

The increase in capacity obtained by increasing the out-loading rate from 6600 tph to 7200 tph has varied between 1.40 MTPA to 1.85 MTPA. It is interesting to note that increase in capacity due to improvement in loading rate is less with 1-berth/1-shiploader or 2-berths/2-shiploaders combinations compared to the 2-berths/1-shiploader case. In the former cases, there is spare outloading capacity while in the latter case, the outloading capacity is the limiting factor. Thus any increase in outloading capability has comparatively larger impact on port capacity in this case.

5.2 Effect of Adding a Berth

Table 2 shows the effect of adding a berth on the port capacity, while operating on two different loading rates. The increase in capacity is slightly higher with higher loading rate.

Table 2: Effect of Adding a Berth

Fixed Port Parameters	One Berth	Two Berths
Single shiploader, low loading rate	20.00	28.80
Single shiploader, high loading rate	21.40	30.65

The results show that addition of a berth has quantum jump in port capacity. When the outloading system is operating at 6600 tph, the capacity increase is 8.80 MTPA, while the increase at higher loading rate is 9.25 MTPA. The combined effect of increase in loading rate and addition of a berth is 10.65 MTPA.

5.3 Effect of Adding a Shiploader

Table 3 shows the effect of adding the second shiploader on port capacity. The effect is estimated at the two loading rates.

Two shiploaders are only meaningful when there are at least two berths. The addition of a shiploader with 7200 tph capacity has the capability to increase the port throughput substantially to the tune of around 15.5 MTPA.

Table 3: Effect of Adding a Shiploader

Fixed Port Parameters	One Shiploader	Two Shiploaders
Two berths, low loading rate	28.80	44.50
Two berths, high loading rate	30.65	46.00

6. DISCUSSION AND CONCLUSIONS

The detailed analysis of simulation outputs has shown that system improvements are able to increase the port capacity. The port management had several options to enhance the port capacity and meet the increasing demand.

A synthesised view of the results of increase in port capacity by discrete improvement and addition of facilities is shown in Figure 9. The port capacity is shown to increase to 46 MTPA with a 2-berths/2-shiploaders configuration with higher loading rate at 7200 tph from just 20 MTPA for one-berth/one-shiploader system at 6600 tph loading rate. The capacity contribution of each discrete addition is displayed in Figure 9. The shiploader contributed to an increase of about 15 MTPA, the berth increased thecapacity by about 9 MTPA and the improvement in loading rate from 6600 tph to 7200 tph resulted in an increase in port capacity by about 1.5 MTPA. These figures are considered to be good ball-park figure for the contribution made by each facility but are most effective when the particular facility is the limiting factor in capacity expansion.

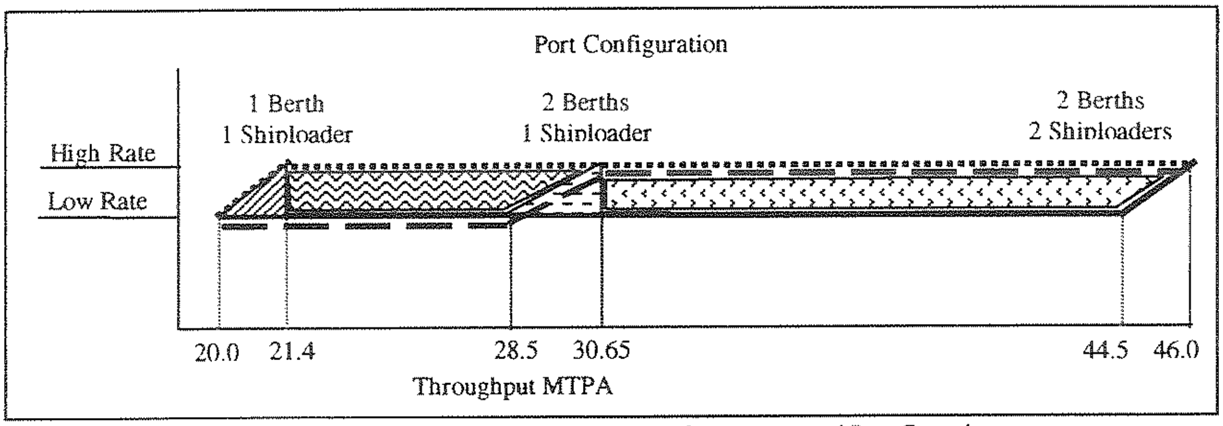

Figure 9: Relationship Between Infrastructure and Port Capacity

While it was operating with a single berth, single shiploader and with a outloading string capacity of 6600 tph, the port capacity was about 20 MTPA. At this stage, the port management could add a second berth and make more effective use of the shiploading capacity. It could also enhance the port capacity by increasing the outloading string capacity to 7200 tph, either independently or in conjunction with the addition of another berth. After adding the second berth, significant jump in port capacity could come from acquisition of another shiploader as one shiploader is not able to cope with the two-berth facility. The shiploader had become the limiting resource.

7. REFERENCES

Wadhwa, L. C., and D. L. Morel, Decision-Making in Port Operations Using Simulation, MODSIM 95, Modelling and Simulation Society of Australia, vol. 3, 262-267, 1995

Wadhwa, L. C., Planning Operations of Bulk Loading Terminals by Simulation, *ASCE Journal of Waterways, Ports, Coastal and Ocean Engineering* 118(3), 300-15, 1992

Wadhwa, L.C., Planning for Expansion of a Bulk Commodity Terminal, in *PORTS 2000, Papers of the International Conference, Hong Kong Institution of Engineers*, 29-33, 1992