Capacity and performance of bulk handling ports

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Abstract:

The application of a port simulation model for establishing relationships between port performance and throughput at a high volume bulk loading terminal is demonstrated in this research. The concept of port capacity in terms of important queueing characteristics is reiterated. The port is considered to approach its operational capacity when any of its performance indicators violate the desired service levels. It is interesting to observe that the model simulations showed roughly the same port capacity on the basis of queueing delays, turn-a-round time, queue length and demurrage charges. The model has also been used to evaluate several alternatives aimed at improving port capacity.

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Introduction

A number of specialised ports in Australia have been established on the eastern and western coasts to handle a single bulk export commodity such as coal, grain, ores, sugar etc Due to the heavy reliance of Australia's economy on the export of agricultural and mining output, these ports must be competetive and able to handle high throughput with maximum efficiency and minimum overall costs. This requires the optimal utilsation of resources with a view to achieving the maximum possible capacity from ports' infrastructure.

The objective of the research presented here is to define port capacity as a function of port performance and to establish relationship between throughput and port operational indicators. Although the discussion is general, it is directed more towards ports with high tidal variations. Most ports are assumed to have relatively shallow channel and thus depend on tide for the summer draft.

This research uses a specially developed port simulation model to develop the concept of port capacity and its relationship with operational characteristics. The model simulates the operations of an example port using comprehensive actual data. Policies aimed at increasing port capacity have also been evaluated by using the model although detailed results of these simulations are not included in this paper. Rather, the emphasis has been on the interdependence of port capacity and performance.

Port operations

Typical ship movements and events

A ship on arrival at a port joins a queue. The first-come first-served discipline is normally employed. Therefore, if a ship is at the head of a queue, it will be a candidate for granting permission to berth. The permission is usually based on a number of checks which include

- availability of a suitable berth
- availability of material to be loaded
- open port (not closed due to strike, weather, maintenance, etc.)
- availability of tugs, pilot, etc.

When granted permission to berth, a ship may still have to wait because of insufficient tide. Once all conditions are fulfilled, the ship makes its way to the terminal usually with a pilot on board. There is finite and constant time involved in this endeavour

On arrival at a berth, the ship will anchor or secure and wait permission to load and for the commencement of loading. This may take about two hours.

The loading is continued until completed except when interupted by weather, breakdowns, hatch changes, deballasting delays or by tidal restrictions. The loading time is a function of the loading equipment capacity, although this rate may be reduced due to anumber of mechanical, electrical or operational problems.

After the completion of loading, a ship may have to wait before it can sail out. The tidal conditions are the most significant factor for this delay especially for larger ships. Other factors may include documentation including weighing, and waiting for tugs and pilot.

Definitions

The main chronological events of ship movements in a port are:

1. Ship arrival
2. Permission to berth
3. Pilot on board
4. First line
5. Commencement of loading
6. Completion of loading
7. Completion of documentation
8. Ship sails
9. Pilot disembarks

The following definitions apply for terms used in this paper and in the model. Some are conveniently described in the context of the above events.

Port empty is the period when no ship is in the berth and no ships are waiting in the anchorage queue.

Port closed is the period of time the port is closed (because of weather, maintenanance, strikes, etc.)

Interarrival time is the time between arrival of ships.

Turnaround time (or Total port time) is the time from ship arrival to pilot disembarks after ship sails (from event 1 to event 9).

Waiting for stock is the time a ship waits from when it would have gained permission to berth if stock were available and permission to berth

Permission to berth is given to a ship if the port is open, the berth is not committed and the stock is available for that ship. If more than one ship is a candidate for permission to berth priority is given in order of arrival.

Queueing time is the time from ship arrival to permission to berth (from event1 to event 2).

Berth commitment is the time from permission to berth to pilot disembarks (from event 2 to event 9).

Berth occupancy is the time from first line to ship sails (from event 4 to event 8).

Tide delay before berthing is the time from permission to berth to pilot on board (from event 2 to event 3).

Tide delay before sailing is the time from completion of documentation to ship sails (from event 7 to event 8).

Loading time is cargo loaded divided by the load rate. It excludes all tide and deballasting delays.

Debalasting delay occurs only if the deballasting time is greater than the loading time. Then it is the deballasting time minus the loading time.

Total cargo lost due to tidal restrictions is the amount of cargo which not loaded because the available draft at high tide would not allow it

Overall loading rate is the total cargo loaded divided by the total loading time for all ships loaded.

Average loading time is the total loading time divided by the number of ships loaded.

Allowed laytime is cargo loaded divided by agreed load rate. The agreed load rate may depend on the commodity and the ship's dead weight tonnage.

Actual laytime is the time from commencement of loading to completion of loading (from event 5 to event 6) if queueing time is less than 12 hours. If queueing time is more than 12 hours, actual laytime is the time from 12 hours after ship arrival to completion of loading (from event 1 plus 12 hours to event 6).

Despatch hours equal allowed laytime minus actual laytime.

Demurrage hours equal actual laytime minus allowed laytime.

Port Capacity

Port capacity is commonly expressed as the amount of cargo or the throughput that can be handled by a port. As the number of ships and the amount of cargo passing through the port increases, a point is reached at which the capacity of some part of the system is fully utilised. This may be evidenced by port congestion and an increasing queue of ships at some places depending on which part of the system is providing the bottleneck.

Key factors for indicating port congestion and system capacity are the classical queueing system performance measures. In case of port systems, these include

(i) length of queues (number waiting in the queue and in the system)

(ii) berth occupancy (berth utilisation factor)

(iii) port empty (proportion of time system is idle)

(iv) average turn-around time (time spent in the system which is equal to waiting time plus service time plus all other delays)

(v) average queueing time (waiting time before being accepted for service)

Another measure of port performance in case of bulk loading terminals is the number of despatch and demurrage hours. This is defined in a later section.

The capacity of a port system can be expressed as a function of the ship's waiting time The capacity may also be defined as the annual throughput which does not cause port conditions to violate the following:

(i) berth occupancy of say a maximum of x percent

(ii) waiting time in the queue not to exceed y hours

(iii) number of ships waiting for service must be less than z

The selection of values for x, y, z, etc. are based on the level of service which the port considers to be desirable and which in its view will give a favourable impression to the shippers about the existing port conditions. Of course, higher throughput may be possible but would create unsatisfactory conditions at the port. Additional throughput represents additional revenues for the port which has to be balanced against additional waiting time for ships, demurrage charges and poor image of the port.

Determinants of port capacity

Port capacity is primarily determined by the port configuration, and the number and capacity of the plant and equipment (berths, storage and material handling including loading/unloading and transportation). However, there are a number of other factors which can influence the port throughput.

Every port has specific operating conditions and rules which can also significantly affect its capacity. Wind, wave, swells, fog, bad visibility, storms or night time restrictions for some classes of ships can limit the berth operational availability. Approach channel can also have significant effect on port operations. Seasonal variations in operations due to weather conditions or due to supply and demand can also limit port capacity. Tidal harbours introduce strict restrictions on deep draft vessels. Actual physical limitations in turningcircles, or in the area around the berth can introduce delays Human factors related to industrial labour problems or remote port location should also be considered. If the port is connected with a railroad link, the rail line capacity could be the limiting capacity factor

Some alternatives of capacity expansion are essentially hardware or capital investment type while others may be of management and operational type, and hence not capital intensive. The former includes new berths, material handling equipment, stockyard expansion, channel dredging etc. while avoiding stockouts and optimal maintenance policies are examples of the latter type.

Port simulation models

A port simulation model is a facility used by port management for determining the effects of changes in throughput, and various operational, technological and investment options and, thus, to assist in decision-making process.

A good port simulation model is capable of simulating the performance of ports under

- varying cargo volumes,
- new ship types and sizes,
- different cargo handling facilities and procedures,
- strikes and other disruptions, etc.

It may also permit the evaluation of operating and investment proposals such as

- changes in priority systems,
- additions or alterations to berths,
- channel dredging,
- new improved cargo handling facilities, etc.

Some existing simulation packages

A number of port simulation models have been developed over a period of time Most of the models have been tailor made for specific ports. Few attempts have, however, been made to develop generalised models and used for a number of different ports The World Bank developed PORTSIM to evaluate all proposals for funding of port projects in developing countries. TOMS (Terminal Operations Management System) was developed by Datap Systems and Swan Wooster to simulate harbour facilities around the world (Engelhart and Radomdske, 1982). Soros Associates have developed PORTLOG for simulating the operations of a port complex and YARDLOG to simulate the operations of the material handling systems interconnected with the port (Zador, 1984). These models have been used on a very large number of bulk handling ports. A generalised model, named PORT, has been developed at James Cook University and used to simulate two ports on the West Australian coast (Wadhwa, et al, 1981). The Richards Bay Coal Terminal personnel developed CTS (Coal Terminal Simulation) as an improvement to TOMS which provided versatility to model the coal terminal and reduction in execution time. Techni Multidiscipline Services (Pty) Ltd developed the IMS simulator for port design and materials handling plants (Ramos and Goodwin, 1985, 1989). Although earlier models were written for mainframe computers, microcomputers are now being increasingly used for many simulation applications. The cost of carrying out a simulation has considerably decreased in the past few years.

Simulation of port performance and capacity

The port simulation model developed for this study was used to establish a relationship between throughput and various performance measures.

Throughput

The interarrival time of ships arriving at the terminal was multiplied by a factor to represent change in throughput. A factor greater than 1 reduces the number of ships and the cargo loaded while a factor smaller than one represents increased traffic and throughput. This method maintains the ship size distribution and commodity mix. The objective of this simulation was to determine the effect of changes in throughput on port performance measures. Increase in throughput is not achieved without penalty. Port performance indicators clearly show an increase in maximum queue length, higher turnaround and queueing times, and a significant increase in demurrage charges. This is shown in Table 1.

Berth commitment and throughput

A linear relationship exists between berth commitment and throughput. This is given by

$$\text{Throughput (million tonnes)} = 0.11265 + 0.24212 * \text{berth commitment (\% of total time)}$$
$$R^2 = 0.999$$

Table 1: Effect of throughput on port performance

Inter-Arrival Factor	Through-put Mt	Av. Turn-Around Time, hrs.	Av. Queue Time hrs.	Port Empty hrs.	Demurrage Net hrs.	Max Queue length	Berth Commit %	Berth Avail hrs
1.5	9.98	69.3	46.1	2432.7	2338.0	6	41.0	4766.0
1.2	12.95	74.4	51.0	1613.8	3809.4	10	53.4	3680.0
1.1	14.28	78.2	54.7	1315.1	4548.4	10	58.9	3194.0
1.0	15.68	84.7	61.4	1037.7	6152.6	10	62.7	2848.0
0.9	17.30	101.0	77.4	762.4	10619.7	14	71.3	2113.0
0.8	19.28	122.7	99.3	442.2	17782.3	17	79.1	1424.0
0.7	22.13	237.4	213.8	83.7	57156.2	30	91.1	377.0
0.6	23.61	1894.0	1870.8	0.8	661429.3	164	97.2	0.0

The range of berth commitment used in this analysis varied between 40 and 100%. The current berth commitment at the example terminal is around 63 % with an annual throughput of some 15.67 Mt. The model simulations show that one percent increase in berth commitment increases the annual throughput by 0.24 Mt. A maximum throughput of 24.32 Mt. is indicated.

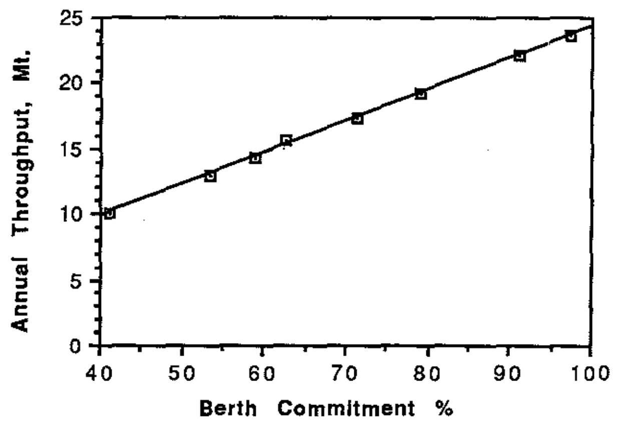

Fig. 1: Berth commitment and throughput

Berth availability vs throughput

As is to be expected, a linear relationship is exhibited between throughput and berth availability The relationship for the example port is

$$\text{Berth availability (hours)} = 8286.9 - 354.23 * \text{Throughput (million tonnes)}$$
$$R^2 = 0.998$$

Annual values of the dependent and independent variables are used. The berth availability reduces by 354 hours for each Mt. of throughput at the example port.

Port empty vs throughput

The relationship between throughput and port empty is similar to the above relationship between throughput and berth availability.

$$\text{Port empty (hours)} = 3902.7 - 174.05 * \text{Throughput (million tonnes)}$$
$$R^2 = 0.963$$

It is seen that each additional million tonnes of annual throughput at the example port reduces the time for which the port is empty by 174 hrs. The relationships shown in Figures 1 to 3 show the maximum capacity of the example port to be about 22 to 23 Mt

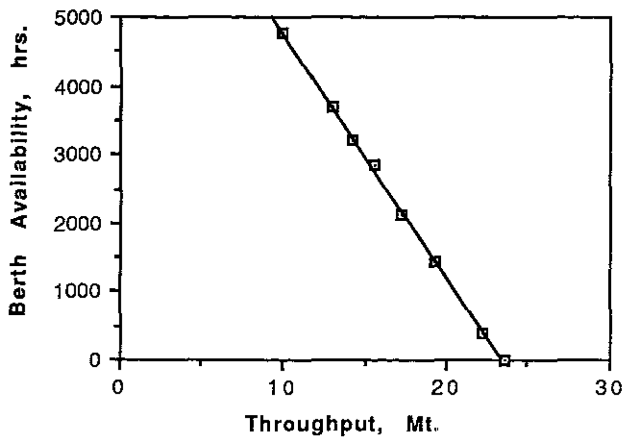

Fig. 2: Berth availability as a function of throughput

Throughput and queueing time

Consistent with the experiences of queueing situations, the average waiting time of ships before being given permission to berth increases sharply as the throughput reaches a certain level. The system experiences serious congestion as the capacity of some part of the system is fully utilised.

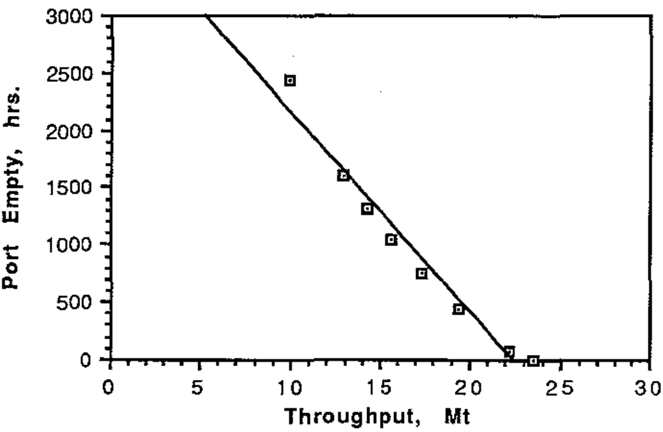

Fig. 3: Port empty as a function of throughput

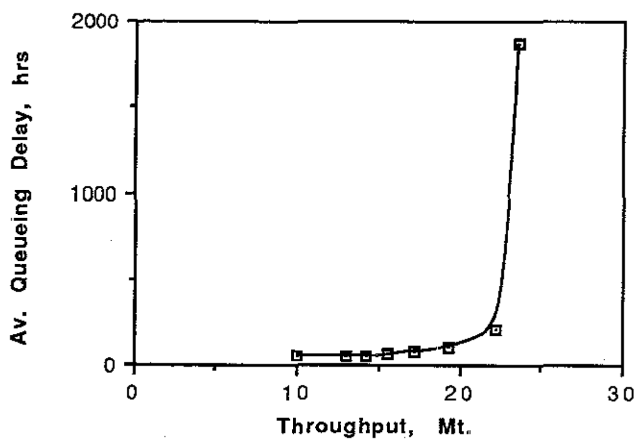

Fig.4: Effect of throughput on waiting time

Figure 4 clearly shows that the example port is not able to handle more than 20 Mt of cargo annually without causing extreme delays. The port may exhibit undesirable operating conditions even at 18 Mt

Throughput and turnaround time

Figure 5 shows the typical relationship between throughput and turnaround time. The turnaround time (or the total port time) at the example port increases sharply as the throughput reaches 20 million tonnes A system failure is indicated at higher throughputs.

Throughput and queue length

As the amount of cargo passing through the port increases, the maximum queue length increases Consistent with the effect on turnaround time and waiting time, a throughput in excess of 20 million tonnes results in extremely long queues at the example port

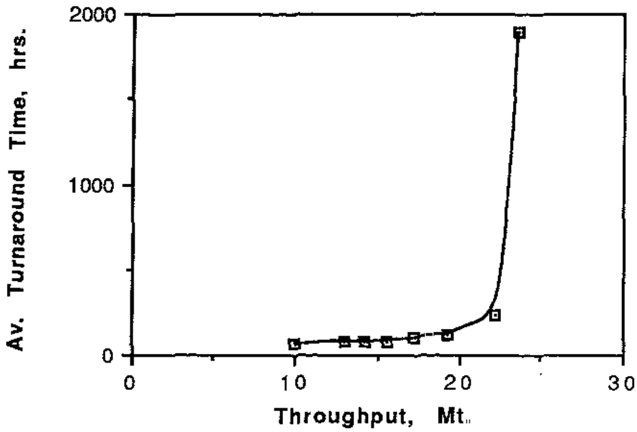

Fig. 5: Effect of throughput on turnaround time

Throughput and demurrage

Figure 7 shows that as the amount of cargo passing through the port increases, the demurrage charges associated with delays experienced by ships increases. Consistent with the effect on turnaround time, waiting time and queue length, a throughput in excess of 20 million tonnes through the example port results in massive demurrage. (See above for definition of demurrage.)

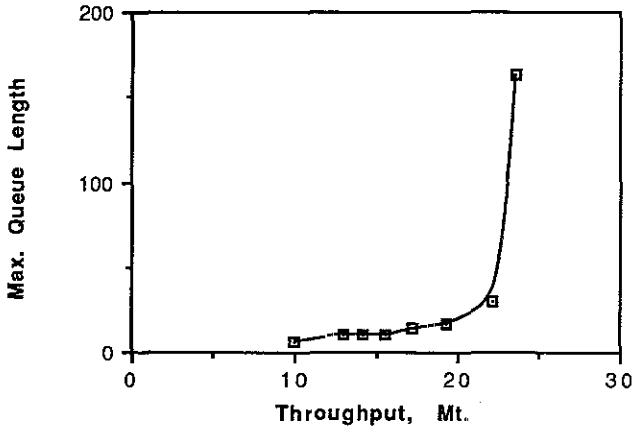

Fig. 6: Effect of throughput on queue length

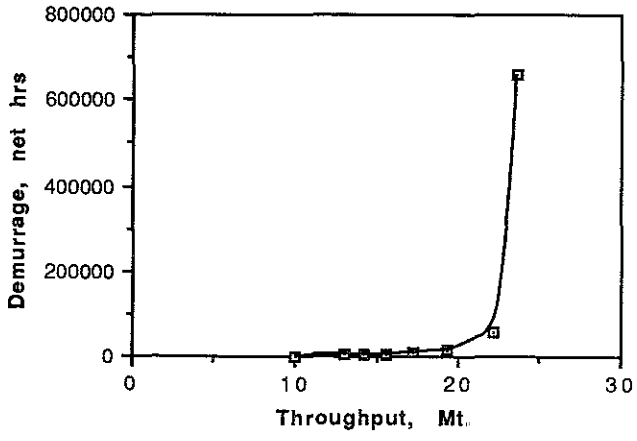

Fig. 7: Effect of throughput on demurrage

Simulation of port capacity expansion

Effect of increase in port capacity

A bulk loading terminal may have to handle a certain number of ships and a certain amount of cargo based on the markets served Therefore, the changes in port capacity may not always be realistically represented by the amount of cargo handled. The port capacity may, however, be linked to port performance indicators as shown in Table 2.

Port expansion alternatives

For the same amount of cargo handled, higher port capacity will result in reduced congestion and delays, fewer ships experiencing delays, and shorter turnaround time The effect of some selected factors on port performance and capacity as a result of changes in operational or investment policies are summarised below:

Table 2: Effect of Increase in Capacity on Port Performance

Performance Indicator	Effect of Increased Port Capacity
CARGO	
Total throughput	Increased
Cargo lost	Decreased
SHIPS	
Queue length	Shortened
Number of ships incurring various delays	Reduced
DELAYS	
Turn-around time	Decreased
Queueing time	Decreased
Other delays	Reduced
UNUSED CAPACITY	
Period for which port is empty	Increased

In this section, the percent improvement relates to the present operating conditions.

Increasing available draft

The increase in port capacity is clearly demonstrated by significant reduction in various delays experienced by the ships. The tidal delays during loading are reduced by as much as 90 percent and delays before sailing by 50 percent with a 2 m. increase in available draft The number of ships experiencing tidal delays is correspondingly reduced.

Eliminating stockouts

The stockouts have not been infrequent in 1988. The frequency and duration of stock delays is read from the ship data file along with other ship characteristics. The effect of reducing stockouts is to reduce the queueing delay by about 50 per cent, turn-around time by 30 per cent, queue length by 10 per cent, and increasing the period for which the port is empty by over 70 per cent. Positive effects on many other performance indicators are anticipated.

Doubling the loading rate

The turnaround time and queueing delays are reduced by 20 percent; the period for which the port is empty is increased by 28 percent and the net despatch minus demurrage is increased by about one and a half times. However, there is a significant increase in the number of ships waiting for the required draft. Consequently, the tidal delays before sailing are increased by 47 percent. Obviously, the loading of cargo is completed sooner but the required draft is not available until the next or successive high tides.

Discussion and Conclusions

This paper has demonstrated the application of an appropriate port simulation model for establishing relationships between port performance and throughput at a bulk loading terminal. The concept of port capacity in terms of important queueing characteristics is reiterated. The increase in throughput results in higher berth commitment and reduced period for which the port is empty. It is also accompanied by longer queueing and turnaround times for ships, higher demurrage charges and longer queue length The port is considered to approach its operational capacity when some of its performance indicators vioate the desired service levels. It is interesting to observe that the model simulations showed roughly the same port capacity on the basis of queueing delays, turnaround time, queue length and demurrage charges. The simulation model has also been used to evaluate a number of alternatives aimed at improving port performance and capacity. The study presented in this paper deals with high volume bulk loading terminals but the approach can be generally applied

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