# Development and Economic Evaluation of Strategies to Reduce Turnaround Time at the Calcutta Haldia Port Complex: A Simulation Modeling Approach

By

MADHUBANI GHOSH

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Centre for Strategic Economic Studies
Victoria University of Technology

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# ABSTRACT

The broad objective of the thesis is to estimate the demand for port services at Calcutta which can be visualised as a queuing system. The fall in the operational efficiency, aggravated by the riverine nature of the port of Calcutta is widely held responsible for the decline in the port's performance and the sagging demand for its services. The survival of the Calcutta-Haldia port complex is particularly critical as it serves as a lifeline to a vast hinterland with a rich industrial and resource base, comprising of the eastern part of the Indian subcontinent and also including the neighbouring landlocked countries of Nepal and Bhutan.

This study is directed specifically at: (a) estimating and identifying the principal determinants of turnaround time of ships calling at the port with the help of a simulation model; (b) estimating improvements in turnaround time which may be expected by varying the values of the principal determinants; (c) tackling the aspect of demand estimation by making use of the simulation model to estimate the queue technology; and (d) discussing the optimality of prices given the resources.

This is achieved by developing a simulation model, specifically tailored for the ports of Calcutta and Haldia, which incorporates, to a fine degree of detail, the navigational constraints faced by the calling vessels. It is the first model of its kind which deals with the riverine intricacies of an Indian port and incorporates the river draught and tidal considerations which are major hindrances to the port's users. At the chosen level of detail, the model has the capability of predicting the performance of the port under a range of varying physical and operational conditions and of identifying those factors which would improve the turnaround time as well as the degree of improvement. Thereafter, the tool of the simulation modeling is combined with classical econometric methods of solving simultaneous equation systems in order to estimate the demand for port services and assess the optimality of prices charged. The thesis demonstrates that prices could be a crucial instrument in regulating queue performance at the port complex.

# CHAPTER 1

# INTRODUCTION



## 1.1 The Calcutta-Haldia Port Complex: Issues at Stake

A port is a country's window to the world. Its primary objective is to provide efficient interchange facilities between modes of sea transport and land transport. In order to fulfil this objective, there must be proper planning and coordination among the various agencies operative in a port system. The origins of this study lay in the widespread dissatisfaction with the performance and operational efficiency of certain Indian ports and their adverse impact on the demand for port services (Maser 1985).

India has an impressive coastline spanning about 6000 km dotted with 12 major ports and 139 intermediate and minor ports. The Indian ports sector handles about 179 million tonnes of cargo (1993-94) of which about 95% is handled by the 12 major ports. They are, Bombay, Calcutta-Haldia, Cochin, Jawaharlal Nehru Port Trust (JNPT), Kandla, Madras, Mormugao, New Mangalore, Paradip, Tuticorin and Vishakhapatnam (Vizag). Dry and liquid bulk cargo constitute 80% of traffic by volume while the rest 20% is contributed by general cargo which includes containerised cargo. Containerised cargo accounts for 35% of total general cargo traffic as opposed to about 60% or more in most countries. Containerisation is an expensive process especially in the case of developing countries like India where the domestic transport system is not adequately equipped to handle containers. The World Bank Strategy Report on the Indian Port Sector (1995) observes that the standards of port facilities at the major ports vary widely. The Jawaharlal Nehru Port Trust (JNPT) in Nhava Sheva and Madras have modern container and bulk cargo handling facilities and equipment. However ports like Calcutta and Bombay have some outdated facilities which affect port productivity. Although the availability of equipment has improved in recent years to 75% of actual demand, it is still much below international standards.

All the ports in India are Government owned. The major ports are under the jurisdiction of the Central Government and the administering ministry is the Ministry of Surface Transport. The properties, funds and assets of the major ports are owned by the Central Government and are vested in the respective Port Trusts for the purpose of administration. The Indian ports are primarily service ports and each conduct port operations like pilotage, towage and other marine services, cargo handling and shore storage with their own staff and equipment. Private sector firms are generally involved in stevedoring on board ships and pick up of cargo for delivery.

The World Bank Report observes that, in many ports, the working time of different organisations as well as different departments within the Port Trust are not synchronised and valuable operation time is lost. Although in the past five years, port productivity in some major ports in terms of turnaround time, average output per ship berth-day has improved by some 30%, productivity still lags behind some of the better known Asian ports. In 1994, Indian ports handled about 11 to 12 containers per hour on an average as opposed to 30 handled by Bangkok and Colombo and over 40 by Singapore.

The inadequacies of the Indian port sector have resulted in enhanced total cost of delivering a containerised or breakbulk consignment which includes stevedoring, shore handling, storage, customs clearance, etc. as well as sea transport costs. A

World Bank comparison of four major Indian ports namely Bombay, Calcutta, JNPT and Madras with that of Bangkok, Colombo and Singapore show that these costs are 45 to 50% higher for containerised cargo in the Indian ports. Specifically, customs agents fees and transport and handling charges are higher in India representing up to 38% of the through cost of containers. Efforts need to be made to reduce these costs which amount to about US$70 million per year. The World Bank Report points out that, sea transport costs in ports, i.e. the costs incurred by a vessel's turnaround time are higher in India than elsewhere. Vessels have to spend more time in these ports which enhances costs to a great extent. Even a moderate reduction of ship time at berth, in line with international output standards would allow potential savings to ships calling at Indian ports of US$100 million per year, based on 1990-91 traffic volumes according to World Bank estimates.

These problems are further magnified in the case of the riverine Calcutta-Haldia port complex. The port of Calcutta, situated on the left bank of the river Hooghly about 129 km upstream from the river's estuary in the Bay of Bengal, is the eastern-most major port of India with a long and chequered past. Historically, it has played a crucial role in the trade and commerce of the region. Although the Calcutta Port Trust officially came into existence on 17 October 1870, the port had been operational long before that date. The two most salient features associated with the history of the port are its glorious past and subsequent decline. Calcutta was one of the leading ports of India until about the mid 1960s. It was during the early 1960s that large scale machinery imports were the order of the day in order to keep pace with the programme of industrialisation sweeping the country. The steel plants of Eastern India and the Railways required massive imports of plant and equipment, resulting in the boost of the import traffic during this period. The situation however, changed for the worse in the following years. During the eighties, the single redeeming feature of the import traffic through Calcutta was large scale imports of petroleum and other lubricants (POL). Navigational constraints hindering the operations of Calcutta port led to the commissioning of the subsidiary port of Haldia in 1977 constructed 104 km downstream from Calcutta on the right bank of the Hooghly. Both Calcutta dock system and Haldia dock complex, often referred to as the Calcutta-Haldia port complex, are under the administrative supervision of the Calcutta Port Trust. However, in spite of the construction of a new deep water subsidiary port, the Calcutta-Haldia port complex could not live upto expectations.

A number of reasons have been held responsible for the decline of inward and outward traffic at the port. A major factor for decline that has been identified, is the poor operational efficiency at the port, manifested in a high turnaround time of ships. The turnaround time is the total time that a ship spends in port, from arrival to the reporting station to departure from the reporting station. The UNCTAD Manual on Port Management (1969) observes that:

> From the point of view of shipowners and hence the port authorities in trying to judge, how good a service is given to ships, the total turnaround time of ships in port is the primary indicator — as well as its components, waiting time and ship's time at berth.

Table 1.1 compares the average turnaround time of ships calling at the eastern Indian ports of Madras, Vishakhapatnam, Calcutta and Haldia at certain time points during the past two decades. It is quite clear from the table that, compared to the seventies, there was a substantial increase in the turnaround time of ships visiting Calcutta. This was not matched by any enhancement in traffic as in the case of Madras or Vishakhapatnam. Although the turnaround time at Haldia was not as high, it however, did not compare as well with the other ports in terms of traffic tonnage. In other words, the ports of Madras and Vishakhapatnam gave almost as quick turnaround to ships as Haldia, but handled much larger volumes of traffic. There was a growing need to understand the causes behind the longer turnround time of ships visiting Calcutta and Haldia and identifying the problem areas. This was particularly crucial from the shipowner's or charterer's viewpoint as profits earned during a voyage could be quickly devoured by delays in the port. The issue of operational efficiency linked with the cost competitiveness of the port complex thus required urgent attention which had an immediate bearing on the demand for the port's services.

**Table 1.1 Selected Port Performance Indicators**
(traffic in mn tonnes, average turnaround time in days)

| **Madras** | | | | |
|---|---|---|---|---|
| | **1970-71** | **1985-86** | **1987-88** | **1990-91** |
| Av. Turnaround | 6.39 | 8.50 | 6.80 | 7.2 |
| Traffic | 6.92 | 18.15 | 22.82 | 24.52 |
| **Visakhapatnam** | | | | |
| | **1970-71** | **1985-86** | **1987-88** | **1990-91** |
| Av. Turnaround | 5.85 | 8.90 | 5.6 | 7.1 |
| Traffic | 8.73 | 15.91 | 15.37 | 19.42 |
| **Calcutta** | | | | |
| | **1970-71** | **1985-86** | **1987-88** | **1990-91** |
| Av. Turnaround | 7.40 | 17.2 | 11.3 | 11.9 |
| Traffic | 5.79 | 4.16 | 4.39 | 4.13 |
| **Haldia** | | | | |
| | **1970-71** | **1985-86** | **1987-88** | **1990-91** |
| Av. Turnaround | 7.50 | 7.90 | 5.60 | 6.5 |
| Traffic | 0.28 | 7.97 | 8.68 | 11.11 |

Source: Administrative Reports of Relevant Ports (various issues)

## 1.2 Identification of the Broad Area of Research

Calcutta, which was once the premier port of the nation had lost its supremacy to other major Indian ports like Bombay, Madras and Vizag. There was a marked decline in the volume of traffic handled through the port since the mid sixties which had adversely affected its revenue generation. Delays in port operations resulted in a high turnaround time of ships which hampered its competitiveness. This became a crucial issue in the wake of calls for privatisation and microeconomic reforms where the financial self sufficiency and revenue generating capacity of state run enterprises came under close scrutiny. Since, slower turnaround of ships had been a major cause for concern, the first step was to precisely estimate the turnaround time of ships visiting the port complex, given its geographical and facility constraints and identify the problem areas. This was done with the aid of a simulation model that was developed using a special purpose simulation language called SLAM II. The model was suitably verified and validated against actual port data. Various experiments run on the model clearly indicated the main areas of concern with regard to the delay elements. Armed with the simulation model, the thesis then deals with ways to improve the performance and profitability of the port complex through estimation of the demand for port services at Calcutta. The thesis develops a methodology which combines the output obtained from the simulation model with traditional econometrics relating to simultaneous equation systems to estimate the demand for port services and the optimality of prices charged.

The thesis is thematically divided into three parts:

**Part 1:**

This is a historical account of the development of the port complex detailing the volume and composition of traffic. It is substantiated with the aid of actual traffic data for the last sixty years which records the performance of the port over time vis-a-vis that of other major Indian ports. The traffic analysis revealed that large chunks of traffic were being diverted to other ports. Probable causes of this traffic shift are analysed.

**Part 2:**

In part two, a computer simulation model has been developed with the help of a special purpose simulation language called SLAM II which estimates the level of operational efficiency at the port complex. Computer simulation is widely used to mimic real life situations and has a wide range of applications in the physical as well as social sciences. A port is an operational system in which simulation modeling has been widely used, its range and scope varying with the objective of study. In this thesis, a simulation model has been developed as a tool for the estimation of turnaround time of ships visiting the Calcutta-Haldia port complex given the port's facilities and the arrival pattern of ships. The model replicates the movement of ships from arrival to the reporting station right up to departure and estimates the turnaround time of vessels given the resource and geographical configuration of the port. In order to develop this model, actual port data for the year 1988-89 was considered. Ship arrivals were randomly generated on the basis of the actual arrival distribution pattern. The model was tailored to estimate the turnaround time of container vessels visiting Calcutta and tanker vessels visiting Haldia and the model results were successfully validated against actual observations. Later the container ship model for Calcutta was generalised to include all ship types.

**Part 3:**

The demand for port services represented by number of ships and traffic (cargo) per ship as a function of exogenous variables, is specified by a 4 equation system. This has been discussed in detail in chapter 7, section 7.3.

*Technology*

$$T_t = f_{1t} \ (n_t, c_t) \qquad (1)$$

$$T_t = d_t + c_t h_t \qquad (2)$$

*Demand*

$$n_t = f_2 (d_t, h_t, p_t) \quad (3)$$

$$c_t = f_3 (d_t, h_t, p_t) \quad (4)$$

where,

$T_t$ is the turnaround time in period $t$ in hours

$t$ refers to the relevant time period

$p_t$ is the real price paid to the port in Rupees thousands per hundred tonnes of cargo in 1981 prices

$n_t$ is the number of ships sent

$c_t$ is the traffic per ship in hundred tonnes

$d_t$ is the non cargo handling time in hours

$h_t$ is the time required per unit cargo handled in hours per hundred tonnes

It is postulated that equations (1), (2), (3) and (4) *simultaneously determine* *T, d, n,* and *c* (the endogenous variables) through *p, h,* and *t* (the exogenous variables).

The end purpose of this modeling exercise is to estimate the demand for the services of the riverine port of Calcutta. This is done by combining the output of the simulation model with the econometrics of simultaneous equation determination.

## 1.3 Review of the Literature

### *1.3.1 General Remarks*

The literature review is divided into two parts. The first part deals with various aspects of the Calcutta-Haldia port complex in particular and the other deals with the development of literature on simulation modeling specific to port studies as well as other related queuing models.

The first part of the review clearly indicates that there has been a growing concern about the future of the Calcutta-Haldia port complex, and that improvements in the operational efficiency of the complex are essential for its revival and growth. In order to cope with the existing constraints, a number of improvement measures have been suggested that would enhance port operations. The functional distinction between Calcutta and Haldia with respect to the type of ships that may be serviced best, given the riverine restrictions, has also been identified, as has been the importance of reducing the turnaround time of the ships using this port complex.

### *1.3.2 Literature Pertaining to the Calcutta-Haldia Port Complex*

The early period of the port of Calcutta dates back to the beginning of the 18th century. Since the formal inauguration of the Calcutta Port Trust in 1870, official administrative reports were published annually. Apart from these, there are numerous articles, letters, minutes of meetings and notes prepared by various departments of the Port Trust over the years, on a wide range of issues.

As the first systematic historical account of the growth and development of the port of Calcutta by Mukherjee (1968) shows, the initial years were a period of sailing ships lying at river moorings with loading and unloading done with the aid of country boats and port stay extending over months. Even in those early days of the port, navigability of the river Hooghly was a major concern for the port authorities. In 1853, even before the Calcutta Port Trust formally came into existence, there was a very strong representation by the leading Chamber of Commerce to the Government, stressing the necessity of establishing a port called Port Canning on the river estuary near the Bay of Bengal. However, after some initial construction work, the project was shelved and maintaining the navigability of the Hooghly to nurture the port of Calcutta was stressed.

Nevertheless, the concern for the development of an auxiliary port further downstream kept surfacing regularly. The expansion of coal trade in the early years of the present century led to a scheme for constructing a coal depot for the accommodation and shipment of coal at a place called Luff Point on the right bank of the Hooghly, further downstream from Calcutta. This project was later shelved due to vehement opposition from a large section of the mercantile community. In 1956, the Bengal National Chamber of Commerce recommended to the Central Government that a subsidiary port should be constructed at Geonkhali, further downstream in the river to offer better services to port users.

The idea for constructing a subsidiary port got a fresh impetus from the support of the World Bank Mission which, in 1957, examined the problems of Calcutta port, and recommended the development potential of a subsidiary port at Haldia, which would not only relieve the congestion at Calcutta and provide easier access to ships, but would also grow to become the nucleus of a new industrial complex. Mukherjee identifies several industries in the Haldia region, namely, an oil refinery, a fertiliser plant, a petrochemical complex, ship repairing and dry docking facilities and other port related industries which had the potential for growth.

The Project Report on the Proposed Subsidiary Port at Haldia, published in 1960, by the Commissioners for the Port of Calcutta gives an account of the need for the subsidiary port and how Haldia was chosen. The World Bank team of economists was led by Dr M. Hoffman and was supported by Prof. Larras, a French expert on harbour engineering, Mr F. Posthuma, Deputy Director of Rotterdam port and Prof. Danel, the Director General of the Grenoble Laboratory. The consulting engineers, Messrs Rendel, Palmer and Tritton independently investigated the situation and endorsed the selection of Haldia. It recognised that modernisation and extension of existing facilities at Calcutta could not remove the restrictions imposed on ship size and draught due to its upstream location. The port catered to a vast hinterland with the richest coal and iron ore mines, the entire tea and jute industry, and a heavy concentration of iron and steel and engineering industries. Due to the considerable importance of the hinterland and its effect on the economy of the nation, the inadequacies of Calcutta as the single port outlet of the region were stressed to be of particular significance. However, due to navigability restrictions and resultant inability to accommodate larger ships, over congestion in the port area with choked inland transportation arteries and an overall operational inefficiency, Calcutta was losing a good deal of its bulk traffic such as iron ore and coal to other major competing ports on the eastern seaboard. It was envisaged that the development of the subsidiary port of Haldia would reverse this trend. The main advantages of Haldia summarised in the Report dealt with the ability to handle larger, deeper draughted vessels and quicker turnaround of ships. The faster turnaround was expected to reduce the imbalance between sea and rail freights of coal and also reduce the freight charges of iron ore, making it more competitive in the world market. Deep laden ships with cargo for Calcutta could first off load at Haldia or, on the way out, could top up at Haldia thereby saving on ship costs. The pressures on Calcutta would be substantially lessened and the port complex would cater more successfully to the prevalent shipping needs.

Mistry (1965) discusses why Calcutta port is so different compared to other Indian sea ports like Madras or Bombay. The effects of sandbars on the river bed, the tidal occurrences, the narrowness of the river in the upper reaches etc. on the navigation of ships to and from the port are explained in detail. The riverine constraints detailed by Mistry have been incorporated in the simulation model that has been developed in this thesis to estimate the turnaround time of ships.

The situation improved to a certain extent after Haldia commenced operations. The restrictions imposed on ship size visiting the port of Calcutta warranted some kind of functional demarcation between Calcutta and Haldia. Calcutta came to handle small and medium sized general cargo and container vessels whereas Haldia concentrated on deeper draughted, large bulk carriers and tankers (Chakrabarty 1976). It also became useful to offload heavier ships at Haldia and send the Calcutta bound cargo by water barges, road or rail. However, in spite of high expectations, Haldia could not live up to its initial promise. Chakrabarty (1976) inquired into the functional aspect of optimum usage of port facilities at Calcutta and Haldia. He argued that the economic conditions prevalent in the hinterland had considerable impact on the volume of trade through the port complex. He extrapolated past traffic trends for the period 1947-48 to 1974-75 to forecast the traffic up to the year 2000. Reasons cited for the declining traffic trend were poor navigability of the Hoogly resulting in long waits and therefore high turnaround time of the calling vessels, upsets in the economy of the hinterland, decisions at the central level to equip certain other ports to handle bulk cargo resulting in traffic diversion. Chakrabarty predicted that Calcutta would primarily handle general cargo while Haldia would handle bulk cargo like ore, coal and POL (petroleum and other lubricants).

Haldia commenced its operations as an exporting port after 1974-75. Thereafter, exports through Haldia increased over the years reaching about 4.45 million tonnes in 1993-94. The primary export items were coal and petroleum products. The traffic in coal, which was once the mainstay of exports through Calcutta was, in later years, almost entirely diverted to Haldia. The export of POL has been steadily increasing over the years through Haldia. Large scale imports of POL through Haldia have been the single most redeeming feature of the port complex over the years. Crude petroleum which is mainly imported from the gulf countries is refined at Haldia by the Indian Oil Corporation, with a refining capacity of 2750 thousand tonnes per year. POL products are also imported amounting to about 5000 thousand tonnes per year. In spite of this, the port's performance fell below expectations. Haldia was primarily designed to operate as a bulk port handling coal, iron ore and petroleum. These were items which were supplied by or demanded by the natural hinterland of the port complex. However, due to conscious policy decisions of the Central Government, often dictated by buyers, a massive chunk of the cargo was transferred to sea ports on the east coast like Paradeep and Vizag which did not have any draught restrictions.

There were several supply and demand constraints which further inhibited the growth of the Haldia port to the desired extent (Sau, 1980). These constraints ranged from lack of infrastructural facilities, problems of the river, low operational efficiency at the port, labour unrest, over-dependence on traditional types of cargo whose demand was declining, political decisions to equip other competing ports with modern cargo handling equipment and so on. As the Calcutta Haldia port complex has been the chief artery of sea transport for the eastern region and the lifeline to a large hinterland, a strong case was made for concerted efforts to develop the complex in the best possible manner, within its existing limitations (Sau, 1980).

In 1989, the Japan International Cooperation Agency (JICA), prepared a comprehensive study to chalk out a Master Plan for Calcutta and Haldia Dock systems for the period up to 2005 and within that framework, prepare a short term development plan up to 1995. The study was jointly commissioned by the Governments of Japan and India. The report forecasts the volume of cargo and the amount of ship traffic through the port complex for the years 1995 (20 million tonnes), 2000 (27.2 million tonnes) and 2005 (36.9 million tonnes). With the growth of maritime trade and containerisation of cargo, the report envisages Calcutta and to a greater extent, Haldia, emerging as important feeder service ports for container vessels. The emerging trend of larger, more capital intensive ships had made it more economical for shipowners to choose routes with lesser port stays and quicker turnaround. Thus, cargo from a wide geographic region is often routed through a single major port which is the 'hub' or load centre. Smaller ships then link these hubs to regional and sub regional 'feeder' ports. The two main hubs serving the eastern seaboard of the Indian subcontinent are Singapore and Colombo. The Calcutta Haldia port complex was considered to be an important feeder port of the future.

Considering the trend towards progressively larger ships, arising from the need to maximise economies of scale, the role of Haldia seems to have grown in importance compared to the Calcutta dock system. The development of Haldia as a growth centre was also projected as a way to reduce the over congestion pressures on Calcutta. The JICA report stresses the need for modernisation and augmentation of container handling facilities, improvement of inland transport links, modernisation and restructuring of port operations system with computerised documentation system, improvements in draught restrictions through enhanced dredging etc., argueing that implementing these changes would reduce the turnaround time of ships which would lead to huge savings in ship cost.

The Central Inland Water Transportation Corporation (CIWTC) published a feasibility study in 1990 on the development of a ship repair complex at Haldia. According to this report, due to a dearth of repairing facilities, a vast amount of foreign exchange is spent every year to repair Indian ships abroad. Based on earlier projections of repair costs of the Indian fleet, the report estimated that, in 1995-96, the repair bill would be as high as Rs.2536 million. In order to bridge the yawning gap between ship repair demand and existing facilities, the development of dry dock facilities at Haldia was proposed. It argued that the large industrial belt and infrastructural facilities available at Calcutta and its proximity to Haldia would help in building a supportive network for the dry dock and repair facilities and in catalysing the growth of subsidiary industries. The study thus pointed out another avenue along which the development of Haldia port might be worthwhile. However, even such alternative activities cannot support the port complex unless there is an improvement in the operational efficiency of the port itself.

The National Institute of Port Management (NIPM) undertook a project in 1992 on the Calcutta port which was based on the premise that the natural restrictions imposed by the river build a case for greater operational efficiency at the port complex in order to ensure faster turnaround of vessels. Given the existing situation, the report focused on possible improvements in the utilisation and management of cargo handling equipment and utilisation of cargo storage space.

In his book *Maritime India: Ports and Shipping* (1993), Dr. Animesh Ray discusses the origin and development of the port of Calcutta since the very inception of the Calcutta Port Trust to the present day. The problems encountered by the riverine nature of the port have been emphasised in this book. Dr. Ray stresses the need for proper river training programmes and enhanced dredging to prevent the rapid siltation in a bid to combat the problem of river draught in the Hooghly.

### *1.3.3 Literature Pertaining to Specific Port Simulation Models*

In this subsection, the major port simulation models as well as some other related queuing models are reviewed. A port is an operational system in which techniques of operations research are frequently applied for various decision-making purposes. Simple analytical models such as queuing models have been used in the past for ports. However, their usage is restricted to problems of limited scope. When, for some reason, analytical techniques fail to give a sufficiently accurate and comprehensive solution, the most powerful alternative tool is simulation. Simulation is the most popular and widely used technique in operations research and management science and its popularity is on the increase. As noted by Frankel (1974), the purpose, the degree of detail and the extent of simulation modeling vary widely. The technique can be used in port management information system models, general port operations management models, as well as port investment project appraisal models. Simulation models present the port's performance under realistic input conditions and allow experiments thereon, thus giving an edge over other modeling techniques. Although simulation modeling has been most effectively used in port operations analysis and planning since the early seventies, the very first attempt in simulation modeling in the context of an Indian port was done by Raman and Ramakumar (1988) with regard to the port of Madras. Some of the major port simulation models developed so far, is discussed below.

**a) The UNCTAD port operations model**

This is one of the first efforts in simulating port systems. It was developed by the United Nations Conference on Trade and Development (UNCTAD) in 1969 and it permitted evaluation of port operations and dealt with various facets of a port system including the effects of port expansion. This simulation package consists of six programs which were written in three different general purpose languages: SIMULA, FORTRAN IV, and ALGOL. A simulation package denotes a general computer programme from which, it is possible to make specific models by supplying input data and setting parameters according to one specific case.

The port is regarded as an operational unit made up of a number of sub-systems such as pilotage, berth allocation, equipment allocation, towage, etc. If a port is to operate efficiently and minimise the port-related costs of sea transport, it is necessary for all the sub-systems to be available at the required time and in the required quantity. There may exist or will exist, bottlenecks in one or more of these sub-systems. The main task facing the modeller is to determine which capacity constraint or bottleneck to eliminate to improve port performance. The UNCTAD simulation process begins with a data accumulation programme. This includes information about the properties of arrival time, type and amount of cargo, type of ship, etc. The data accumulation programme sorts this information and accumulates it to be used later by the forecasting programme and the traffic generator. The forecasting programme makes frequency lists for future situations in the port giving predictions about the number of each type and size of ships that will visit the port. The traffic generator programme uses the data contained in these frequency lists as input and by a process of random drawing, it establishes the traffic pattern to be simulated. The main input of the simulation programme is the traffic pattern. Finally, the simulation programme reproduces the operations of all port elements while varying ship traffic and cargo flow patterns and operational conditions. The UNCTAD model was developed for usage in the rationalisation of port operations under static conditions. It attempted to achieve the overall improvement of the port with the criteria of attainment of minimum costs or maximum capacity. The simulation package thus developed was successfully used for a detailed examination of the operational characteristics of the ports of Casablanca and Vancouver, which were used as case studies.

**b) PORTSIM**

This port simulation model which was developed by the World Bank in 1974 can represent the operations of a port system with minimum computational effort by the user. Its primary objective is to serve as a project evaluation tool. The user is assumed to be primarily interested in evaluating the benefits and cost configurations of a proposed change in the port system rather than in fine tuning the existing port facilities. As a result, the intricate details of existing port facilities which do not directly involve the major proposed future changes are kept outside the purview of the model. The port which is defined as a multiberth, multiqueue system is described by user specification of the following:

- number and description of each ship type;
- number and description of each berth;

- berth eligibility and preference of each ship type;
- ship berthing priorities; and
- unit cost of ships, berths and other port equipment.

The results of this port simulation model are grouped as under:

- time related summary of operations such as waiting time, turnaround time, etc.
- cost related summary of operations; and
- miscellaneous operational results such as probability of delay, maximum queue length, etc.

Details of ship operation, cargo handling, hinterland operations etc. are not within the direct purview of the model as it was not intended to serve as a management tool. The model provides useful insight into the working of a port system which is essential for the economic evaluation of a port project. It has been successfully used by the World Bank staff as an evaluation tool for new investment projects.

**c) Other Port Simulation Studies**

The University of California, Los Angeles, conducted a simulation study to analyse the utilisation of existing berth facilities of the ports of Los Angeles and Long Beach during the year 1969-70. The study used a special computer simulator called TRANSIM III and was applied to the above mentioned ports.

Nehrling (1970) developed a simulation model to simulate the loading-unloading operations of a container vessel using the special purpose simulation language GPSS. These operations were compartmentalised into several steps and were simulated in great detail. This model is a tool for a detailed assessment of loading-unloading operations of a particular ship type and not for general application to all aspects of port operation.

Parsons and Hill (1971) developed a model in PL/1 language to simulate the day to day operations of a tanker port. This was a simplified model in the sense that it only considered a unidirectional flow of commodity from the tanker to the oil tanks located at the port or its vicinity. As a result, only the unloading operations were considered.

Hansen (1972) used the technique of simulation to optimise the capacity of a sea port. The capacity of a port was measured by its capability to achieve the following:

- load and unload ships frequenting the harbour;
- transfer cargo in and out of the port area; and
- store cargo within the port area.

Storage of cargo outside the port area and inland transportation network were left outside the scope of his modeling exercise. He conducted a sensitivity analysis of the relevant parameters in order to determine the optimum port size with regard to dry bulk cargo. The economic criteria used was the total cost of berths, cranes and the ships' waiting time. The outputs obtained gave in statistical form all relevant information about the servicing and delay of ships and utilisation of port equipment within the terminal. The programme was written in FORTRAN IV with an IBM 360/75 computer. From the simulation exercise it was concluded that, both the ship size and the crane capacity distributions have little significance within certain wide ranges. Certain general indications were deduced regarding the optimum number of cranes to be installed. The optimum number of cranes, in general, for bulk cargo terminals, where all cargo is handled by low capacity quay cranes, should at most, be equal to the average number utilised when the quay is fully occupied. This is a study designed to optimise port operations based on a sensitivity analysis of the pertinent parameters to variations in the distribution of ship sizes and crane capacities.

Pierre (1973) constructed a port simulation model where the chosen optimisation criterion was to minimise the total unit cost per container for a given volume of traffic to be handled. The model used the GPSS simulation language.

UNCTAD (1973) developed two more simulations models programmed in GASP II, a FORTRAN based special purpose simulation language. The models were designed on the ports of Karachi and Valparaiso. Detailed features of cargo handling such as distribution of cargo among hatches were incorporated in the model. This was a more sophisticated port simulation model compared to an earlier model developed in 1969. It used a special purpose simulation language which made it more flexible, simpler to use and incorporated a greater degree of detail.

Frankel (1974) developed a model to determine the cost configuration of a multi-purpose port under varying physical and operational conditions. A berth preassignment policy was introduced in the model which permitted a certain priority discipline to be employed by the programmer in allocating berths to a waiting ship. This allocation was done as a part of prior planning before actual ship arrival. The service time of various types of ships was not generated from a predetermined probability distribution but was calculated by the actual amount of cargo to be handled. This model was quite important as it bore some of the real life features of port operations. The model elements included ship type and berth definition, navigation system definition and ship generation and gave a comprehensive idea about the state of efficiency of port operations.

Hwang (1978) developed a simulation model which was a modified extension of Frankel's model incorporating certain features of PORTSIM discussed above. The model was a specialised one dealing exclusively with container ports. It permitted differentiation among ships on the basis of size. Priority allocation rule, as envisaged in Frankel's model with regard to ship type was extended in this model to include ship size. It uses Erlang family of distributions to generate ship arrivals. As the Erlang family covers a wide range of distribution patterns, it permits the model to be utilised in a more general way. As in Frankel's model, the service time was not generated from a given probability distribution, but was determined by the number of containers carried by the ship, handling equipment made available and the handling rate of such equipment. The model provided various options to select desired output statistics which enabled it to be used in a cost effective way. Hwang's model was applied to the Norfolk International Container Terminal and useful insights were obtained regarding port operations and future planning perspective at Norfolk.

Mytton and Walker (1978) published a survey of various types of computer models that are used in the planning of container terminals. The two types of tools that are generally applied for such purposes were statistical, analytical models and simulation models. The choice of either tool would be determined by the nature of the problem and the required degree of detail and accuracy. It was observed that although, analytical tools are quite effective in certain situations, they suffer from some setbacks. Changes in service time distribution of container vessels due to a multitude of complexities existing in any port situation may be impossible to estimate without using simulation. Thus, it was concluded that the technique of simulation offer the port planner, realistic models of the complex processes which actually take place in a container terminal.

Otimong (1983) developed a simulation model using data pertaining to Dar-Es-Salam port for the period 1977-1981. Port shipping was identified as a queuing problem and the simulation approach was used to understand the problem. The model was coded in FORTRAN 77 and implemented in four stages and alternative assumptions were considered at each stage. The model considered only the port shipping aspect and ignores related areas of port operation. It did not take into account specialised or reserved berths for particular ship types but assumed a homogeneity of berths which could accommodate any arriving ship.

Balmer and Paul (1986) investigated the deficiencies in the current simulation environment and attempted to achieve an 'ideal' simulation environment and illustrated the progress that has been made towards its implementation. They began from the premise that although simulation has widely been accepted as an important tool for modeling complex problems, it would be much more popular if it was cheaper and easier to comprehend by the end users. The CASM project at the London School of Economics was set up with a view to researching ways of reducing the major disadvantages of using simulation. The paper conducts a survey of simulation methodology concentrating on those studies which form the main theme of the CASM programme. The main issues discussed include:

a) model structure;
b) interactive simulation program generators (ISPGs);
c) simulation environment; and
d) programming languages and computers.

According to the authors, the three main developments making an impact on simulation modeling are the increasing power of microcomputers, availability of cheap computer graphics, and the development of ISPGs. The authors also discuss how the simulation environment itself can be generalised into allied modeling areas of solution by queuing theory, system dynamics, control theory, econometrics and differential equations. The CASM research project thus attempts to build the ideal simulation environment with the above mentioned add-ons to greatly enhance the efficiency of simulation modeling.

Sheikh et al. (1987) constructed a microcomputer based simulation model to aid in the planning of future berth developments of a port based on CASM, discussed above. The port handles a variety of cargo using a mixture of specialised and general berths which can accommodate 20-25 ships at any one time, depending on ship length. Based on one years observation, the arrival and service time distributions of all ships were calculated. The berth allocations were made by port authorities on a day to day basis following some guidelines which were not exhaustive. Hence allocations were often made on an ad-hoc basis. The study estimated the number of berths required in the short and medium term and examined the impact of the proposed handling improvements. The berth requirement depended on:

a) expected traffic at a port;

b) handling rates for different commodities; and

c) acceptable level of service for user ships.

The objective was to assess the required berth days for 1990 traffic projections and for different groups of improvements in handling rates. Then on the basis of simulation results, the required ship waiting time was estimated, thus forecasting the requisite measures to be undertaken to accommodate the 1990 traffic. The required berth days were assessed for three cases:

a) using current handling rates;

b) including projects under implementation or committed and including; and

c) projects not yet committed.

These handling rates were then applied to the forecast traffic in order to calculate the required berth days, which expressed in terms of the percentage of occupancy predicted the number of requisite berths. A computer simulation model was prepared to encompass the various allocative decisions and allow experiments thereon. The model was written in UCSD Pascal on a SIRIUS 1 microcomputer using the ELSE set of Pascal routines. The model produces a variety of annual strategies on ships including berth utilisation and total ship waiting days per annum. The purpose of the model was to estimate ship waiting time for various levels service and demand at a port corresponding to different handling rates. The model was tested against historical data and the output matched the expectations of port management and consultants.

As noted above, Raman and Ramakumar (1988), developed a model designed for the ore and general cargo berths at the port of Madras. It analysed the sensitivity of waiting time of ships and berth occupancy with respect to the following:

- duration of detention at berth;
- time lost due to wave height constraints in the turning basin; and
- increase in the number of vessels calling at the port.

The port of Madras had two major constraints, namely:

- wave disturbance inside the port basin; and
- sand drift parallel to the region threatening to silt up the channel, thus blocking the port entrance.

The data for the model was collected from the Madras port authorities for the year 1980-81 to be used as inputs to the model. Random numbers were used to generate ship arrivals, time at berth, wave height conditions, etc. Comparison of actual and simulated output were carried out for validation purposes with satisfactory results. A sensitivity analysis was undertaken by systematically varying the values of the parameters or input variables, one at a time. The model was coded in FORTRAN IV and was an example of the event-oriented approach to simulation that successfully replicated a complex real life port situation.

Guimaraes and Kingsman (1989) described a case study of grain terminal operations at the Portuguese ports of Lisbon and Leixoes. This was considered to be critical when the evaluation of the objective function or any of the problem constraints become directly associated with the occurrence of 'rare events'. Rare events are those situations where very long simulation runs were needed in order to obtain accurate estimates of those functions for any one set of decision variables. The model shows how these difficulties can be overcome by a careful exploitation of the particular structure of the problem under study. The simulation programme was written in FORTRAN IV and implemented on a CDC 7600 computer. The model is so designed that it can be used to explore strategic changes in the overall inventory policy of a grain terminal in a port such as feasibility of larger port storage facilities or additional handling equipment for the grain cargo.

ESCAP/UNDP (1993) formulated a port capacity simulation model called POSIM. The model was designed to assess the adequacy of port infrastructure and operations, given the forecast trade and shipping levels. From the model output, the modeller can observe the utilisation of facilities within the port and assess their adequacy. The model has been developed for IBM compatible microcomputers.

Hayuth, Pollatschek and Roll (1994) developed a simulation model for port operations in C language. The model addresses a number of issues in port functions, ship arrival patterns, labor and productivity issues. The model was applied to the port of Ashdod in Israel.

### *1.3.4 Summary*

The above review indicates that the marine port is an area where the technique of simulation has been successfully employed ever since the early 1970s. A great variety of simulation models mentioned above, has been developed, to understand the various complexities of individual port systems and plan future strategies. These models vary from one another in purpose, focus of attention, degree of detail and so on. It is possible to simulate a port to a very fine level of detail by building a model for a specific port. It may not be possible to incorporate the same degree of detail on a general purpose port simulation model which addresses a limited number of issues. The technique of simulation modeling with respect to port situations has become more sophisticated over the years and has been accepted as a very useful tool in the hands of the port planner. As computer technology and software sophistication have improved, the simulation models have become more versatile and multidimensional.

However, this technique has not been used in the Indian context to understand and simulate the intricacies of a riverine port in India. The present study, incorporates in its simulation exercise, the various restrictions imposed by the river on the Calcutta-Haldia port complex and estimates the turnaround time and its components of specific types of calling ships.

Moreover, simulation models developed to estimate the performance of a queueing system, while suggesting policies regarding resource configurations, hardly ever take into account the effect of changes in those resource configurations on future arrival rates. Textbooks on simulation modeling such as Solomon (1983) typically contain collections of cases which do not model variability of arrival rate with performance and price. Neither do recent journal articles such as Peterson et al. (1995) who study airport congestion and Pope et al. (1995) who study road congestion in cities with marine container terminals. Peterson et al., for instance, use carefully constructed Markov and semi-Markov models of weather variations at the Dallas-Fort Worth airport to study the effect of "demand smoothing" and conclude that this is potentially useful as peak period waiting times are thereby considerably lessened while non-peak period waiting times are not too adversely affected. However, the authors perform demand smoothing by imposing a cap on peak period demands and shifting excess demand from such periods to the nearest one where "there is room", *while assuming that this new procedure will keep the original demand pattern unchanged.* Similarly, when Pope et al. consider the effect of opening a new route or adding a unit train in the Hampton Roads, Virginia area, they do not consider the change this will induce in the source flow of traffic. In the particular context of port operations other instances of assuming constancy of arrival rates are Tugcu (1993), Silberholz, Golden and Baker (1991), El Sheikh et al. (1987), Park and Noh (1987) and Hansen (1972). Decision support systems built to assist port operations such as van Hee et al. (1988) do not make use of the notion of demand feedback either.

On the theory front, a sizeable literature exists on queueing situations where customers base their decision to join the queue on statistical data possibly gathered from past experience - a situation referred to as *queues without balking* by Hassin(1995). This literature, which has a focus on determining whether a particular queueing environment is socially optimal or not, has some notable contributions in Edelson and Hildenbrand (1975), Hassin (1986) and Dewan and Mendelson (1990) to name a few. Recently Atkinson (1997) and Van Ackere and Ninios (1996) have studied the problem of a monopolist operating a single server facility with balking where the arrival rate is affected by the (steady state) proportion of customers who balk. Finally, there are several papers where customers choose arrival rates as Nash Equilibrium strategies in certain games as exemplified by Haviv (1991). In applied economic contexts, congestion related phenomena have been discussed in De Vany and Saving (1977, 1980). Despite this body of theoretical work, there has not been actual empirical studies which make use of the simultaneous equations framework.

Although the importance of operational efficiency has been acknowledged in rejuvenating the port complex, a tool, specifically designed for the port complex to estimate this efficiency under varying conditions, needed to be developed. The present thesis meets this need by developing such a tool which enables one to precisely identify bottlenecks in ship handling at the port complex and quantify the impact of alternative improvement strategies aimed at improving the operational efficiency. It also takes into account the feedback loop where changes in facility configurations affect future arrival rate of entities in a queueing situation and estimates the demand for port services.

## 1.4 Aims of the Thesis

The broad objective of the thesis is to estimate the demand for port services at Calcutta which can be visualised as a queuing system. As noted above, the fall in the operational efficiency, aggravated by the riverine nature of the port of Calcutta is widely held responsible for the fall in the port's performance and the sagging demand for its services. The survival of the Calcutta-Haldia port complex is particularly critical as it serves as a lifeline to a vast hinterland with a rich industrial and resource base, comprising of the eastern part of the Indian subcontinent and also including the neighbouring landlocked countries of Nepal and Bhutan. Apart from this, 21,282 skilled and unskilled persons are directly employed by the port complex and their well being is critically linked with that of the port. This study is directed specifically at: (a) estimating and identifying the principal determinants of turnaround time of ships calling at the port with the help of a simulation model; (b) estimating improvements in turnaround time which may be expected by varying the values of the principal determinants; (c) tackling the aspect of demand estimation by making use of the simulation model to estimate the queue technology; and (d) discussing the optimality of prices given the resources.

This is achieved by developing a simulation model, specifically tailored for the ports of Calcutta and Haldia, which incorporates, to a fine degree of detail, the navigational constraints faced by the calling vessels. It is the first model of its kind which deals with the riverine intricacies of an Indian port and incorporates the river draught and tidal considerations which are major hindrances to the port's users. At the chosen level of detail, the model has the capability of predicting the performance of the port under a range of varying physical and operational conditions and of identifying those factors which would improve the turnaround time as well as the degree of improvement. Thereafter, the tool of the simulation modeling is combined with classical econometric methods of solving simultaneous equation systems in order to estimate the demand for port services.

This results in the development of a stylised methodological tool which shows how the demand functions of number of ships and traffic will depend on price, delay (the turnaround time minus the cargo handling time) and rate of cargo handling. Finally, an answer will be sought for the following question: Given the variables whose magnitudes capture resource effects, what is the revenue maximising price that should be charged? The thesis demonstrates that prices could be a crucial instrument in regulating queue performance, which, in this case is the turnaround time of ships.

## 1.5 The Database

The plan of the thesis generated data requirement at three different levels:

a) Detailed traffic data for Calcutta and Haldia ports over time vis-a-vis that of other major Indian ports. This is required for the initial traffic survey. Relevant data for the last fifty years was collected and processed for a clear understanding of the pattern of change in the total volume of trade as well as the composition of trade over the years. The raw data available in various issues of annual Administrative Reports of the major Indian ports and Ministry of Surface Transport publications was collated, tabulated and compared. The composition of traffic for each port over time was considered and reproduced in the form of pie charts.

b) Turnaround time of all ships visiting Calcutta and Haldia as well as their components, such as waiting time, pilotage time, loading unloading time, idle time, etc. was required to develop the input parameters for the simulation model. This was available in the form of a ship log called a ship card, for each individual ship calling at the port for the entire year. This information was available at the Planning and Research cell of the Calcutta Port Trust. The relevant data was identified, collected and processed from individual ship cards.

The data provided values that the model attributes may have and also defined the relationships involved in the various activities. One of the commonly encountered problems of simulation modeling is that few real world systems exhibit constant, predictable behaviour. In most cases, the process of arrival and departure of an entity, is random. In the port situation under study, ships arrive at random to the system. Despite this inherent unpredictability, some abstraction is required to analyse the real situation. A way to represent this element of randomness is by using probability distributions. Once the distribution is identified, random samples are drawn to predict the future occurrence of an event. For example, suppose the interarrival times of arriving ships are known to follow exponential distribution with a certain mean. Then, a random sample drawn from that particular distribution would represent the time displacement until the next ship arrives. Thus, the concepts of probability and theoretical distributions are central to the element of data acquisition for simulation studies. The most important aspect is to pick the right distribution that would best fit the data. After careful consideration, the right theoretical distribution is chosen, its parameters are estimated and a goodness of fit test is made. This is done at various stages in the model development phase in relation to the arrival pattern of ships, the loading unloading time of ships, the idle time spent by ships at berth, etc.

The ship cards mentioned above, contained precise information on all activities of each ship between arrival and departure. The relevant information for model development was extracted and processed from the raw data. The statistical distribution pattern of ship arrivals, service time and idle time of ships at berth were computed. A Chi square test was run to verify the hypothesis that the interarrival time of ships followed exponential distribution with a certain mean.

Apart from this, a comparison of total turnaround time of ships visiting Calcutta and Haldia over time, as well as some other major ports in India was also carried out in order to justify the choice of turnaround time of ships calling at the port complex as an efficiency parameter.

c) Detailed data regarding the facility and resource configuration of the port for the period under study (the river draught data as well as the data for the port's ship related income and expenditure) was collected from the Calcutta Port Trust Authorities.

## 1.6 Chapter Outline

An outline of the chapter plan of the thesis is given below.

***Part 1***

Chapter 2 discusses the historical perspective and background of the Calcutta Haldia port complex. This also involves a traffic survey of the port vis-a-vis other major ports. This is followed by a discussion about the decline of traffic since the mid sixties where the probable causes have been analysed.

***Part 2***

Chapter 3 introduces the concept of simulation modeling, its historical development and its special features. This includes an analysis of the various stages of model development. Chapter 4 defines the system boundary in the present context and justifies the choice of the simulation technique and the selection of turnaround time of ships to be the efficiency parameter. It then defines turnaround time and its components with special connotations in a riverine port and discusses the basic model structure and flow chart. This is followed by the construction of a computer simulation model to estimate the turnaround time of ships calling at the port using a special purpose simulation language called SLAM II. The Appendix includes a description of SLAM II nodes and symbols. Chapter 5 discusses the application of the model to the port of Calcutta, discusses the special features of Calcutta port and estimates turnaround time and components thereof. The model is then validated against real life observations and the efficiency bottlenecks are identified. Alternative experiments on the Calcutta model are then carried out to understand the benefits of various policy options in terms of turnaround time savings. This is followed by a discussion of results. Chapter 6 essentially involves an application of the model to the port of Haldia. This also involves the identification of efficiency bottlenecks and simulation experiments are carried out on the Haldia model to understand the benefits of various policy options in terms of turnaround time savings.

***Part 3***

Chapter 7 is primarily concerned with the demand estimation of port services with the objective of revenue maximisation. This brings into focus the debate regarding micro economic reform and enhancement of the efficiency of public enterprise so that they can cover their own costs and become self sufficient. This chapter discusses the estimation of demand for port services at Calcutta and evolves an optimal pricing strategy. The main thrust is to develop a methodology to estimate the demand for port services, making use of the simulation model to estimate the queue technology and combining its output with a simultaneous equation system. This is followed by a discussion on the optimality of prices given the port's resources. Chapter 8 is the concluding section of the thesis where the main findings of this exercise have been summarised. This also includes a section indicating the scope for further research followed by the bibliography.

## 1.7 Summary of Significance and Further Research Ideas

It has been pointed out earlier that Calcutta was once the premier port of the nation, but over time, there was a marked decline in the volume of traffic handled through the port which adversely affected its revenue generation. This became a critical issue in the wake of calls for privatisation and microeconomic reforms as the financial self-sufficiency and revenue generating capacity of state run enterprises such as the port came under close scrutiny. Slow turnaround time of ships causing inordinate delay was found to be a major flaw in the working of the port system. A simulation successfully verified and validated model was developed in order to estimate the turnaround time of ships and earmark the delay elements. The thesis then estimated the demand for port services at Calcutta which can be visualised as a queuing system. The potential significance of the thesis is in developing a methodological tool by weaving the output of the simulation model in a simultaneous equation system to estimate the demand for port services and comment on the optimal pricing strategy given the objective of profit maximisation. In the case of the port complex under study, where the stigma of inefficiency has tarnished its earlier reputation of being the premier port of the nation, this kind of analysis serves as an extremely useful tool for the port planner. The methodology that has been developed during the course of this exercise may also be extended to find answers to other similar queuing problems with suitable parametric adjustments.

Although, the literature survey reveals that there exists a wide range of articles and papers dealing with the problems of the Calcutta Haldia port complex in general, there has been no earlier attempt to estimate the operational efficiency of this riverine port with the aid of a simulation model especially in the Indian context. The combination of a simulation model with classical econometric tools to estimate demand is also a novel methodological contribution. The study provides quantitative assessment of operational efficiency at the port complex and be able to predict the level of demand for port services. It develops a stylised technique for estimating an optimal price and facility configuration for the port.

There are a number of related areas where further research will produce useful insight into the system. The prevalent maritime technology is biased in favour of larger and deeper draughted vessels. This kind of study can be further developed to indicate the range of ship sizes that can effectively call at the port complex, after the required improvements in port operations, as suggested by the simulation model, are carried out. Given the emerging technological trends of larger ship size, it may be possible to indicate, whether, it will be useful to invest further on Calcutta or the funds should be better spent on Haldia or some other neighbouring deep water port. Small improvements in river draught conditions will certainly allow marginally larger ships to come in. However, given the cost implications for dredging facilities, the size of ships that may be effectively accommodated at Calcutta and Haldia is an issue that may be addressed with the help of this study.

India is positioned quite strategically in the South, South East Asia region which has shown tremendous growth potential in international trade in the past decade. Real GDP has increased at an average annual rate of 5.9% during the decade of the 1980s. For the next decade, average annual rate of 7% is forecast by Consensus Economics (UK). This obviously has a positive implication for the region's port and shipping sector which is poised for unprecedented growth. The findings of the present study may be an interesting input to identify the scope and future prospects of the port in the changing maritime trade scenario of the region.

The significance of this study will be principally in, but not restricted to, the contribution it makes to the ways of improving operational efficiency and demand estimation of the port of Calcutta alone as the study will be of interest to researchers and managers in the port sector in general. Discussions held with Australian experts in this connection indicated, for example, that the nature of some of the problems addressed in the thesis bears resemblance to those faced by the Port of Melbourne Authority. Optimal reduction in turnaround time of ships is an issue of general interest in the field of port planning and transport economics. Thus, it is believed that the simulation model developed in this study and the technique of demand estimation of the riverine port will add to the methodological and technical stock of information available to researchers and port planners in general.

# CHAPTER 2

# THE CALCUTTA HALDIA PORT COMPLEX: A HISTORICAL PERSPECTIVE



## 2.1 The Early Years of Calcutta Port

The origin of Calcutta dates back about three hundred years when on August 24, 1690, a weather beaten band of English sailors led by Job Charnock scrambled up the muddy banks of the Hooghly. The selection of site for Calcutta port was justified by its proximity to coal and iron ore deposits, jute, rice and tea growing districts and a massive up country market. In Charnock's era, the size of vessels were such that they could easily be accommodated by the navigable depths of the river. However, with the passage of time, ship size increased considerably and navigability became a problem. The Calcutta Port Trust formally came into existence on October 17, 1870. At this point of time, the port had only four jetties for sea going vessels and a wharf for inland trade. By 1881-82, there were eight jetties in operation and the volume of the port's trade began to expand. During this period, the trade in petroleum imports was growing rapidly. In 1882, petroleum importers urged the Government of Bengal in a memorandum to improve the facilities for this trade which had grown five fold during the earlier four year span. Till then, petroleum used to be stored in Garden Reach at considerable risk to the port, in case of a possible fire hazard. In order to counter this problem, the specialised Budge Budge petroleum wharf was constructed and formally commissioned in August 1886. The trade in tea was expanding as well and a new tea warehouse was commissioned in August 1887. The extension of these facilities had a positive impact on the traffic of the relevant commodities and as a result, trade flourished through the port.

Gradually, a need was felt for rail transport in and around the port area for faster movement of cargo on the land side. The first stretch of the Port Commissioner's railway line was opened in 1875. By 1893, the total length of the railways in the port area stretched to 8.26 miles. These facilities improved the operational efficiency of the port and made it more attractive to port users. In the international arena, the opening of the Suez Canal greatly boosted maritime trade in general by reducing sailing distance between England and other European countries and the ports of the east. Till about 1870, seaborne cargo was generally carried in sailing vessels, but this trend was slowly changing. After the opening of the Suez route, there was a decline in the number of sailing vessels visiting the port of Calcutta from 803 in 1861-62 to 478 in 1880-81. But this was more than compensated by the increase in the number of steamers from 89 to 506 in the same time span. This obviously meant bigger and heavier ships and greater volume of cargo handled at the port.

Even in those early days, diversion of traffic from Calcutta to other competing ports was a real problem. In a memorandum submitted in February 1881, the Bengal Chamber of Commerce and Industry drew the attention of the Government regarding diversion of traffic in certain specific items to other Indian ports. It was observed that, the comparative cheapness of Chittagong was diverting Calcutta's trade in jute. The opening and extension of railways crisscrossing the country especially in northern and western India was making it more and more economical to choose ports like Bombay and Karachi rather than Calcutta. Burmese ports like Rangoon provided keen competition to Calcutta as far as the rice trade was concerned. Bombay was a contender in the field of grain trade. As the result, the Calcutta port authorities always had to consciously fight this competition and attract user interest.

With the increase in the size of vessels and the general enhancement of traffic, the need was felt for a proper dock system. In 1885, The Government of Bengal, after careful consideration, sanctioned the Plan for the construction of Kidderpore Docks. It was declared open to maritime traffic in 1892 and 'Louise' was the first vessel to be admitted to the Docks on June 21, 1892. In course of time, the capacity of the Docks was extended to a maximum of 27 berths. Of these, 17 were reserved for export trade and special bagged imports namely sugar and rice. The rest of the berths were devoted to the handling of coal.

During these early days, the composition of trade at the dock system was typical of a country's early stage of development. The main items of export were primary commodities like jute, both raw and manufactured, rice, wheat, barley, maize, pulses, linseed, other oilseeds, hemp, hides and skins, tea, lac, manganese ore, pig iron, manure and raw cotton. Jute was the bulkiest of all exports accounting for the lions share in tonnage. Jute exports increased about tenfold within the span of 1882-83 to 1912-13. However, the export of wheat and other grains through the port of Calcutta continued to fluctuate as there was a tendency to divert wheat exports from the Central Provinces to Karachi which was a natural outlet for the produce of that area. Other items of export showed a steady rise during the period 1893-94 to 1912-13. Tea registered an increase from 50,000 tons to 88,000 tons during this period. Hides and skins rose from 26,000 to 60,000 tons, manure from 15,000 to 42,000 tons, lac from 6000 to 21,000 tons and hemp from 1,400 to 16,000 tons. Exports of manganese ore and pig iron rose considerably during this period. However, the export trade in opium and indigo fell considerably and was reduced to an insignificant minimum by 1914. On the import side, the main items of trade were iron and steel and metals, railway plant and rolling stock, cement, timber, wood, cotton piece goods, glass and earthenware, paints, paper and paste board, provisions, salt, sugar, molasses and liquor. Between 1893-94 to 1912-13, imports almost trebled with an annual rate of increase of about 5%. A noteworthy feature of this period was the massive imports of sugar from Java.

However, the outbreak of World War 1 in August, 1914 had a tremendous effect on world trade. Calcutta port also had to bear the brunt of the war as both import and export traffic showed a marked decline. The Port Commissioners resorted to emergency war surcharges to bridge the widening gap between income and expenditure. The primary reason behind the decline in traffic tonnage during this period was the virtual stoppage of import of iron from German ports and Antwerp which was primarily carried by German vessels. There was a fall in other major import items such as piece goods, railway material, machinery, cement, hardware and cutlery. Nevertheless, imports from Japan, America and Scandinavia showed an upward trend which mitigated the crisis to a certain extent. On the export front, the commodity which suffered the greatest setback was coal whose traffic declined dramatically. During the war years, most of the ships from Europe were diverted from the direct Suez route to the winding Cape of Good Hope route. This resulted in longer voyages and lesser frequencies of port calls. The most crucial war year for the port of Calcutta was 1917-18. The unrestricted submarine attacks on the merchant vessels, diversion of ships, restricted import of Burma rice etc., resulted in recurring losses for the port. Calcutta being an inland riverine port escaped the direct ravages of the war except when the German cruiser 'Emden' sank five steamers in the Bay of Bengal. The sea port of Madras on the other hand, was bombarded several times during the war.

The post war years saw a slow but steady revival of trade in the port and in 1924-25, it was officially noted by the Commissioners that the port was attaining its pre war level of traffic in imports. In case of exports the volume of traffic grew by leaps and bounds after 1926-27. There was a noticeable increase in the average size of vessels during this period. This trend continued till the Great Depression of 1930-31, which once again upset the worldwide economic balance. The timing of the Depression was indeed a great blow to the port which had then embarked upon a massive investment project for the construction of a new and modern dock system.

The new dock was named King George's Dock after the contemporary ruling monarch of England, which was an honour and a recognition of the ports services. The dock was formally inaugurated by Lord Irwin and the first vessel 'Novara' berthed on 23rd February, 1929. The exhilaration was short lived and soon the Depression crippled world trade. There was a 24% decline in the port's total traffic between 1929-30 and 1930-31 resulting in a sharp drop in the port's revenue. However, the worst was soon over and recovery was made after 1934. Massive imports of rice from Burma, sugar from Java and wheat from Australia helped to improve the traffic situation. There were increases in the shipment of coal, pig iron and manganese ore. This trend of revival continued and in 1939-40, the total traffic tonnage through Calcutta amounted to 9,965,911 tons which was the highest figure since 1929-30.

No sooner had the port authorities heaved a sigh of relief, peace was shattered by the outbreak of the Second World War. After 1940-41, the effect of the war made its presence felt as there was a distinct decline in traffic tonnage. In 1942-43, Calcutta experienced the direct impact of the war, thanks to frequent Japanese air raids and traffic was less than half of that of the previous year at 3,626,293 tons. In the second half of 1943, the port once again was busier with brisk movement of army stores. However, on 5th December, 1943, Kidderpore Docks was directly bombed by the Japanese and all ports activity came to a standstill. Towards the end of 1944, the flow of traffic picked up once again.

The Partition of India in 1947, once again lent an element of uncertainty to the trade of the port. Large jute growing tracts went to the erstwhile East Pakistan now known as Bangladesh. Commodities like raw jute, cotton and wool, which were once export items, now featured in the import list. Food grains too, had to be imported. The Government resorted to various corrective measures which included, restrictions on the import of consumer goods, emphasis on export promotion, bilateral trade agreements and efforts to step up domestic production of raw materials.

## 2.2 The Problems of the Hooghly

Just as London has the Thames, Paris has the Seine, and Rome has the Tiber, Calcutta has the Hooghly. The river Hooghly and the port of Calcutta are intricately woven in a tapestry of historical development covering a 300 year time span. The problem of navigability of the river had dogged the port authorities since the very early days. In 1853, the Bengal Chamber of Commerce drew the Government's attention to the decline in navigability of the Hooghly. In 1853-54, the Hooghly Commission, a three member team to investigate the matter was set up. The Commission could not reach a unanimous decision regarding the situation. Nevertheless, it was mentioned that, 'it may be well not to lose sight of Matla as an auxiliary port'. Matla was situated further downstream in the estuarine region of Sunderbans. A decade later, in 1863, there was cause for concern once again regarding the navigability of the river. H. Leonard, Superintendent Engineer, PWD, was appointed by the Secretary of State of India to investigate the issue. Leonard apprehended further deterioration in the Hooghly and suggested river training works as a remedial measure. Numerous experts were consulted in the following decades namely G. Robertson in 1872, L. F. Vernon Harcourt in 1891, Lindon Bates in 1899, Major Hirst in 1915, Sir William Wilcox in 1930, T. M. Oag in 1938, Sir Claude Inglis in 1947 and so on. The suggested remedies included extensive river training works and consistent dredging. In 1947, the proposal to construct an alternative ship canal to by pass the difficult stretch between Calcutta and Diamond Harbour was abandoned for being too expensive. Although there has been divergence in some of the opinions expressed and the remedial measures recommended, there has been remarkable unanimity regarding the necessity of adequate headwater supply.

A study of the navigability of the river over time indicates a gradual deterioration of navigable depths in the river. This is a common phenomenon of a tidal river where a decline in head water supply progressively silts up the upper reaches and extends downstream. The quantum of water required for the improvement of the port of Calcutta has been a controversial issue. However, a minimum headwater discharge of 40,000 cusecs per year was agreed upon by the experts. In later years, two major projects to counter the problem of navigability, the construction of the Farakka Barrage to ensure greater headwater supply and the development of the subsidiary port of Haldia were considered to be giant steps in the right direction.

## 2.3 The Planned Era

Various investment projects were sanctioned during the First Five Year Plan (1951-1956) which included purchase of wagons and locomotives, construction of two general cargo berths, river training works, installation of a 200 ton cantilever crane and the development of a heavy lift yard at King George's Dock. The developmental efforts were directed mainly towards acquiring various crafts for improving navigation and replacement of worn out facilities during the Second World War. Some of these projects were carried over and executed during the Second Plan period (1956-1961).

The Second Five Year Plan saw a total outlay of Rs. 199 million sanctioned for the port of Calcutta. The earlier continuing projects included the construction of the general cargo berth, river training works at Falta and Hooghly Point reach and acquisition of two anchor vessels and one suction dredger. The new projects of the Second Plan included reconditioning and strengthening of portions of Kidderpore Docks, installation of electric cranes, improving facilities at the dry docks, purchase of new equipment and reconstruction of approach roads and bridges. Provisions were also made during this Plan period for the purchase of a number of dredgers for river conservation programmes. The purchase of survey vessels, dock tugs, launches, lighter barges, wagons and steam locomotives was also part of this Plan project for the Port of Calcutta. During the Second Plan period, the total expenses incurred by these developmental projects amounted to Rs. 157 million. This was the golden era in the history of the port of Calcutta which often handled 65 to 70 ships per day. During this period, Calcutta could claim to be among the ten best ports of the world. The stress on industrialisation during the Second Plan period was responsible to a great extent for the enhancement of traffic. The composition of traffic also began to show a change in pattern. Steel, mechanical equipment, heavy plant and machinery contributed to the bulk of imports while coal and iron ore were the major export items. A 200 ton massive electric crane was installed in August 1957, in order to cope with the heavy lift items of import cargo. The port continued to flourish and went from strength to strength during this period. Lal Bahadur Shastri, the contemporary Minister for Transport and Communications remarked during this period that, 'Calcutta is our biggest port and will continue to be so'.

During the Third Plan period (1961-1966), the main focus of attention was the completion of the port projects which were already under way especially those which dealt with river conservation. The prevalence of larger, deeper drafted vessels necessitated the improvement of riverine conditions leading to the port. The two major schemes that were introduced during this period were the construction of an ancillary dock system at Haldia and a barrage at Farakka for improved headwater supply to the Hooghly throughout the year. At this point of time, a team of economists from the World Bank led by Dr. M. Hoffman visited India and strongly recommended the construction of the subsidiary port of Haldia where deep water facilities could be provided to the calling ships. Haldia was selected to be the best option site from among a number of contenders like Dariapur, Geonkhali, Kaikhali etc. Provisions were made for the deepening of the river channel at Balari for better navigation in the Hooghly. The cost estimates of these schemes amounted to Rs. 280 million. A World Bank loan of 21 million dollars in various currencies was sanctioned in June 1961 in order to finance some of the proposed projects.

The riverside oil jetty at Haldia was commissioned in August 1968 falling in the Third Annual Plan period of 1968-69 which immediately preceded the Fourth Five Year Plan (1969-1974). The total outlay during the Fourth Plan for the Calcutta-Haldia port complex was Rs. 621 million. This was spent on the completion of spillover schemes from earlier Plan periods as well as on new improved facilities for dry docking, ship repairs etc.

The Fifth Five Year Plan (1974-1979) schemes for Calcutta Port comprised of spill over schemes from earlier Plan periods as well as modernisation of cargo handling facilities and replacement of old river crafts. Project work for Haldia included the completion of the new lock entrance, dredging of port approaches, installation of mechanical handling equipment, finalisation of railway marshalling yards and construction of a huge transit shed.

During the Sixth Five Year Plan (1980-1985), a new oil jetty was sanctioned at Haldia. The objective was to reduce the great burden of POL traffic on the single oil jetty and improve the turnaround time of tankers. Priority was also given to container handling facilities and ship to shore gantry cranes were installed at Haldia during this period. Emphasis was given on acquisition and replacement of cargo handling equipment for Calcutta port. Replacement of tugs, survey vessels, pontoons and gangways for riverside jetties, mobile equipment for cargo handling, acquisition of dredgers, improved workshop and repair facilities and development of inland port railway network. Improvement of lock entrances was also carried out as a part of the development programme. Schemes for Haldia included river training works, new cranes, expansion of workshop facilities and plant repair. The outlays for the Sixth Five Year Plan approved by the Planning Commission for Calcutta, Haldia and river training works were Rs. 303 million, Rs.214 million and Rs. 197 million respectively.

The Seventh Five Year Plan (1985-1990) had schemes for Calcutta and Haldia which looked at modernisation of port's railways, road network, development of infrastructural utilities and expansion of container handling facilities. The Plan sanctioned a total outlay of Rs. 1390 million of which, Rs 470 million was for Calcutta, Rs. 620 million was for Haldia and the rest was to finance river training projects. Important continuing projects included construction of a second oil jetty at Haldia and the dredging of Jiggerkhali Flat in the Hooghly estuary. This was followed by two annual plans.

In the Eighth Five Year Plan(1992-1997), modernisation of docks and cargo handling facilities have received top priority. As containerisation was the order of the day, a lot of attention was given to improving container handling facilities.

## 2.4 Volume of Traffic

In this section, the traffic performance of the port over the years will be evaluated and compared with that of some other major Indian ports. There has been some debate about what should be a proper indicator of traffic performance. Should it be the value of goods passing through the port or should it be the volume of traffic or the traffic tonnage? In this connection, it was observed in the Calcutta Port Trust Report (1914) that,

> Statistics on the value of the trade handled ... can, at best, afford only a general guide for the purpose of drawing deductions in an inquiry of this kind, as the proportion of various classes of goods which make up the trade of a port may vary widely from time to time and there is also a very wide difference between the relative value of different items ... Again the fluctuations from year to year make it necessary to examine with great caution any conclusions based on the values of the commodities dealt with.

The volume of traffic or the traffic tonnage through the port has thus been considered to be a more reliable and representative indicator of traffic performance.

### *2.4.1 Volume of Traffic at the Port of Calcutta*

Figure 2.1 shows the graph of total volume of traffic passing through the port of Calcutta between 1935-36 and 1995-96. The graph indicates that there was an overall upward trend right till the mid 1960s with some fluctuations which, as discussed earlier, were caused by historical events such as the World Wars, the Great Depression, the partition of India etc. After the attainment of Independence, the Government of India embarked upon a number of measures and policy directives to boost the economy of a fledgling nation. There was a great deal of emphasis on self sufficiency in food, building a strong industrial base and achieving a favourable balance of trade. During this period, the quantum of total traffic through the port of Calcutta fluctuated around a rising trend. In 1964-65, total volume of traffic through Calcutta reached a high of 11.1 million tonnes. However, the late 1960s and early 1970s ushered in an era of dismal performance and traffic through the port declined.

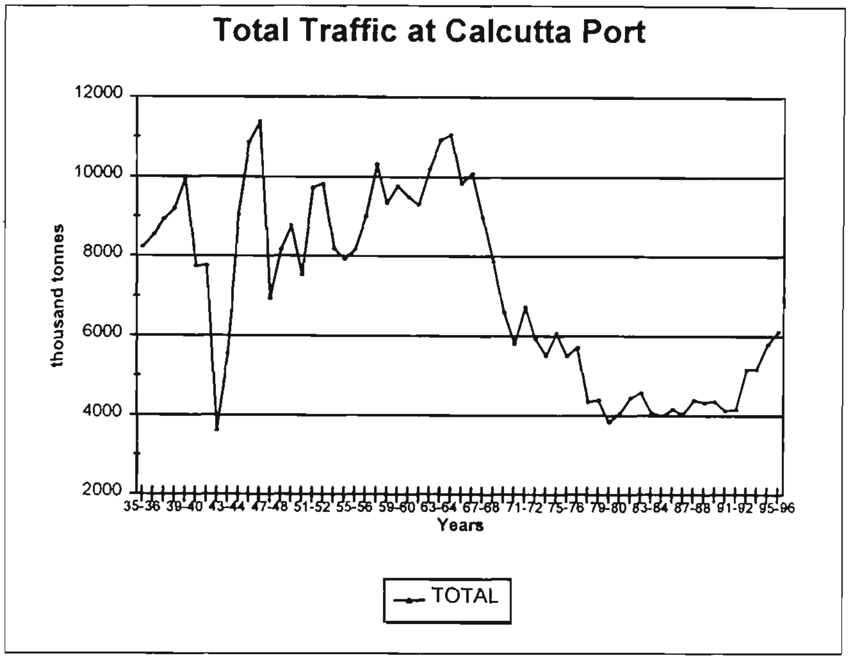


**Figure 2.1**

Source: Calcutta Port Trust Administrative Report (various issues).

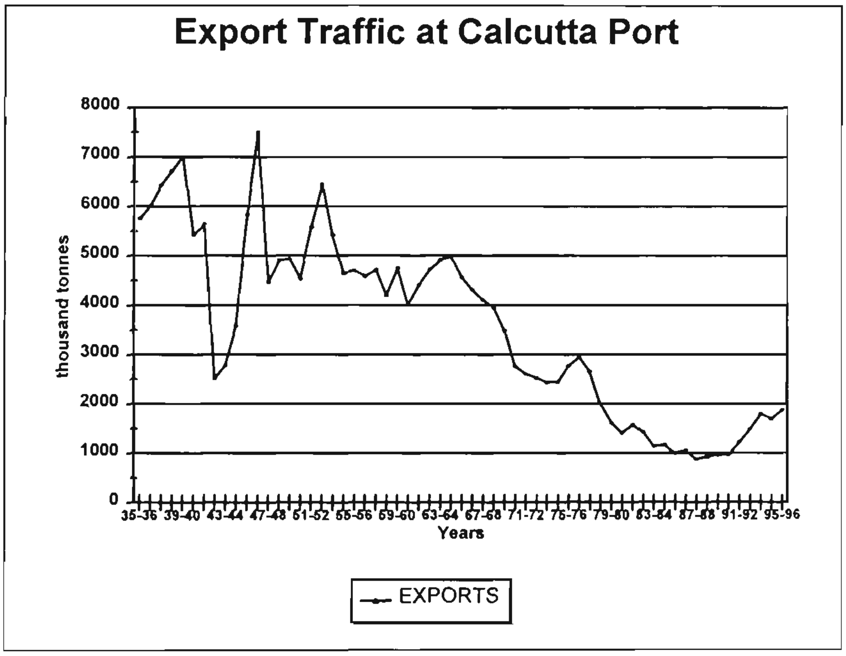


**Figure 2.2**

Source: Calcutta Port Trust Administrative Report (various issues).

During the 1980s total traffic through Calcutta remained more or less stagnant at around 4 to 4.5 million tonnes a year.

### *2.4.2 Export Traffic at the Port of Calcutta*

In Figure 2.2 the flow of export traffic through the port of Calcutta between 1935-36 and 1995-96 has been depicted. The graph shows a fluctuating trend till the mid 1960s with occasional peaks and troughs giving it a jagged appearance. However, after 1965-66 there was a monotonous steep decline falling from about 5 million tonnes in 1964-65 to approximately 1 million tonnes in 1988-89.

### *2.4.3 Import Traffic at the Port of Calcutta*

Figure 2.3 shows that the volume of imports through Calcutta fluctuated over the years between 1935-36 and 1995-96, reaching the highest level between the mid fifties and sixties. It was during this period that large scale machinery imports were the order of the day in order to keep pace with the programme of industrialisation sweeping the country. The steel plants of Eastern India and the Railways required massive imports of plant equipment. This resulted in the boost of the import traffic. However, this was followed by a period of industrial stagnation in Eastern India which made its impact on the port. During the eighties, the main contributor to the import traffic was petroleum and other lubricants (POL) which slightly improved the situation. The commodity component of import and export traffic and its pattern over time was considered for a clearer perception of the traffic scenario.

### *2.4.4 Volume of Traffic at the Port of Haldia*

As noted earlier, the subsidiary port of Haldia commenced operations in the late 1960s and was located 104 km downstream of Calcutta, in order to circumvent the riverine restrictions at Calcutta. Haldia was the first comprehensive port project in India which provided composite cargo handling facilities for various types of traffic with particular emphasis on bulk cargo. It supported the growth of port based and

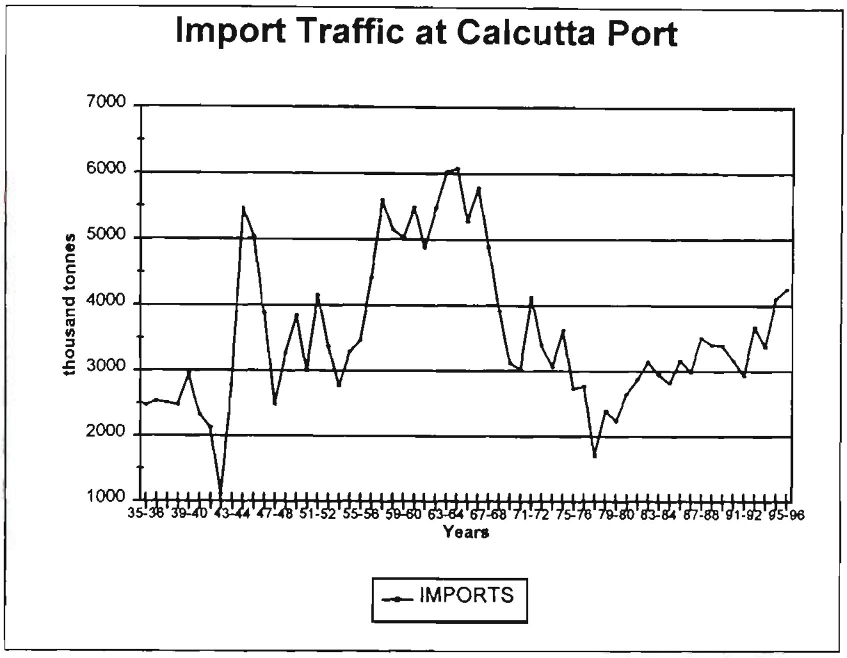


**Figure 2.3**

Source: Calcutta Port Trust Administrative Report (various issues).

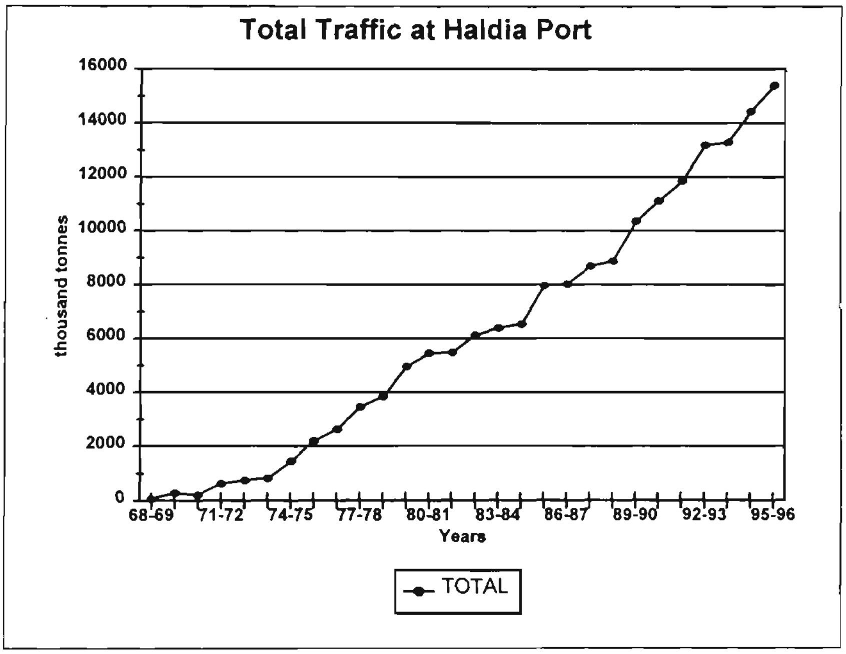


**Figure 2.4**

Source: Calcutta Port Trust Administrative Report (various issues).

port oriented industries and was directed towards being an industrial growth centre of eastern India. Figure 2.4 shows the volume of total traffic handled at Haldia since

1968-69 to 1995-96. The graph is uniformly upward rising during the entire period crossing 10 million tonnes in 1988-89.

### *2.4.5 Export Traffic at the Port of Haldia*

Haldia commenced its operations as an exporting port after 1974-75 as shown in Figure 2.5. Thereafter, the exports through the port increased over the years reaching about 4 million tonnes in 1988-89. The primary export items are coal and petroleum products. The traffic in coal which was once the mainstay of exports through Calcutta was, in later years, almost entirely diverted to Haldia. The export of POL has been steadily increasing over the years through Haldia.

### *2.4.6 Import Traffic at the Port of Haldia*

Large scale imports of POL through Haldia has been the single most redeeming feature of the port complex over the years. Crude petroleum which is mainly imported from gulf countries is refined at Haldia by the Indian Oil Corporation, with a refining capacity of 2750 thousand tonnes per year. The situation on the import front at Haldia is depicted in Figure 2.6. A comparison of the performance of the Calcutta Haldia port complex, vis-a-vis, certain other major ports of India may help to understand the traffic situation better at this juncture.

### *2.4.7 Export Traffic Through Other Major Ports*

Figure 2.7 denotes the volume of export traffic through selective major ports between 1951-52 to 1991-92. The Calcutta Haldia port complex which was once the leading exporting port showed a decline in export tonnage over the years and currently trailed behind all the major ports that have been considered. Calcutta was the leading exporting port till about 1962-63. Until this period, there were periodic fluctuations over a gradual downward trend. However, after 1963, exports through Calcutta declined and she relegated her earlier supremacy to Bombay. Calcutta was surpassed by Vizag in 1967-68 and later by Madras in 1970-71. The rise of the port of Vizag as

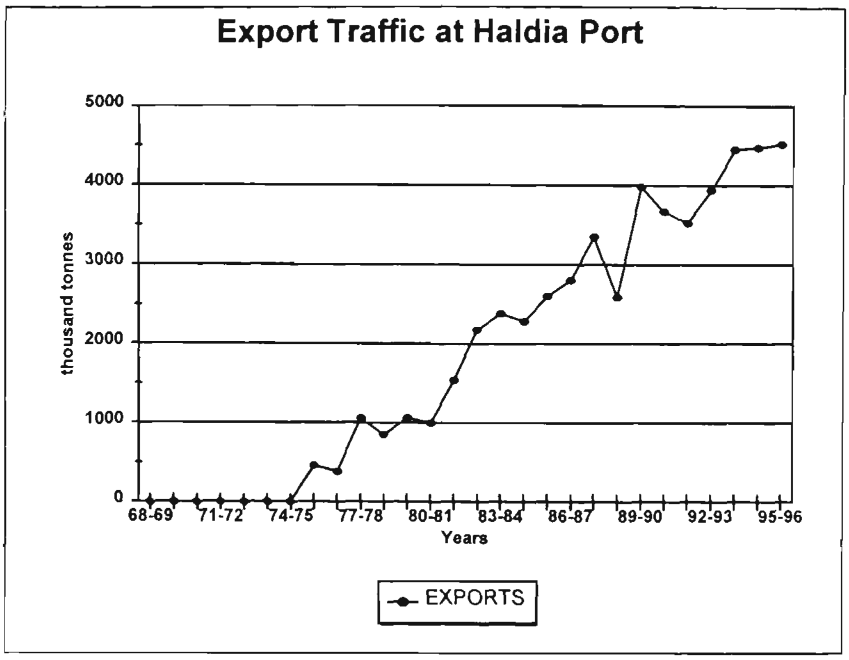


**Figure 2.5**

Source: Calcutta Port Trust Administrative Report (various issues).

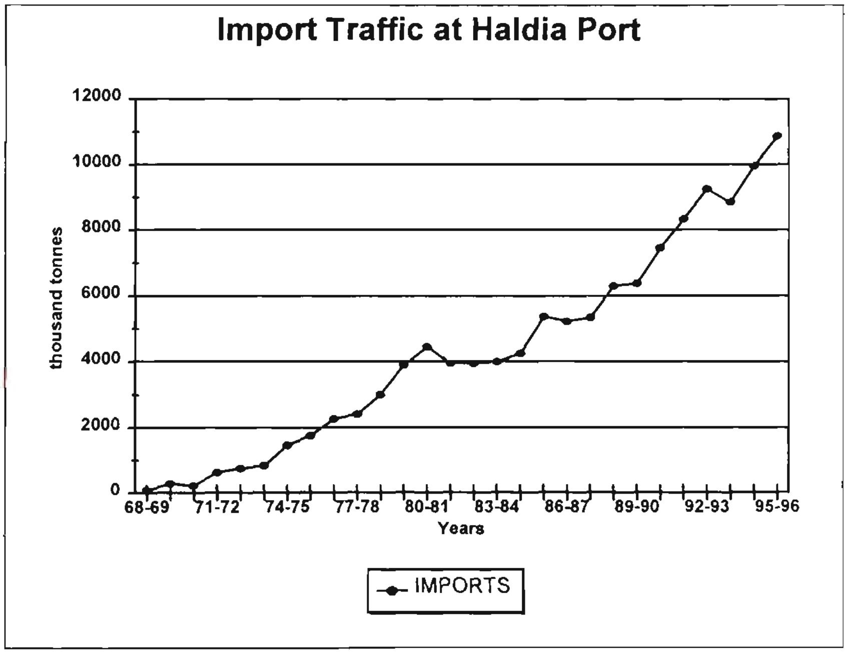


**Figure 2.6**

Source: Calcutta Port Trust Administrative Report (various issues).

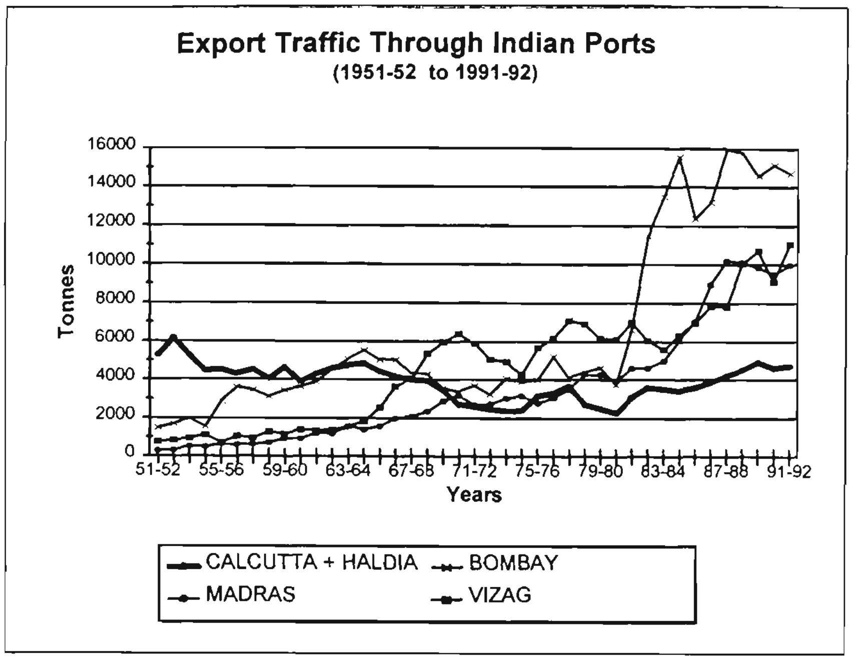


**Figure 2.7**

Source: Administrative Reports of Relevant Ports (various issues).

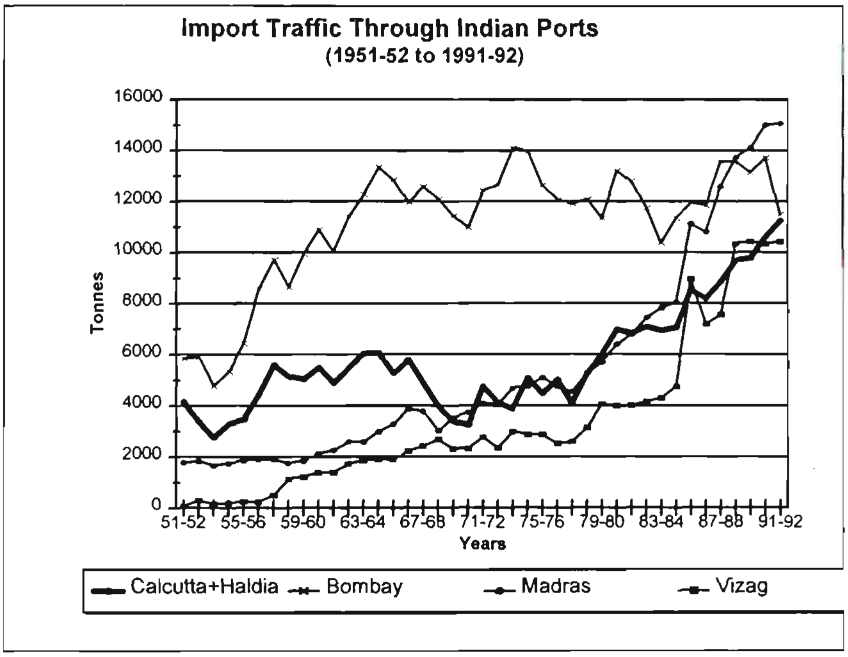


**Figure 2.8**

Source: Administrative Reports of Relevant Ports (various issues).

the leading exporter was primarily due to large scale iron ore exports. To what extent, the poor export performance of Calcutta was caused by traffic diversion to other ports will be clear, once the traffic composition of the competing ports is considered over time.

### *2.4.8 Import Traffic Through Other Major Ports*

Figure 2.8 shows that in case of imports, Bombay maintained a clear lead over the other ports throughout the period under study. The Calcutta-Haldia port complex was distant second, although after the mid sixties, she was periodically surpassed by Madras. It was primarily due to the import of Petroleum and other Lubricants (POL) through Haldia which enabled the port complex to maintain her position as will be clear when traffic composition over the years is discussed in detail.

A detailed discussion of the composition of traffic through these ports over time has been included in Appendix 2.1. A comparative analysis of the traffic composition of Calcutta and Haldia vis-a-vis that of Bombay and Vizag clearly indicate the reasons behind the success stories of the latter ports in terms of traffic volume.

## 2.5 The Role of the Hinterland

Historically, Calcutta had been the focal point of British capitalism in India and was the nerve centre of trade and commerce. Chakrabarty (1976, p. 11) observes that:

> Most of the items of export carried through Calcutta are those which have produced wealth in its hinterland. Jute and products therefrom, tea, iron ore, iron and steel, general engineering goods etc., produced in the eastern region of India have accounted for the export traffic through Calcutta. Similarly, the import traffic has been nothing short of what was required by the economy of the hinterland. The premier position of the port of Calcutta is, therefore, nothing but a statement on the premier status of the economy of the eastern region in India. The symbiosis that emerged between the port and its hinterland can hardly be overemphasized.

However, over the years, the success story of the hinterland changed as a slow process of industrial stagnation and economic deceleration became operative in the eastern region. The sluggish growth of the economy of the eastern region was in contrast to that of the hinterlands of Bombay, Madras and Vizag which diversified into new and developing areas of production. Calcutta continued to depend on traditional items like jute, whose worldwide demand was waning in the face of stiff competition from synthetics. In case of tea, which was another staple general cargo item through Calcutta, the area under cultivation did not increase very much over the years and most of the tea gardens faced the problem of aging of the tea bushes which had surpassed their peak yield period. The separatist movement in North Bengal in the late 1980s and early 1990s also adversely affected tea exports. Indian tea faced stiff competition from Srilanka which pursued an aggressive marketing strategy and made quite an impact in the international market. In the area of iron and steel industry, the inherent problems plaguing the industry in the eastern region were power shortages and lack of modernisation. The power sector, which plays a major role in the industrial growth of any region was severely neglected. Between 1951 to 1980, the growth of installed capacity in the eastern region was 724% as opposed to 2000% in the west. In the agricultural sector we find that fertiliser consumption in the east was quite low in the east compared to the southern region. The direct consequence of this may be observed in the low level of fertiliser imports through Calcutta, as opposed to Vizag or Madras. The sluggish growth of the hinterland's economy adversely impacted the port's trade.

## 2.6 Diversion of Traffic

The traffic analysis in Appendix 2.1 revealed that the success stories of ports like Bombay, Madras and Vizag are greatly dependent on oil, petrochemicals and bulk cargo like iron ore and coal. In the past, the mainstay of Calcutta's traffic was based on coal, iron ore and general cargo comprising traditional items. However, in later years, the ore and coal traffic was diverted to other ports as a result of conscious policy decisions at the political level (Sau 1980). A major part of the coal traffic which entered the trade of the port was coastal in nature and faced stiff competition from the railways. With the improvement of the rail network, it was decided to carry coal to the southern region using the all rail route. This seriously hampered the coastal coal traffic through Calcutta. In case of the overseas coal traffic originating in the Jharia Ranigunj belt in the immediate hinterland of the Calcutta Haldia port complex, Paradip port in Orissa emerged as the chief competitor of Haldia. Often, Paradip was given preference to Haldia although the latter had a specialised coal berth with all modern handling facilities. Haldia, Paradip and Vizag were also competitors in the handling of iron ore trade from the ore deposits in Bihar. However, MMTC (Minerals and Metal Trading Corporation of India) channelled the ore frequently through Paradip although this involved an additional railway distance of 296 km between the port and the mining area.

It has been argued that the fall in iron ore traffic through the Calcutta Haldia port complex was due to the recession which hit the world steel industry in the early 1980s. However, this temporary recession could not explain the virtual stoppage of iron ore handling at the Calcutta Haldia port complex and the equipping of the port of Vizag with modern ore handling facilities resulting in a complete diversion of traffic. In support of such a decision, the Report of the Working Committee on Ports for the Seventh Five Year Plan observes

> Iron ore is one of the major commodities of export for the country ... In view of the recession in the international steel industry and consequently in the demand for iron ore, it has become difficult for the exporting countries to maintain even the present level of exports. As freight plays an important part in the landed cost of ore at the receiving ports, buyers are keen to move the ore in as large vessels as possible to economise on the raw material cost ... The receiving ports in Japan are also being improved to receive larger and larger vessels sometimes on two port discharge basis. Viewed in the above context of market studies, and the facilities available and being provided by the competing ports, selective deepening of some of the ore exporting ports, to keep our exports competitive becomes inevitable.

This inevitability was reflected in the complete diversion of ore traffic from the Calcutta Haldia port complex. In the face of such selective transport policy, it is small wonder that although Calcutta lay closest to the ore producing zone and Haldia was originally designed to load iron ore, these ports languished from a total absence of ore traffic. Once again, the problem of navigability in the river Hooghly restricting the movement of larger vessels sealed the fate of the Calcutta-Haldia port complex.

Draught deficiency in the river Hooghly has been a major blockage in the smooth flow of traffic at Calcutta port and responsible for a great deal of traffic diversion. Chakrabarty (1976) observes that this constraint was not applicable to Haldia to that extent, as Haldia was specifically constructed further downstream in order to alleviate this problem. However, the draught constraint, although a very serious one, could not fully explain the decline in traffic.

A survey was conducted for the Calcutta Port Trust by Maser Private Limited in 1983 in order to assess port users' opinion on the subject of traffic diversion from the Calcutta-Haldia port complex. A factual analysis preceding the survey indicated that, between 1977-78 and 1982-83, all India port traffic indicated a compound growth rate of 8% per annum while the corresponding figure for the Calcutta Haldia port complex was 6.5% per annum. The basic conclusions drawn from the survey were as follows:

- traffic had been diverted from the Calcutta-Haldia port complex in the preceding decade;
- the extent of diversion was as high as 40% for bulk cargo and about 25% for general cargo;
- substantial diversion in imports took place in case of engineering goods and raw materials, food grains, fertilisers and cement. Major ports benefiting from this diversion were Bombay, Vizag, Kandla, Madras etc.; and
- in case of exports, diversions mainly occurred in case of iron ore, carpets and engineering goods benefiting ports like Vizag, Paradeep, Madras, Bombay and Kandla.

These observations indicated that there was a growing lack of confidence among port users on the efficiency of the Calcutta Haldia port complex which reminded one of a long river passage and related delays which could detain a ship indefinitely with huge cost overruns. A ship owner or charterer always prefers a port which gives a quick turnaround to vessels thus minimising the delay element and cutting operational costs. On comparing the average turnaround time of the port of Calcutta and Haldia to that of some other major ports, it was found that the turnaround time at Calcutta where there was a chronic shortage of traffic was almost as high as that of Bombay, which happens to be the nation's busiest port. A need was therefore felt to precisely estimate the turnaround time at Calcutta and identify its components to seek an answer to this riddle. What were the elements causing delay and how best could the situation be improved? This has been attempted with the help of a simulation model developed in the following chapters.

## Appendix 2.1

### *A2.1.1 Composition of Exports at the Port of Calcutta*

The composition of export traffic through Calcutta has been considered for the period 1952-53 to 1992-93 at regular intervals shown below in Figure 2.9. In 1952-53 coal was the largest contributor to the total export tonnage accounting for 53.19%. The largest and richest coal deposits of India were in the Ranigunge-Jharia-Karanpura belt on the Bengal Bihar border which lay in the natural hinterland of the port. Apart from coal, iron ore was the bulkiest item of export followed by jute. Once again, the rich iron ore belt of Orissa found the port of Calcutta to be the closest and most convenient outlet for export.

The era of industrialisation in independent India saw exports of iron steel and machinery through Calcutta. Tea was another important export item due to the proximity of the rich tea belt of North Bengal (Darjeeling) and Assam. POL had entered the export trade in a small way. In 1957-58, coal was still the major item of export although its share had declined. The share of iron ore had however risen and jute and tea marginally improved their respective positions. A more or less similar pattern is observed in 1962-63 except for a decline in the share of iron ore from 21.27% to 11.65%. Whether this was because ore traffic was being diverted to other ports will be clearer when the traffic composition of other competing ports is considered. In 1967-68, the share of coal was almost halved and jute had emerged as the bulkiest of all exports. The share of iron and steel and machinery had registered a substantial increase. In 1972-73 coal was once again, the bulkiest export item followed by jute. The share of iron ore had fallen even further and that of iron and steel and machinery had declined as well. In 1977-78, iron ore which had once covered 21.27% of exports through the port was completely absent. Coal and jute remained the two bulkiest export items followed by iron and steel and machinery. A more or less similar picture is observed in 1982-83 with coal and jute accounting for the highest shares of export tonnage. There was a decline in the share of iron and steel and machinery in this year. A remarkable feature in 1987-88 was that coal, which was one of the bulkiest items of export through Calcutta was virtually wiped out with jute taking up 36.46% of total exports. A look at the traffic composition of Haldia would reveal that, coal traffic of Calcutta was almost totally diverted to Haldia. Iron and steel and machinery, tea and POL were the other main items of export through Calcutta. In 1992-93, the share of jute declined remarkably due to a worldwide slump in jute demand. Iron and steel and machinery and tea remained the two other major export items. It is indeed ironical that iron ore and coal, which were the bulkiest of exports through Calcutta were diverted to other ports and jute lost out due to falling world demand.

### *A2.1.2 Composition of Imports at the Port of Calcutta*

In the following pie charts in Figure 2.10, the composition of import traffic through Calcutta has been considered for the period 1952-53 to 1992-93 at regular intervals. In 1952-53, food grains and POL were the two major import items. India had not attained self sufficiency in food and was dependent on large scale food imports. Salt was an important item of import as it was then considered to be economical to ship in salt from the west coast of India. A small percentage of iron and steel and machinery was imported and fertilisers had just made a modest beginning in the imports list. In 1957-58, in spite of the drive towards self-sufficiency, food grains continued to capture a major chunk of total imports. This was the beginning of the second five year plan period which stressed on the industrialisation of the nation. The large steel mills of Eastern India were being set up resulting in large scale imports of iron and steel and machinery. POL continued to be an important import item while the share of salt dwindled due to increased competition from railways. In 1962-63, more or less a similar pattern continued with POL consolidating its major share in the imports list while the share of salt dwindled even further. In 1967-68, massive food grain imports took place caused by consecutive poor harvests in the country. POL continued to be a major item of import and fertiliser gradually enhanced its importance. In 1972-73, the nation's goal of self sufficiency on food was on its way to realisation with food imports dwindling from 37.69% in 1967-68 to only 4.62% of total imports in 1972-73. POL emerged as the most important constituent of imports and this seemed to be the trend for years to come. In 1977-78, fertiliser emerged as a

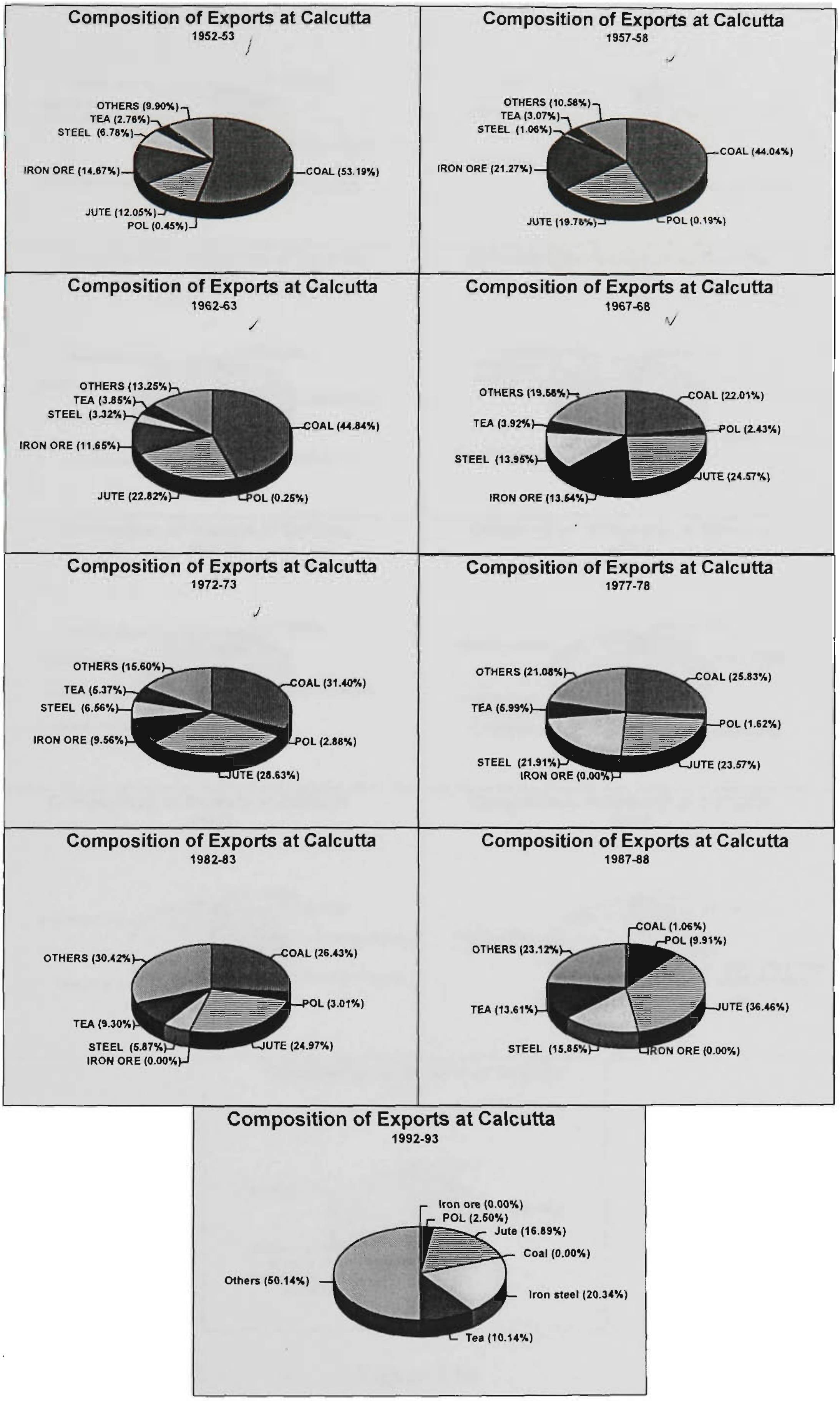


**Figure 2.9**

Source: Calcutta Port Trust Administrative Report (various issues).

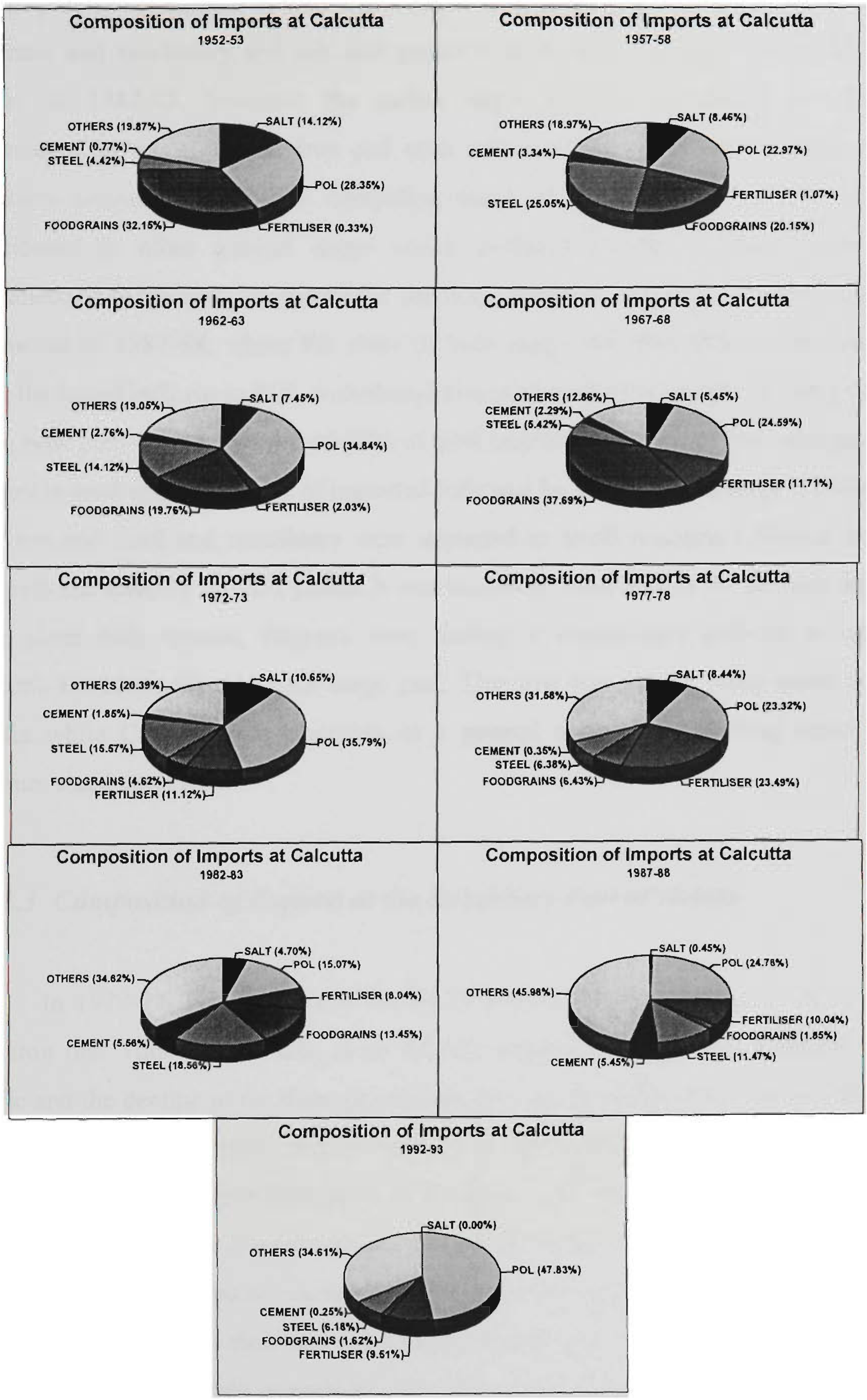


**Figure 2.10**

Source: Calcutta Port Trust Administrative Report (various issues).

very important constituent of total imports followed closely by POL. Food grains, iron and steel and machinery and salt still contributed in small amounts to total import traffic. In 1982-83, however, the earlier major players contributed to smaller percentages in total imports. Iron and steel and machinery, POL, food grains and fertilisers accounted for almost competing shares in the import list. Goods which contributed to other general cargo which included a host of items including containerised cargo now accounted for the lion's share of imports. A similar pattern was noted in 1987-88, where the share of bulk cargo had diminished even further. Only the liquid bulk cargo POL contributed to a quarter of total imports. Other general cargo now contributed to about 45.98% of total imports. In 1992-93, POL emerged as the single most important item of imported followed by other general cargo. Fertilisers and iron and steel and machinery were imported in small amounts followed by an insignificant quantity of food grains. It was becoming clear that in the modern day of large sized bulk vessels, shippers were finding it increasingly difficult to utilise Calcutta economically as a bulk cargo port. That role was slowly being taken up by Haldia while Calcutta was emerging as a general cargo port handling small and medium sized vessels.

### *A2.1.3 Composition of Exports at the Subsidiary Port of Haldia*

In 1977-78, POL accounted for 54.22% of export tonnage followed by coal and iron ore. Thus we see that, since its very inception, Haldia was handling bulk traffic and the decline in the share of coal and iron ore from the export list of Calcutta could partly be explained by traffic diversion to Haldia during this period. A curious feature of the composition of exports at Haldia in 1982-83 was that, iron ore which contributed to 12.58 % of total export traffic in 1977-78, now contributed only 0.46% of exports. Coal captured an enormous 69.18% of total export traffic followed by POL at 28.39%. It was quite clear that the Calcutta-Haldia port complex lost its entire iron ore traffic to some other competing port. The same pattern of traffic composition pertained at Haldia in 1987-88, with the share of coal gradually increasing to an overwhelming 78.17%. Small quantities of other general cargo which included tea, jute and jute products were being exported through Haldia as well. A more or less identical picture is observed in 1992-93 with coal and POL remaining the important components of export and steel making a modest beginning in the export list. Thus, it was observed that the entire coal exports through Calcutta was diverted to Haldia which could accommodate larger ships, while the entire iron ore traffic was totally diverted from the port complex to some other Indian port.

### *A2.1.4 Composition of Imports at the Subsidiary Port of Haldia*

Ever since its inception, the single most important commodity that has been imported through Haldia is POL. In 1972-73, it was in fact, the only commodity that was imported through Haldia. Five years later, POL still accounted for almost the entire import traffic at 99.99%, with other general cargo making a modest beginning at 0.01%. In 1982-83, the overwhelming dependence on POL had somewhat reduced with new items such as coal, fertilisers and other general cargo entering the import list. In 1987-88, it was observed that the share of POL had fallen to 82.86% while items such as coal, fertilisers and other general cargo were gaining importance. In 1992-93, coal increased its share to 22.66% followed by fertilisers and other general cargo. However, POL continued to be the single most important item of import contributing to 70.94% of the imports. A study of the export and import traffic compositions of some other major ports like Bombay and Vizag will now be considered to obtain a comparative picture.

### *A2.1.5 A Comparative Analysis*

As early as 1952-53, a diverse mix of commodities entered the export trade of Bombay as is depicted by Fig 2.13. It may be observed that the inclusion of POL and fertilisers in the export list as early as 1952-53 indicated an industrially diverse and developed hinterland. In 1957-58, POL clearly emerged as the single most item of export at 49.04%. In 1967-68, POL consolidated its share in the export list, contributing about 61% of total exports. Other general cargo gained importance while the share of iron ore and manganese ore declined. A more or less identical composition was observed in 1987-88 with POL still remaining the single most

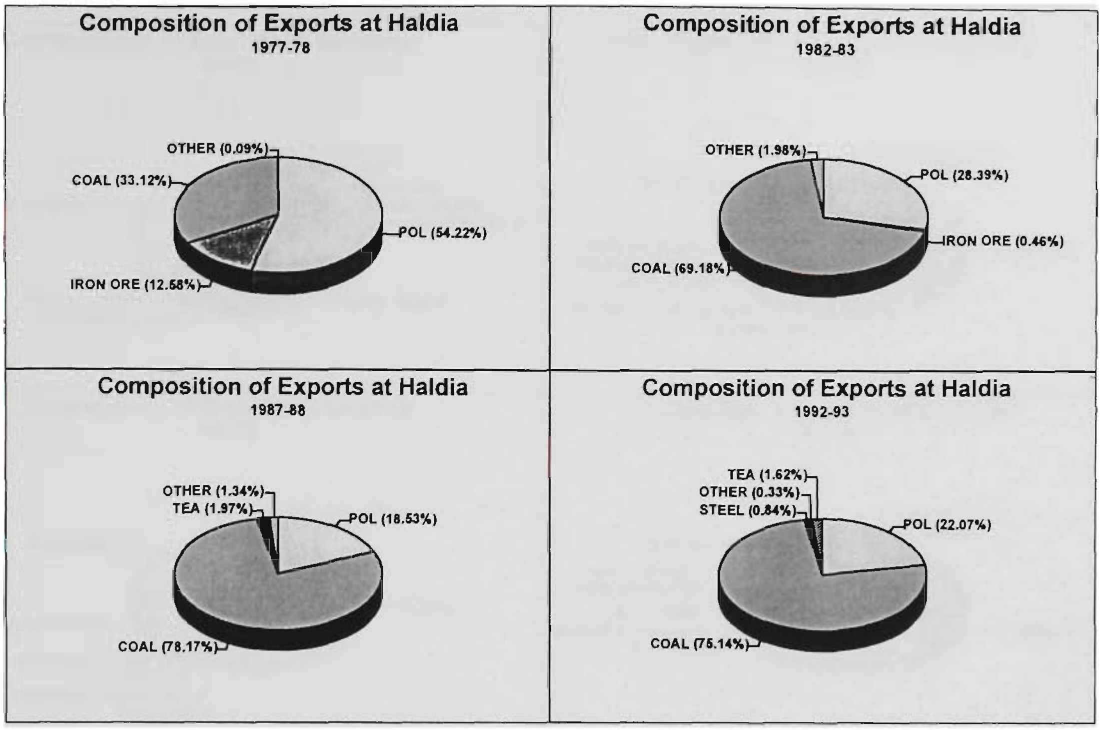


**Figure 2.11**
Source: Calcutta Port Trust Administrative Report (various issues).

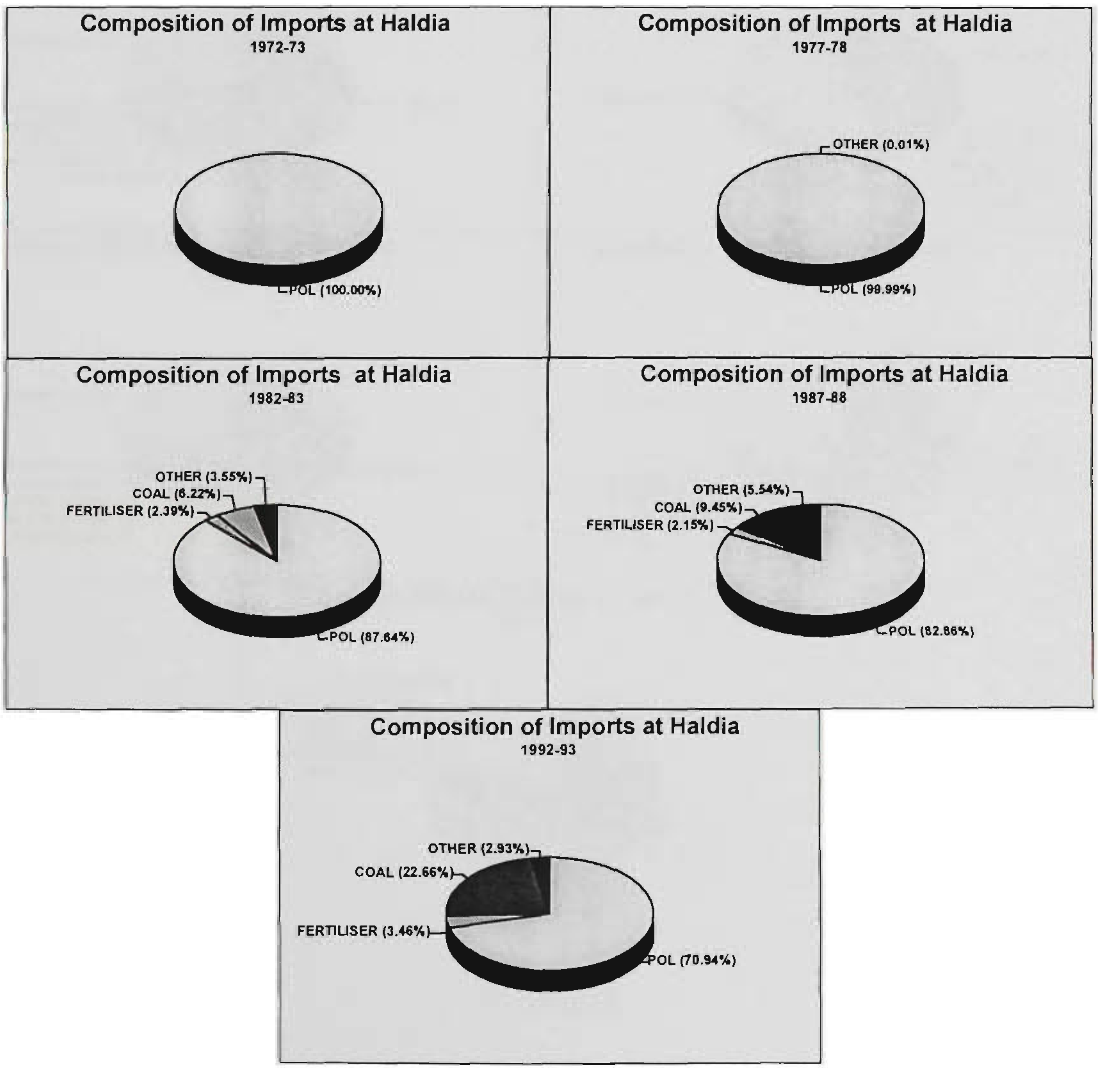


**Figure 2.12**
Source: Calcutta Port Trust Administrative Report (various issues).

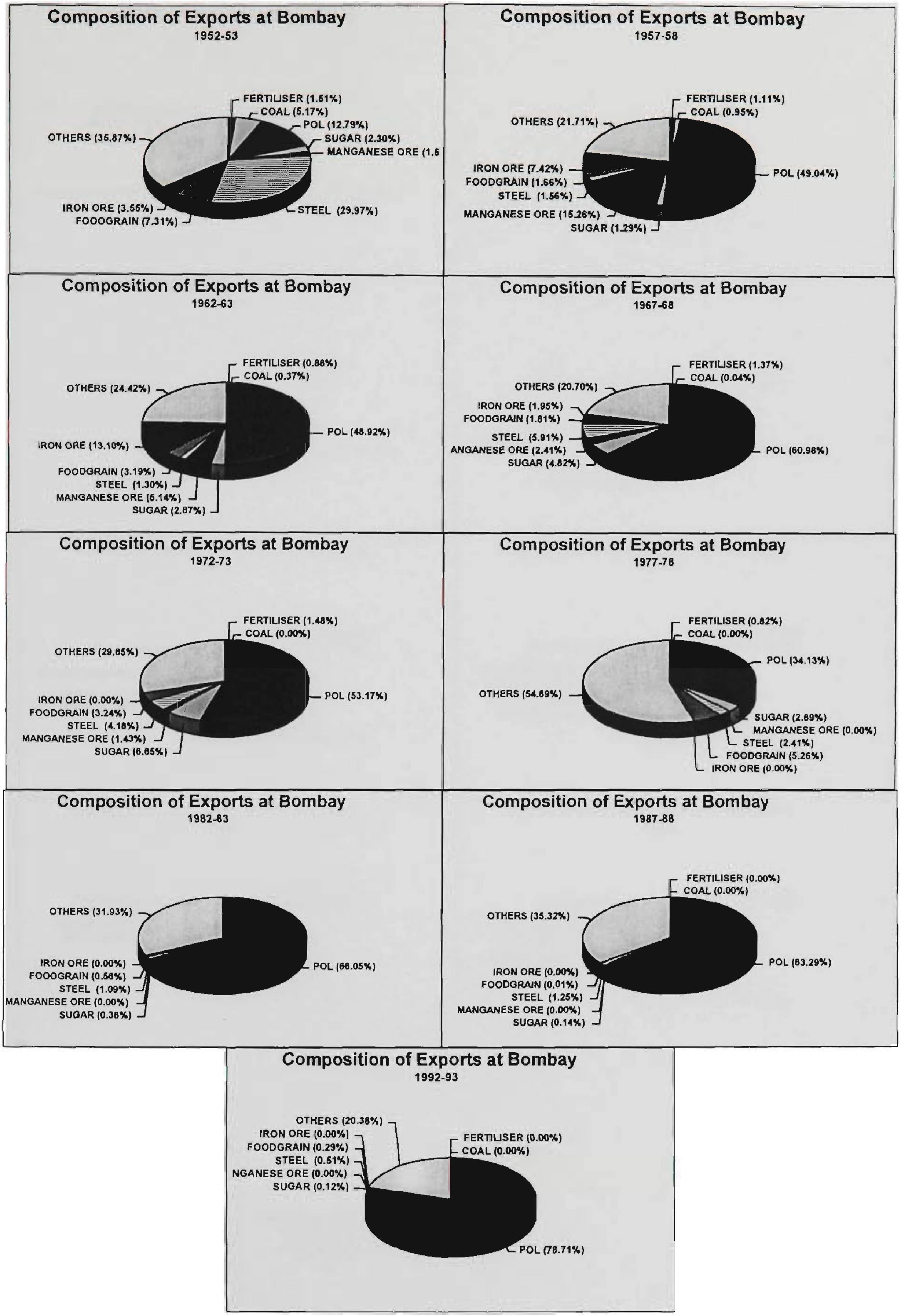


**Figure 2.13**

Source: Bombay Port Trust Administrative Report (various issues).

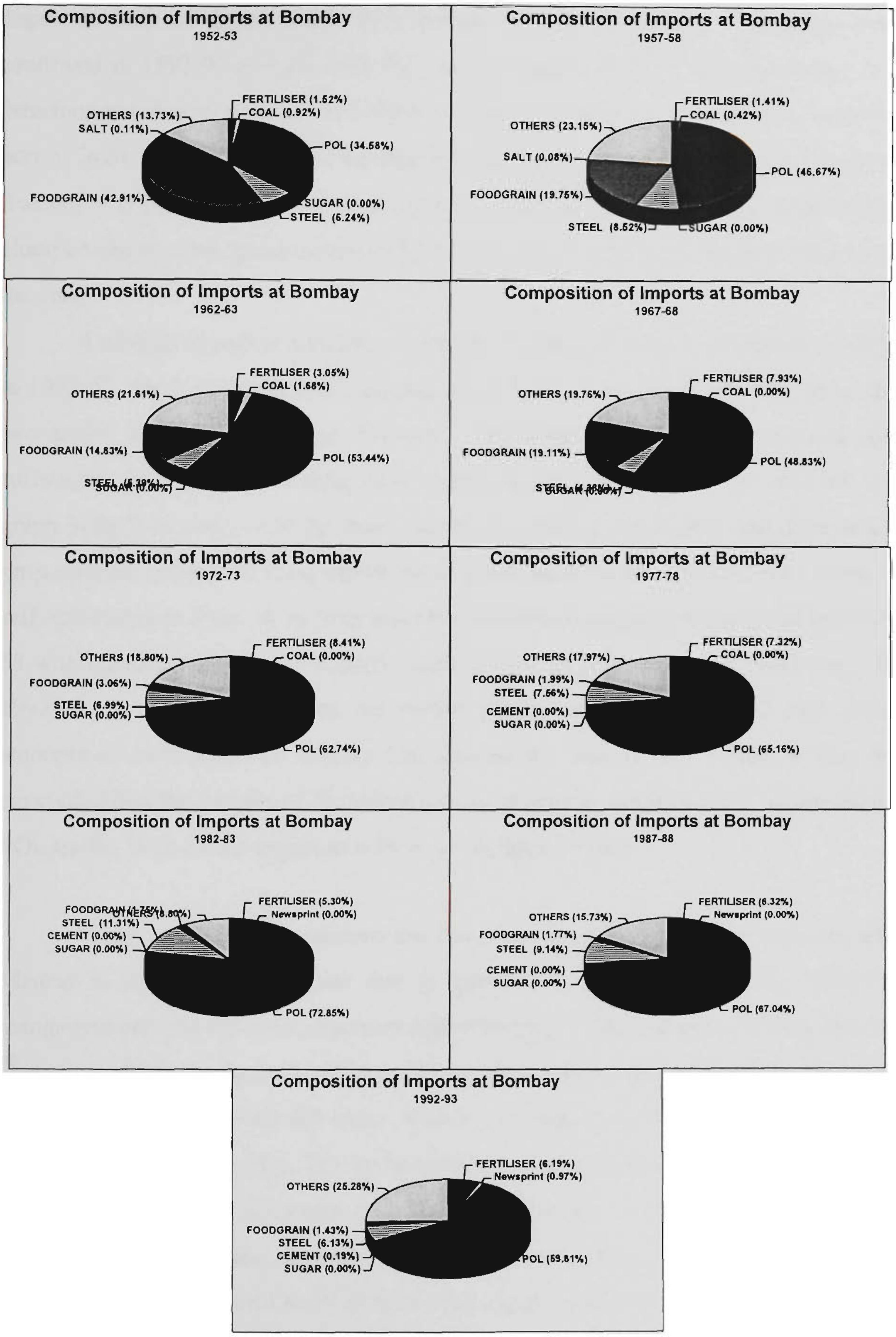


**Figure 2.14**

Source: Bombay Port Trust Administrative Report (various issues).

important item of export traffic followed by other general cargo. The same trend continued in 1992-93 as well, with POL accounting for 78.71% of export cargo. It is therefore possible to conclude that Bombay took over the mantle of 'leading exporting port of India' from Calcutta, on the strength of a single bulk commodity namely POL. Bombay's export performance was further supported by the group of commodities clumped under other general cargo which grew in terms of total actual tonnage over the years.

A similar impressive picture of growth is observed in case of imports as well. In 1952-53, the initial period of planning era in India, food grains and POL were the two major items of import at Bombay. The country had not yet attained self sufficiency in food, necessitating large scale import of food grains. In 1957-58, the graph in fig 2.14 shows that the share of POL increased considerably and there was a proportionate decline in the contribution of food grains as the nation moved towards self sufficiency in food. A more or less identical import composition is noted in 1967-68 with fertilisers slowly but steadily consolidating its position on the import list. In 1992-93, it was observed that the earlier pattern remained unaltered and small amounts of newsprint and cement had entered the import list. Thus, it may be concluded that the success of Bombay port was to a great extent, caused by largescale POL traffic, both on the export as well as on the import front.

Vizag, a port on the eastern sea face almost midway between Calcutta and Madras is the other major port that is considered in this analysis. In 1952-53, manganese ore was the most important export through Vizag claiming 69.74% of total exports as shown in fig.2.15. Vizag also exported other bulk commodities like iron ore and coal. In 1967-68 the share of iron ore rose from 10.19% in the previous period to a massive 61.53%. It may be noted that the massive rise in iron ore exports through Vizag almost coincides with the sharp decline in iron ore traffic through Calcutta indicating a clear diversion of traffic from Calcutta to Vizag. In 1972-73 the share of iron ore increased to 79.83% of total exports while the rest of the traffic was shared by manganese ore, POL, other general cargo and iron and steel and machinery. Vizag had clearly emerged as the major iron ore exporting port of India. In spite of the deep water subsidiary port of Haldia, this important item of traffic was entirely

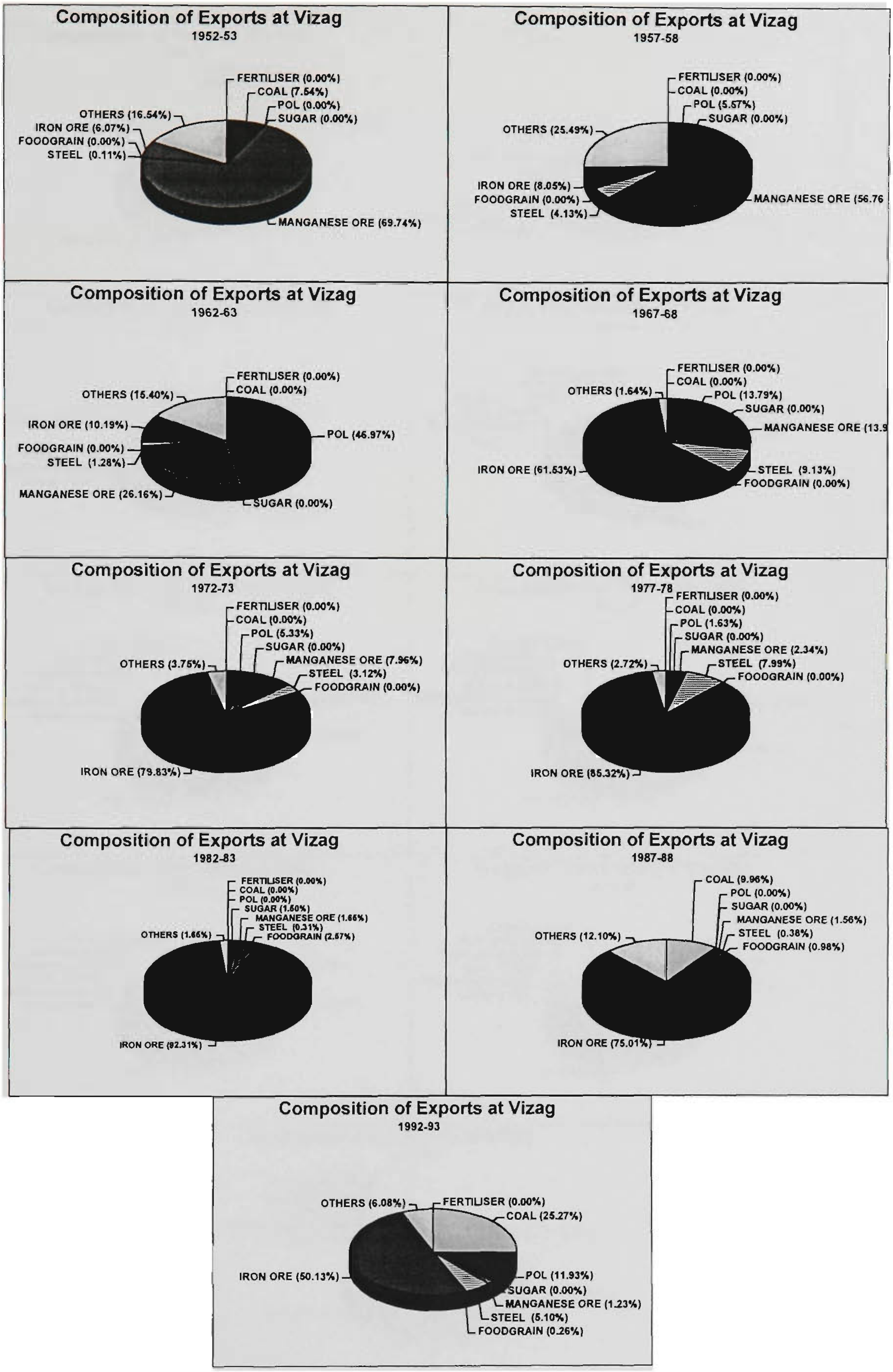


**Figure 2.15**

Source: Vizag Port Trust Administrative Report (various issues).

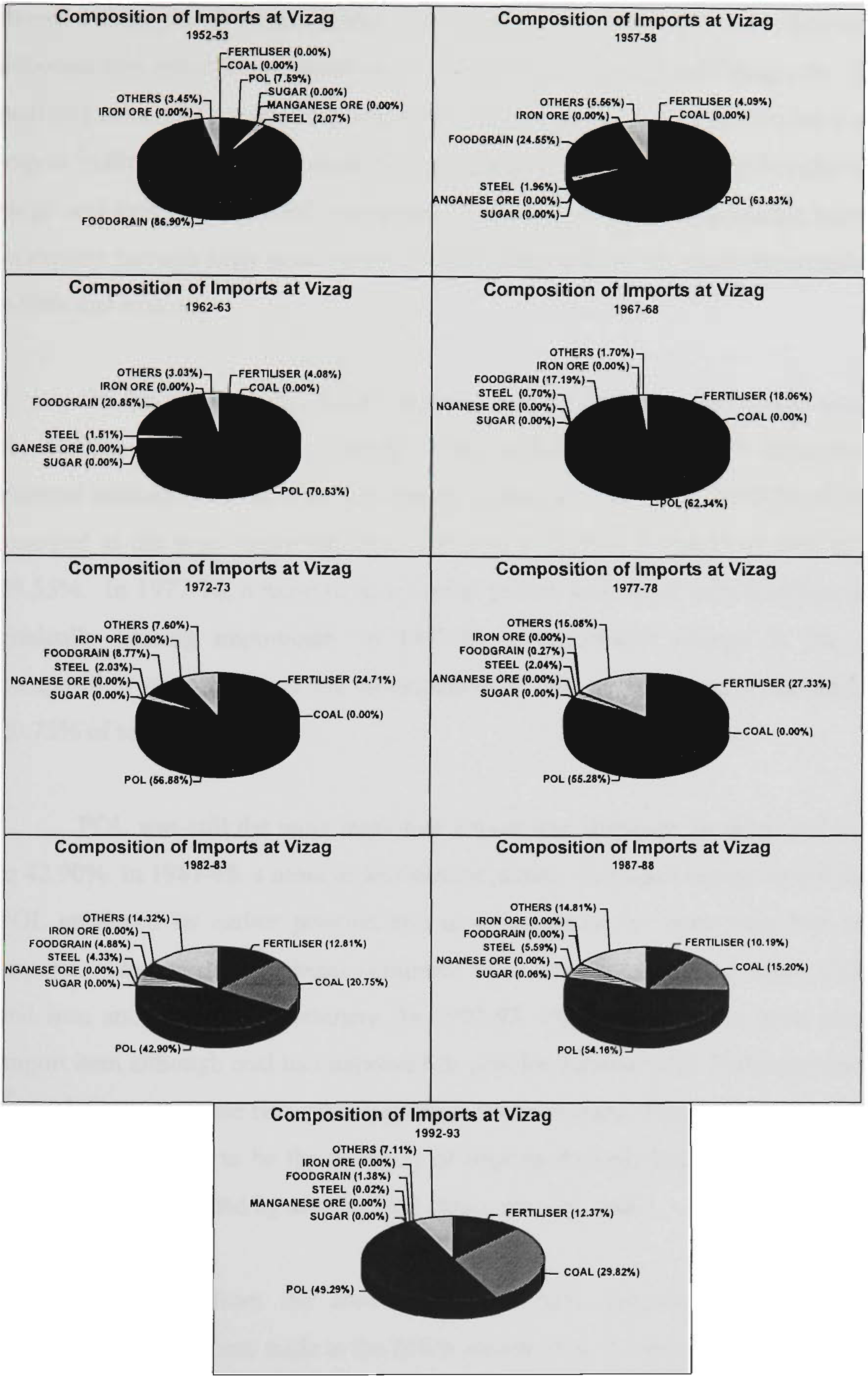


**Figure 2.16**

Source: Vizag Port Trust Administrative Report (various issues).

diverted from the Calcutta Haldia port complex. In 1992-93, it was observed that, although iron ore still accounted for more than half of total export cargo, the share of coal had enhanced considerably and it now contributed to more than a quarter of total export traffic. POL was yet another important item of trade followed by other general cargo and iron and steel and machinery. As always Vizag maintained her supremacy in exports through large scale exports of bulk commodities, the most important among which was iron ore.

On the imports side, it was observed that in 1952-53, food grains accounted for 86.90% of total imports through Vizag reflecting the nation's dependence on external sources for food. Fig 2.16 depicts a complete change in 1957-58, when POL emerged as the most important item of import at 63.83% followed by food grains at 24.55%. In 1977-78, a more or less similar pattern was noted with fertiliser imports gradually gaining importance. In 1982-83, a remarkable change in the import composition of Vizag was the introduction of coal in a big way, accounting for 20.75% of total imports.

POL was still the most important import item although its share had declined to 42.90%. In 1987-88, a more or less similar pattern continued except for the fact that POL enhanced its earlier position and now accounted for more than half of total imports. The other major items continued to be coal, other general cargo, fertilisers and iron and steel and machinery. In 1992-93, POL was still the most important import item although coal had improved its position substantially. Fertilisers and other general cargo were the two other important items of trade. Thus it may be concluded that POL continued to be the mainstay of imports through Vizag over the years and was later supplemented by another bulk cargo, namely, coal.

It is clear from the above discussion that, Calcutta made a significant contribution to maritime trade in the fifties especially in the field of exports. However, after the mid sixties, the performance of Calcutta declined considerably. Even in comparison to other major Indian ports, the performance of Calcutta has been dismal. Between 1928-29 to 1988-89, the average annual rate of growth of traffic at Calcutta port was 0.05% while that of other major ports was around 2%. In spite of the commissioning of the subsidiary port of Haldia, the situation had not improved much except for the large scale import of POL through Haldia. The entire iron ore traffic was diverted to other ports resulting in excessive idle capacity at Haldia. Ports like Bombay and Vizag flourished due to impressive trade in bulk commodities like POL and iron ore. The supply and demand conditions in the hinterland of Bombay necessitated the growth of traffic in new and diversified directions. On the other hand, Calcutta's traffic became bogged down by an over-dependence on traditional items of cargo like jute whose demand was flagging in the world market.

# CHAPTER 3

# THE CONCEPT OF SIMULATION MODELING



## 3.1 Introduction

According to Webster's Collegiate Dictionary, 'to simulate' is to feign, to assume the appearance or character of, to attain the essence of, without the reality. In a general sense, simulation is defined as an act or process that gives the appearance or the effect of some part of reality. The history of simulation dates back about 5000 years to Chinese war games called weich'i and continued through to 1780 when the Prussians used such war games for training the army. According to Render and Stair (1994), major military powers all over the world have used war games to test military strategies under simulated environments. During World War II, John Von Neumann developed a quantitative technique called Monte Carlo Simulation to solve problems in physics which were too complicated for physical models. He was working with neutrons and used the technique of simulation to analyse the complex nature of the problem. The random nature of the outcomes suggested the use of a roulette wheel in dealing with probabilities, hence the name. Because of this gaming nature, he called it the Monte Carlo model of studying the laws of chance. Thereafter, with the advent of computers, the use of simulation became more prolific to obtain solutions to real world complexities. Render and Stair (1994) opined that simulation was the most flexible and fascinating of all quantitative techniques where it was possible to imitate the real world with the help of mathematical models, study the various properties and operating characteristics and thereby draw conclusions and make decisions. They, however, pointed out that simulation was an expensive technique, did not generate optimal solutions as in Linear Programming and that each model was unique and not easily transferable.

Naylor (1971) defined simulation as a 'numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a business or economic system (or some component thereof) over extended periods of time'. With the advancement of computing power and simulation software, the usage of this powerful technique has gathered considerable momentum. Neelamkavil (1987) opines that software development relating to model description, analysis and presentation, availability of inexpensive computing facilities and the introduction of colour graphics have led to the widespread usage of simulation for problem-solving in several disciplines.

According to Pritsker (1986), simulation models can be useful at four levels:

a) as an explanatory device to define a system or a problem;
b) as an analyst determining the elements and components of the problem;
c) as a design assessor to evaluate alternative strategies; and
d) as a predictor to forecast future plans and developments.

## 3.2 Definitions of Related Terminology

### *3.2.1 System*

The concept of a system is central to any simulation study. According to Schmidt and Taylor (1970), a system is a collection of entities that interact toward the accomplishment of some logical end. A system may be business, economic, social, biological, chemical, physical or any combination or component thereof. The term is defined in the dictionary as an orderly collection of logically related principles, facts or objects. When used in the context of simulation, a system generally refers to a collection of objects with a well defined set of interactions amongst them in order to achieve a common goal. How a particular system will be defined, is determined by the objective of the study or the focus of attention. In order to understand the scope of a system, its content and boundaries must be defined. The boundary of a system is generally defined in terms of cause and effect rather than physically. Objects that lie outside the boundary of the system but can affect it somehow, constitute the environment of the system. The state of a system is defined as a particular collection of variables necessary to describe a system at any particular point of time relative to the objective of study (Law and Kelton 1991). The inclusion of the concept of time in defining the state of the system implies that the state of the system changes with time. The process or event that prompts this change is called an activity. Activities occurring within a system are termed endogenous activities while those occurring in the environment of the system are called exogenous activities. A system which has no exogenous activity is called a closed system. Otherwise, it is called an open system. In any system, the term entity is used to denote the object of interest in the system while an attribute is the property of the entity.

### *3.2.2 Classification of Systems*

**a) Continuous and discrete systems**

This classification is interlinked with the nature or behaviour of changes with respect to time in the system state. A system is termed continuous if its state changes continuously with time. This will include variables that can take any real value within a specified interval, e.g. movement of a ship through water. Models of continuous systems are often written in terms of derivatives of the dependent variables or state variables. Equations of this form involving derivatives of the state variables are called differential equations. Discrete systems are those where the changes in state occur in finite quantities and include variables that can assume particular values from among a finite set of alternatives. Thus, a discrete system is one in which the state variables change only at finite number of points over time, e.g. arrival of ships to a dock. Few systems are wholly continuous or discrete. However, the predominant nature of the changes in a system determines the type of the system. Some systems may possess qualities of both discrete and continuous systems and are called combined systems.

**b) Stochastic and deterministic systems**

An activity is said to be stochastic when its outcome may vary randomly over various possibilities, e.g. tossing a coin. A stochastic system contains an element of randomness in its transition from one state to another. A simulation system will be stochastic if it contains one or more random variables. A simulation model of a port would treat the interarrival time and service time of ships as random variables, each with their own probability distribution. Thus the concept of probability is intricately linked with the concept of stochastic simulation models. On the other hand, in a deterministic system, there is no element of chance or randomness. When the outcome of an activity can be completely described in terms of its input and initial state, the activity is said to be deterministic, e.g. pressing the keys of a typewriter (Gordon 1978). Thus, a deterministic system is one in which, the new state of the system is completely determined by the previous state and the interlinking activity. In this situation, a system evolves in a totally deterministic manner from one state to another in response to a given activity.

### *3.2.3 Model*

A model is defined as a precise body of information about a system collected for the purpose of studying the system. According to Neelamkavil (1987), 'A model is a simplified representation of a system (or process or theory) intended to enhance our ability to understand, predict, and possibly control the behaviour of the system'. In order to study the intricacies of a system, one often has to make a set of assumptions which often take the form of mathematical or logical relationships. To develop such an abstraction, the modeller must decide on the elements to be included in the model solely determined by the objective of study. According to Pritsker (1986), the first step is to identify the purpose of modeling, based on which, the boundaries of the system and the level of detail are ascertained. The desired performance measures and alternatives to be evaluated are then incorporated in the model and the entire process is carried out iteratively. The technique for successful development of a simulation model is to begin with a simplistic modeling structure which is embellished in an evolutionary manner to meet the objectives. The final product must be a valid representation of reality in order to enable the planner to effectively use it to make the same decisions about the system, that would be made if it were feasible to experiment with the system itself (Law and Kelton 1991).

Model derivation involves two main tasks:

1. Establishing the structure by determining the system boundary, identification of entities, attributes and activities.
2. Supplying the data which provide the values of the attributes and define the relationships involved in the various activities.

## 3.3 The Process of Simulation Modeling

The process of simulation modeling consists of the following stages as outlined by Pritsker (1986).

### *3.3.1 Problem Formulation*

The very first task in simulation modeling is a clear and concise definition of the problem at hand and an explicit statement of the purpose of study. As mentioned earlier, simulation modeling is an evolutionary activity and as a result, problem identification and definition is a continuous process. As additional insight into the problem is gained and new issues become of interest, the problem is reformulated.

### *3.3.2 Model Building*

The model of a system should consist of a static and dynamic description. The former outlines the elements of the system and their characteristics. The latter, on the other hand, defines the way in which these elements interact with one another and cause the state of the system to change over time. A modeller must understand both the static and the dynamic facets of the system and be able to extract the essence of the system in the form of a model, without including unnecessary detail. The level of detail chosen in the model will be determined by the purpose for which the model is designed. The entire description of the system may be organised in a simplistic way in the form of a series of blocks. Each block describes a part of the system that depends upon a few input variables and results in some output variables. A flow chart is often the most convenient way to depict the relationship among variables.

### *3.3.3 Data Acquisition*

The model formulation phase will generate data input requirements. The data will provide the values that the model attributes may have and also define the relationships involved in the various activities. Some of the data may be readily available while others may have to be collected and processed. Data collection and processing is a very important and laborious task involved in simulation modeling.

One of the commonly encountered problems of simulation modeling is that few real world systems exhibit constant predictable behaviour. In most cases, the process of arrival and departure of an entity is random (Taha 1988). Despite this inherent unpredictability, some form of abstraction is required to analyse the real situation. Thus, the only way to represent the element of randomness is by using probability distributions to describe the variables under scrutiny. Once the distribution is identified, statistical theory provides the means for obtaining random samples based on the use of $(0,1)$ random numbers. These random samples are then used to pinpoint the future occurrence of an event. The empirical distributions based upon actual observations must be processed and hypothesised before they can be used as data inputs in the model. The most important aspect is to pick the right distribution that would best fit the empirical data. After careful consideration of all related aspects when a theoretical distribution is chosen, its parameters are estimated and a goodness of fit test is made. Thus we find that data inputs are initially hypothesised before the model is translated to a computer conceivable form.

### *3.3.4 Model Translation*

Once a model has been developed and initial estimates have been made to hypothesise the input data, one has to translate the model into a computer acceptable form. A simulation model can be programmed using a general purpose language like FORTRAN, BASIC, COBOL, ALGOL, PASCAL or PL/1. As opposed to these, there are some special purpose simulation languages like GPSS, SIMSCRIPT, GASP IV, SIMULA, SIMNET, SIMAN and SLAM. Although the latter group is fast gaining popularity amongst simulation modelers, the former still has some advantages which have been summarised by Law and Kelton (1991) as follows:

a) The general purpose languages are commonly used and very popular. Most modellers feel more comfortable in developing a simulation model in a language they are familiar with.
b) The widespread availability of the general purpose languages is an added advantage since, a special purpose simulation language may not be accessible to smaller computer installations.
c) An efficiently written simulation program in FORTRAN may require less time than its counterpart in SIMNET. This is because the special purpose languages are designed to model a wide variety of complex systems whereas a FORTRAN program can be easily tailored to a specific situation.
d) General purpose languages sometimes allow greater programming flexibility to the modeller compared to certain intricate simulation languages. It has been pointed out that complicated numerical calculations are not easy in GPSS.

However, Law and Kelton (1991) also point out the distinct advantages of using a special purpose simulation language. Such simulation languages automatically provide almost all the features required in programming a simulation model. They are listed below.

a) *Generating random numbers*: Random numbers are used to generate random variables from a specified distribution. There are at least three methods for obtaining random numbers for computer simulation. The first method is to read a table of random numbers into the computer and then treat the random numbers as data for the simulation exercise. A second method is to use a physical device such as the vacuum tube to generate random noise. The third and most preferred method is to employ a recursive equation which generates the (i+1)th random number from previous random numbers. Since the sequence of random numbers is produced deterministically by an equation, they are not truly random and are known as pseudo random numbers. These are essential elements of a simulation exercise and are provided automatically by a special purpose simulation language.

b) *Generating random variables from a specified distribution*: A function which assigns a real number to each outcome in the sample space is called a random variable. Discrete random variables are those that take on a finite set of values while continuous random variables take on a continuum of values. There is no inherent capability in any of the general purpose languages to generate random variates. Computer installations may have a library routine which includes a function that can generate standard uniform variates. If the programmer uses these standard functions he will still have to code the routine to transform the variate to a suitable theoretical distribution. This is easily handled by a special purpose simulation language.

c) *Advancing simulated time*: Management of simulation time is easily done in the special purpose languages. A counter variable called a clock is initiated at the beginning of a simulation run. This clock, according to Taha (1988), is designed to initiate the action of collecting observations at the moment changes take place in a system. The clock is generally set to zero at the beginning of a simulation exercise and subsequently indicates how many units of simulated time have passed since the beginning of simulation. The term simulation time generally means the indicated clock time and not the time that a computer has taken to carry out the simulation. There are two basic methods which exist for the update of time in simulation models. One is to advance the simulation clock to the time at which the next event is due to occur. This is called the event oriented approach and is most commonly used in discrete simulation. In this case, the simulation clock is initialised to zero and the times of occurrence of future events are determined. The simulation clock is then updated to the most imminent future event and the process of advancing the simulation clock from the most imminent event to the next continues until some predetermined stopping condition is satisfied. The other approach is to advance the simulation clock by small, usually uniform intervals of time and determine at each interval point whether an event is due to occur at that time point. This is called the interval oriented or the time slice approach and is generally used in continuous simulation. In both approaches the basic mechanism is the same, i.e. to look ahead in time slices or in events. The data must be updated in an appropriate manner, tables of results must be maintained and appropriate output must be obtained. It is then that a decision will have to be made – whether to conclude the simulation or go through the exercise all over again. This is done most efficiently by a special purpose simulation language.

d) *Determining the next event from the event list and passing control to the appropriate block of code*: In a simulation model, entities with some common property are often grouped together in lists, files or sets. Many complex real world simulations require a very large number of lists or records, each of which may contain a large number of attributes. The special purpose simulation languages have a built-in algorithm which permits efficient storage of the event list and passing control to the appropriate block of code whenever required which have a very significant impact on the model execution time.

e) *Detecting error conditions*: Special purpose simulation languages provide automatic error detection facilities. Since fewer lines are written, chances of error are also slimmer. On the other hand, in a general purpose language the programmer has to make continuous checks for errors in the coded simulation programme which is tedious and time consuming.

Thus we may conclude that, although there are advantages of using both types of languages, the usage of special purpose simulation language has some distinct benefits over the general purpose languages. In addition to the savings in programming time, a special purpose simulation language assists the programmer in model formulation by providing a wide range of tools which greatly reduce intricate programming efforts.

### *3.3.5 Verification*

The verification task consists of determining that the translated model executes on the computer as the modeller intended. According to Fishman and Kiviat (1967), verification is determining whether a simulation model performs as intended, i.e. debugging the computer program. Law and Kelton (1991) have identified different techniques for verifying a simulation model:

a) While verifying and debugging a simulation model one should write and debug the computer program in manageable modules or subprograms. It is always better to start with a simple model and verify it at every step while introducing complexities in the model rather than handle all the complexities at the very outset.
b) It is always better for proper validation of a computer program, to have more than one person read the computer program for checking possible errors that may have escaped the notice of the original programmer. This idea is formally called a 'structured walk through' in certain organisations.
c) Another powerful technique that can be utilised to verify a simulation model is by using the 'trace' option. In a trace, the state of the simulated system is printed immediately after the occurrence of an event in order to check whether the program is operating as intended. The major special purpose simulation languages like GASP, GPSS, SIMSCRIPT and SLAM II provide an inbuilt trace option to the modeller.
d) In order to determine whether a simulation model is performing as intended, the model should be run under simplifying assumptions for which the model's true characteristics may be easily identifiable.
e) One may run the model under different settings of the input parameter and then check if the outputs are reasonable.
f) In certain cases, it may be useful to display the simulation output on a graphics terminal as the simulation progresses. This would enable the modeller to check undetected errors.
g) The sample mean and variance for each input probability distribution may be compared with the historical mean and variance to check whether values are being correctly generated from probability distributions.

h) A simulation package may be used to shorten the program which aids verification.

### *3.3.6 Validation*

The validation task consists of determining whether the simulation model is a reasonable approximation of reality. This concept is quite distinct from verification. When a computer program is verified, it is actually checked to see whether it performs as the modeller intended. However, a verified simulation model may be an invalid one if it does not replicate the real system closely enough. Validation of a simulation is quite an arduous task and there is considerable debate among the experts as to what actually ensures validation. Law and Kelton (1991) outline six general perspectives for validation.

a) A proper validation should ensure that the model which is developed, can actually be of use to the decision maker to make the same decisions in a more feasible and cost effective way, than that would be made on the system itself.
b) A simulation model is only an approximation of the real system and so, one should rather be concerned with the degree to which the model agrees with the system in a cost effective way rather than strive for the ultimate in validation.
c) A simulation model must have a clearly defined objective or purpose. A model may be valid for a particular purpose or objective but not for another.
d) A simulation model may be validated relative to a specified set of criteria that will actually be relevant for decision making.
e) Validation is a continuous process which should be inbuilt at every stage of the model building activity. It is ideally not an exercise that should be attempted close to the end of modeling, time and resources permitting.
f) The use of formal statistical techniques is a part of the total validation process. In most cases validation is done in a subjective manner as most classical statistical techniques cannot be directly applied due to the nature of the output data.
g) The model assumptions must be updated regularly and properly documented at every stage in order to ease the process of validation.
h) Validation is easier if the real system already exists and the model is not too complex and intricate.

Naylor and Finger (1967) had, earlier on, outlined a three step process to validate a simulation model. Their recommendations were later augmented by Law and Kelton (1991) which is discussed below.

- Development of a model with high face validity.

The very first step towards validation is to build a model, which seems reasonable to those who have a clear understanding of the system under study. The modeller must consider the following for a comprehensive knowledge of all the existing information.

i) *Interaction with experts*: The reaction of experts may help to pinpoint flaws in the model and correct doubtful results. Since a simulation model is not a theoretical exercise in abstraction, the modeller should always interact with people who have a clear knowledge of the system.

ii) *Consideration of existing theory*: With regard to the arrival pattern of entities to a service station, existing theory tells us that, most likely, the interarrival pattern of the entities will be exponentially distributed while their arrival pattern will follow the Poisson process. This prior knowledge would help towards building a more valid model.

iii) *Observation of the existing system*: It is always important to closely study the system under scrutiny in order to build a valid representation of the system. Care must be taken during data collection so that the data is representative, accurate and follows the right format.

iv) *General knowledge about the system under study and similar studies*: The modeller must have a comprehensive idea about the particular problem and similar problems that have been simulated. Relevant validated results from similar models should be analysed in order to avoid duplication of modeling effort.

v) *Intuition of the modeller*: The intuition of the modeller is crucial to decide which aspect of the model will behave in what manner under different circumstances. Such hypothesization about the behaviour of the model under varying situations will be an added advantage during validation.

Thus we find that validity may be built into the simulation throughout its conceptual process and may be enhanced by expert reaction to the purpose, scope and output of the model. Perhaps the easiest way to validity is through a conscious development effort, keeping its objective firmly in mind. According to Law and Kelton (1991), it is imperative that modellers should have a close interaction with the users of the simulation model, who will later have the last say in the fruitful application of the model. They are more likely to accept as valid, a simulation model with which they have been associated throughout the developmental process, rather than one which is thrust upon them after completion.

- *Empirical testing of the model assumptions.* Law and Kelton (1991) illustrate the issue of empirical testing with the aid of examples. If, as model inputs, some theoretical probability distribution is fitted to the observed data, then it may be tested with the aid of statistical testing procedures such as the Chi-Square test or the Kolmogorov-Smirnov goodness of fit tests. The second stage of empirical testing involves sensitivity analysis. This technique helps to determine how much the model output will vary due to a small change in an input parameter. If the output is extremely sensitive to any particular parameter, then a better estimate of it should be obtained for improved validation.

- *Determining the representative capacity of simulation output.* The most important check for validation involves the comparison of simulation run outputs with a standard if available. Thus, by far, the most definitive test for validity of a simulation model is to ascertain that the model output closely resembles that of the real system. There exists a number of statistical tests that may be used for comparing the two outputs (Shannon 1975). According to Law and Kelton (1991), this is a difficult task as the output processes of real world systems and simulations are nonstationary, i.e. the distributions of successive observations change over time and sometimes autocorrelated. Present statistical methodology can at best be used for comparisons to modify parts of the model rather than draw overall conclusions about validation. Hence one can question the accuracy of using hypothesis tests with confidence intervals as a tool for validation. Law and Kelton (1991) opine that a more judicious recourse would be to check whether the differences between the system and the model are significant enough to affect any conclusions that may be derived from the model. Turing Test may be undertaken to compare the output data from the model to its corresponding counterpart from the system. Experts on the system are required to check sets of model output data and system output data and identify them. If they can differentiate between the two, then their explanation regarding how they were able to do so is used to improve the validity of the model.

The validity of a model is also of crucial importance in determining whether the model will be able to predict future behaviour of the system under study. Validation is a crucial issue in such cases as systems evolve over time. Sometimes one uses historical input data to build a model and compares it with the corresponding historical output data for validation purposes. An alternative procedure is to use a completely independent set of historical input and output data. The simulation model may be developed using the first set of input data and the model results may be validated by comparison with the second set of output data. There exists a number of ways in which observations from a real world system and the output data from a corresponding simulation model may be compared. The classical statistical tests are one approach of doing this. These tests include the t test, Mann Whitney test, Chi-Square test, Kolmogorov Smirnov test, etc. (Breiman 1973). However, due to the intrinsic nonstationary, autocorrelated characteristics of real life systems and simulation models, all these tests lead to comparison problems. Law and Kelton (1991) point out inspection, confidence interval and time-series approaches to address this problem of comparison.

### *3.3.7 Strategic and Tactical Planning*

Strategic planning involves the development of an experimental design in order to explain the link between the simulation response and the controllable variables. On the other hand, according to Pritsker (1986), tactical planning indicates how each simulation should be conducted in order to skim the maximum amount of information from the available data. The two crucial issues in tactical planning are the starting conditions of the simulation runs and methods for reducing the variance of the mean response.

### *3.3.8 Experimentation*

This is the stage of simulation involving the execution of the simulation model to obtain output values. In the context of simulation, experimental design provides a guideline of determining which system variables to simulate so that the desired information can be made available at minimum cost. However, according to Law and Kelton (1991), the problem of optimisation in simulation is an extremely difficult one as it combines features of deterministic mathematical programming and statistical estimation. The inherent randomness of simulation output further complicates this difficult task. Thus experimentation becomes a crucial task of simulation and utmost caution must be exercised to conduct experiments on a simulation model in order to obtain accurate results.

### *3.3.9 Analysis of Results*

This is the process of analysing simulation output to draw inferences and make recommendations for problem resolution. Two distinct aspects of simulation output analysis are the accuracy and the reliability of the sample values obtained. The output obtained after just a single simulation run of arbitrary length may not ideally represent the system characteristics under scrutiny. The variance of a sample mean is a derived measure of result reliability that can be obtained from replications of simulation runs. Variance reduction techniques are methods that attempt to reduce the variance of the sample mean through the setting of special experimental conditions or through the usage of prior information about the system. There exists a number of variance reduction techniques in existing simulation literature such as antithetic sampling, usage of common random number streams, prior information, application of control variates, stratified sampling procedures, etc. (Bratley et al. 1987). It is generally recommended that, the reliability of simulation outputs should be based on a batch or cycle averages rather than independent sample values.

Thus, we find that simulations which are generally driven by random inputs will produce random outputs. As a result, suitable statistical techniques should be applied to simulation output if the results are to be meaningfully analysed, interpreted and utilised for policy prescriptions. However, the financial burden of making such output analyses is often quite considerable and therefore must be judiciously planned.

### *3.3.10 Implementation and Documentation*

The final stage in the simulation model development is the implementation of results and the documentation of the simulation model for subsequent usage. A simulation exercise can only be considered to be complete if its recommendations are effectively utilised in the decision making process. This is achieved more easily if the model builder and the user have worked in close coordination throughout the model development process. Otherwise, it will be difficult for the model to be implemented in spite of all its sophistication, elegance and validity.

## 3.4 Advantages and Disadvantages of Simulation

Adkins and Pooch (1977) have listed the following advantages and disadvantages of simulation technique:

- Advantages

a) Simulation permits controlled experimentation. An experiment can be replicated a number of times with parametric changes in order to test the behaviour of the system under varying conditions.

b) Simulation allows time compression since operations which would normally require an immense amount of time on the real system can be done in minutes on a high speed computer.

c) Simulation permits detailed sensitivity analysis by manipulation of input variables.

d) Simulation does not disturb the real system which is a tremendous advantage as it is often impossible to carry out experiments on a functioning, online system.

e) Simulation is an effective training tool. Simulators are in use in training institutes such as pilot training where the trainees are shown practical application without actually involving the real system.

f) Simulation provides operational insight and makes the management of any real life system more efficient.

- Disadvantages

g) A simulation model may tend to be too expensive in terms of computer time and trained manpower. This can be reduced through a clear understanding of the system and effective model design.

h) The development of a good simulation model may require a lot of time which the modeller must be ready to spend.

i) Certain hidden flaws may go undetected during the validation process and cause the model to diverge significantly from reality. The analyst is sometimes not sure of the validity of the simulation model and in many cases validity is assumed unless the contrary is shown. This may lead to erroneous results. If a model is not a valid representation of reality, the entire simulation exercise will be futile.

j) The model parameters may be difficult to initialise requiring extensive time in collection, analysis and interpretation.

k) Availability of high speed computers and extensive field studies are essential for the execution of an intricate simulation model.

The technique of simulation has been popularly used to study a wide variety of systems ranging from air traffic control to financial forecasting. The inherent flexibility of this modeling technique and the continuing development of high level simulation languages have been instrumental towards its immense popularity. Simulation has often been used to reproduce marine port systems. This is essential to estimate the structure of the port, under varying operational conditions. Such studies are crucial to the planning of a port system and it is important to determine, how, various operational procedures and technical standards will influence the port's performance. The technique of simulation, if fruitfully applied, can be instrumental in achieving this goal.

# CHAPTER 4

# THE SIMULATION MODEL SPECIFICATIONS



## 4.1 Introduction

In this chapter, the technique of simulation has been used for constructing the model of a port system. Here, the system boundary has been defined and the area of the modeling exercise is identified. The scope and objective of the model, the rationale behind the choice of the technique and the applicability of simulation modeling in port situations is discussed. Thereafter, a network simulation model is constructed to estimate the operational efficiency of a riverine port.

## 4.2 Definition of System Boundary

At the very outset, the boundary of the port system needs to be determined. The boundary is best defined in terms of cause and effect relationships established by the purpose of the model. Entities that remain outside the boundary of the system but of the present port simulation model is outlined in Figure 4.1. In this exercise, we have only considered the ship-port interface of the port system. The inland transportation network, the storage, the demand and supply situation of the hinterland, the paperwork of clearing agents and customs formalities are undoubtedly, essential links in the maritime transport chain. However, in the level of detail chosen in the present study, they may be considered as adjuncts to the main activity of the port, which is ship handling.

## 4.3 The Objective of the Simulation Model

The objective for the development of the present simulation model is to estimate the operational efficiency of a port. In order to assess the efficiency of a port, certain efficiency parameters must be identified which should be easily computable, comparable and universally acceptable. Since time is a crucial factor in sea transport costs, the time that a ship spends in a port is of great concern to all shipping interests. It has been observed (UNCTAD 1969) that port authorities and shipping companies all over the world are extremely conscious of the need for quick turnaround time of ships in port, as the profits earned during a voyage may be entirely devoured by delays at port.

In the present study, the turnaround time of ships calling at a port has been considered to be the efficiency parameter of the port and simulation is the tool for estimating that efficiency parameter. We therefore attempt to estimate the turnaround time of ships visiting a riverine port using the technique of simulation modeling.

## 4.4 Choice of Technique

If the relationships that compose the model were straightforward and simplistic, it would have been possible to use standard mathematical methods and arrive at analytical solutions. However, most real world systems like a port are too complex to allow realistic models to be evaluated analytically. The two commonly used techniques to model port systems which are essentially waiting line systems, are queuing and simulation. The concept of queues is a direct consequence of the element of randomness in the arrival process and servicing of arriving entities.

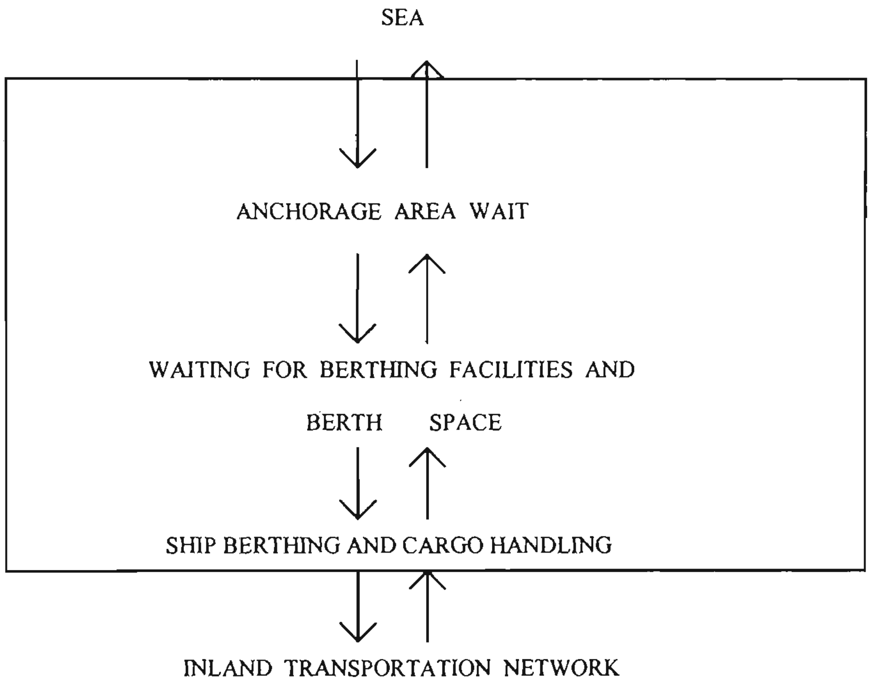


**Figure 4.1**

Generally, there is virtually no prior knowledge of an entity's arrival and service time which results in some form of waiting till a resource is available. The objective behind the study of waiting lines or queues under random conditions is to secure some characteristics or guidelines about the performance of the system. These performance indicators are then used to select the optimum level of service that may be offered to waiting entities (Solomon 1983).

A port is an example of a queuing situation where randomly arriving ships wait their turn before being serviced by available port resources. Since the mid 1960s, many port studies have been undertaken using the traditional queuing model for assessing port problems (eg. Plumlee 1966; Edmon 1975). In such models, ship arrivals and port service times are expressed in terms of probability distributions. Here, both interarrival time of ships and service time are assumed to follow negative exponential distribution in the multiple server system. However, such types of queuing models are limited by restrictive assumptions which limit their scope of application. Only the relatively simpler systems have been represented successfully using this technique. Hwang (1978) points out a number of complicating situations, when for one reason or another, the traditional queuing model becomes infeasible and simulation becomes the chosen option.

In recent times, the simulation approach to queuing problems has largely replaced the traditional queuing model in port situations as it has a number of advantages to offer, the most important being its inherent flexibility. The technique of computer simulation in understanding a port problem has immense possibilities and enables the modeller to study the port system under varying operational conditions. Moreover, the advent of special purpose simulation languages have considerably eased the task of modeling.

Over the years, network simulation modeling has been widely used by planners and decision makers to solve complex real world problems. A network model is a graphical representation of the problem situation involving a set of nodes connected by branches. A branch represents an activity that involves a processing time or delay. Nodes are placed before and after activities and are used to represent decision points or queues. The simulation procedure involves the generation of entities and their processing through the network until no further routing can be performed. Several network simulation languages namely, PERT, CPM, Q-GERT and SLAM II have since been developed and applied to a wide range of issues. Network modeling primarily consists of four stages (Pritsker and Sigal 1983). At first, the system under study is disintegrated into its constituent elements, which are then analysed and described. Thereafter, they are integrated into a network model of the system and lastly, the system's performance is assessed through the simulation of the network model.

In this network modeling exercise, the logic associated with the ship handling process, from the arrival of ships to the port until departure, is depicted in the form of a flow chart. Special considerations have been made to incorporate the features of a riverine port which involve long river passages both inward and outward. The model consists of a SLAM II network section with subroutine insertions in FORTRAN used primarily to include the various intricacies of the port.

## 4.5 The Port Sector and Operational Efficiency

The port and shipping sector plays a key role in the economic well being of a country. The need for proper understanding of the port situation is even more critical in case of a developing country like India as this is one sector where global infrastructural standards have to be met in order to adapt to modern transportation technologies. In this context, a well developed and properly executed port simulation model can be of immense help to the port planner who has to make judicious allocations of scarce resources among alternative uses.

The present simulation model estimates the turnaround time of ships calling at a port, given the port's resources and the arrival pattern of ships. The model is designed to impart information regarding the utilisation rates of the various resources and is able to indicate quantitatively, which of the port's resources should be altered and if so, to what extent. Once the model is verified and validated, the efficiency of the port can be estimated and evaluated under varying operational and physical conditions.

The UNCTAD (1969) manual observes that, 'From the point of view of the shipowners and hence the port authorities in trying to judge how good a service is given to ships, the total turnaround time of ships in port is the primary indicator - as well as its components, waiting time and ships time at berth'. The turnaround time is the time that a ship spends from arrival at the reporting station to departure from the reporting station. A reporting station is the place where an incoming ship anchors before actual berthing in order to avoid congestion inside the berthing area, should it be full already. In the case of riverine ports like Calcutta and Haldia which require long stretches of river passage, the turnaround time may be said to comprise the following components:

1) Waiting time at the reporting station.
2) Inward pilotage time or the time required by the ship to travel from the reporting station to the berth.
3) Service time or the time that a ship spends at berth. This again, may have two components:

i) Net working time or the time taken to perform actual loading unloading activities at berth

ii) Idle time at berth or the time that a ship spends at berth without working.

4) Outward pilotage time or the time required by the ship to travel from berth back to the reporting station during departure.

## 4.6. Basic Model Structure

As noted above, the ship-port interface of a port system can be compared to a queuing problem where the arriving ships or entities wait in queue for the service facilities offered by the port. When the entire processing is completed, the entity departs from the system.

The logic associated with the port simulation model is as follows. Once the first ship arrives at the system, the simulation clock is activated. The simulation clock is a variable in the simulation model which gives the current value of simulated time. In the present network model, the 'next event time advance mechanism' is used. Here, the simulation clock is first initialised to zero and then advanced to the time of occurrence of the most imminent event and so on. Then, the next arrival is scheduled in order to keep up a steady flow of ship arrivals conforming to the actual pattern of arrival at the port. How the ship, which has just arrived as well as those arriving subsequently will act, depends on the existing state of the system. This is defined by the status of the various service facilities such as the river, berths, river pilots, harbour pilots, dock pilots, river tugs and dock tugs.

Suppose, no berth is available for the arriving ship. In that case, it will have to wait in a queue until a berth is free and is allocated to it. The same logic will hold good for all the ports resources or service facilities. The queues for the service facilities are managed on a first come first serve basis. Whenever a free resource is available, the ship that has been waiting the longest will be placed in its service and the status of that resource will be set to busy. The end of service event will be scheduled to occur at the current simulation time plus the time taken by the server in service. When an end of service event occurs, the status of the server is again set to free and the ship moves on to its next activity. When the ship completes all its activities chronologically, it departs from the system and the time of its departure is noted by the simulation clock giving the ships stay time or turnaround time in port. Interval time statistics are collected at suitable junctures to give the various time components of total turnaround time. After a ship completes a service activity, a check is made to see if any other ship is waiting to be served. If there is one, then a free server is assigned to it, the state of the server is set to busy and the simulation continues as before. The process of advancing the simulation clock from one event time to another is continued until eventually some pre-specified stopping condition is satisfied.

Once the problem statement and the basic logic of the model is clearly outlined, the entire port system under consideration can be represented in terms of entities which flow through a network of nodes and activities. The initial model development is done by using graphic symbols which are later translated into computer comprehensible statement form.

At the level of detail chosen in this model, we can identify the following operational procedures:

1) Specification of port resources
2) Generation of arrival time and characteristic of ship arrival
3) Assignment of ship attributes
4) Initialisation
5) Allocation of berth for arrival
6) Allocation of river pilot for arrival
7) Check for suitable riverine conditions for entry
8) River inpilotage
9) Allocation of harbour pilot and river tugs for arrival
10) Allocation of dock pilot and dock tugs for arrival
11) Cargo handling activities
12) Check for suitable riverine conditions for exit
13) Allocation of dock pilot and dock tugs for departure
14) Allocation of harbour pilot and river tugs for departure

15) Allocation of river pilot for departure
16) Ship departure from port system

Figure 4.2 gives a flow chart of the events generated by a ship arrival. The first step while tabulating the data was to classify the ships according to size, in terms of their full load draught requirement as this criterion was of crucial importance in a riverine port situation prone to siltation. The ship's draught is the vertical distance between the water level at which she floats and the bottom of the vessel, i.e. the submerged part of the ship. Full load draught of a ship is the draught required when the ship is fully loaded. Then the various characteristics for each ship type was assigned by fitting probability distributions to take into account the inherent randomness of the system. Actual data was collected on the interarrival time, service time and idle time of ships and this data was used to specify the various interarrival, service and idle time distributions to be used in the model. The service time and idle time patterns of various ship categories were different due to variations in size. The input data was estimated through probability distributions with specified parameters taking these variabilities into account by segregating ships according to size or draught requirement. Precise input data regarding ship handling in the port for a specific year was taken into account. In all ports it is mandatory for port authorities to collect and record precise data about ships calling at the port which may include the following information:

1. Name of the vessel
2. Purpose of visit
3. Overseas/Coastal
4. Flag of ship
5. Size

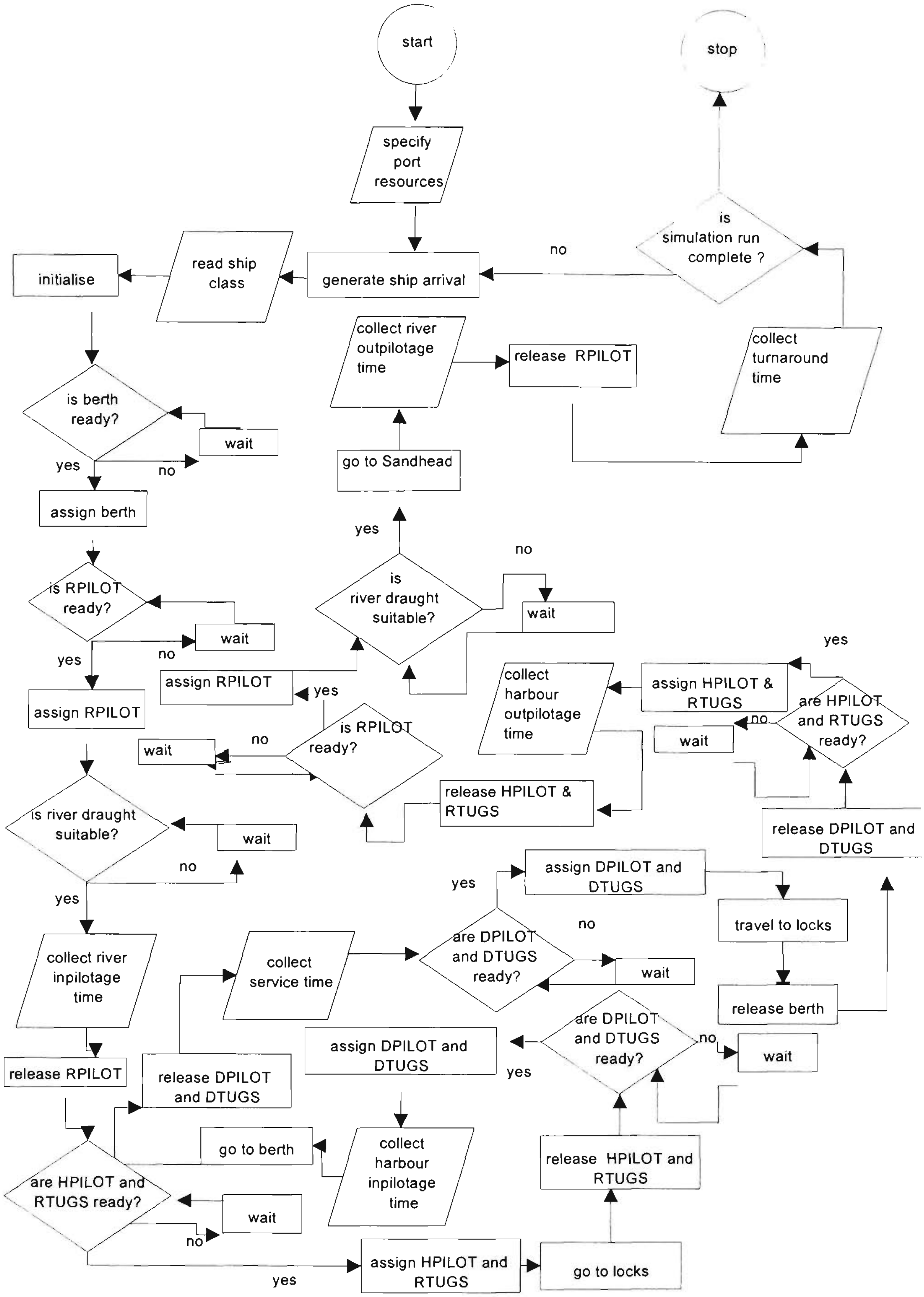
start
stop
specify port resources
is simulation run complete ?
no
generate ship arrival
read ship class
initialise
collect river outpilotage time
release RPILOT
collect turnaround time
is berth ready?
wait
yes
no
assign berth
go to Sandhead
yes
no
is river draught suitable?
wait
is RPILOT ready?
wait
yes
no
assign RPILOT
yes
assign RPILOT
collect harbour outpilotage time
assign HPILOT & RTUGS
yes
are HPILOT and RTUGS ready?
no
wait
is RPILOT ready?
no
wait
release HPILOT & RTUGS
is river draught suitable?
wait
no
yes
release DPILOT and DTUGS
assign DPILOT and DTUGS
yes
travel to locks
no
collect river inpilotage time
collect service time
are DPILOT and DTUGS ready?
wait
release berth
are DPILOT and DTUGS ready?
no
wait
assign DPILOT and DTUGS
yes
release RPILOT
release DPILOT and DTUGS
go to berth
collect harbour inpilotage time
release HPILOT and RTUGS
are HPILOT and RTUGS ready?
wait
no
yes
assign HPILOT and RTUGS
go to locks

**Figure 4.2**

6. Name of the Owner/Charterer
7. Terms of carriage
8. Vessel movement
   a) arrival at reporting station
   b) departure for berth
   c) departure from port
   d) berthwise particulars
9. Pre-berthing delay
10. Nature of cargo
11. Name of cargo
12. Type of operation
13. Quantity of cargo handled
14. Size of cargo stack
15. Period of idle time at berth
16. Quantity handled per berth day
17. Quantity handled per berth day of effective working
18. Prescribed norms
19. Shortfall of item 16 from item 18
20. Reasons for shortfall

From this vast mass of information, one had to pick the right distribution that would best fit the empirical data to represent, the arrival pattern of ships, their service time and idle time distributions, etc. Thus, data inputs were initially hypothesised before the model was translated to a computer conceivable form. In the model, ships are served by the ports resources on a first come first serve basis. We thus exclude any kind of priority rule attached to any particular ship type. Another simplifying assumption in this model is that, a ship once allocated to a specified berth, stays there until all the loading-unloading activities are completed. In actual practice however, there may be some stray situations where ships may be shifted from one berth to another, during their stay. However, port data indicated that this was a rare occurrence and was therefore ignored in the model.

Each port resource had an associated status variable indicating whether it was idle or busy. As and when a resource became idle, it was assigned to the ship which had been waiting the longest. When all the activities generated by each simulated ship arrival was completed, the ship departed from the system. Relevant statistics for each of the queue points and resource release points were collected throughout the simulation run. These were printed at the end of the run in the form of a comprehensive output table. This gave a clear notion about how long a ship had to wait on an average for each resource indicating its level of availability. If there was a long wait for any resource, it meant that the resource was in short supply and needed to be replenished in order to improve turnaround time.

As noted above, in order to estimate the turnaround time of ships at a port, a computer simulation model was developed using the SLAM II special purpose simulation language (Pritsker 1986) with subroutines written in FORTRAN. The usual practice of modeling in SLAM II is to initially develop the graphical network model using SLAM II symbols and notations. The nodes and branches of the SLAM II network provide for routing and processing functions which are assembled by the modeller into a representative model of the system under study. Some of the SLAM II nodes and statements which are used in our model are described in Appendix 4.1. The graphical representation of these nodes provides a medium for better visualisation and conceptualisation of the problem. The graphical network model is later transcribed in statement form and requisite simulation runs are made.

In the present model, ships or entities flow through a sequence of events, activities and decisions which is collectively known as a process. An entity can be assigned attribute values, for example, the type of a particular ship entering the port system can be considered to be an attribute of the entity, ship. The resources of the port are the various servers which include the equipment or personnel for which the ships wait or compete while moving through the system. At the very outset, the SLAM II processor interprets the network statements. This is followed by an initialisation phase during which the processor places on the event calendar, an entity arrival event to occur at each CREATE node at the time of the first release of the node. The CREATE node is used to generate entities within the network. The time of creation is stored as an attribute of the created entity and is known as mark time. The execution phase of simulation begins by selecting the first event on the event calendar. The processor advances the current simulated time TNOW, to the event time corresponding to this event. It processes the event by performing all appropriate actions based on the decision logic associated with the node to which the entity is arriving. After all events have been scheduled the SLAM II processor tests for an end-of-simulation condition. When a simulation run ends, statistics are calculated and the SLAM II summary report is printed.

In this model, the port's resources include items like berth, river pilot, harbour pilot, dock pilot, river tugs and dock tugs. The ships are classified according to their dimensions, more specifically, their full load draught requirements. A complicating factor in the port is a long stretch of riverine passage which ships have to negotiate both during entry and exit. On arrival, along with specific port resources, a ship has to wait for suitable riverine conditions such as river draught for the day and tide timings in order to commence the inward journey. The same applies for departure as well. Following the logic of the flow chart in Figure 4.2 each ship is routed through various nodes and branches in the network model between arrival and departure until the completion of the entire simulation run. The various network nodes that have been used to develop this model are introduced in the Appendix. Thus, with the aid of these network nodes and branches, the various activities initiated by an arriving ship is reproduced sequentially from arrival at the reporting station to departure and the relevant information regarding the system is collected in a pre-specified format.

## Appendix 4.1

### I) SLAM II control statements

These statements are used in writing simulation programmes in SLAM II and typically they start in Column 1. The following control statements have been chronologically used in this model.

i) **GEN**

This is the first statement in any SLAM II simulation program and it provides general information about the simulation such as the project identifier, number of simulation runs and report options or the output format.

ii) **LIMITS**

The second statement is the **LIMITS** statement which is used to specify integer limits on the maximum number of files used in the model, the maximum number of attributes per entity and the maximum number of concurrent entries in all files. This is therefore used to define the size and structure of the filing system.

iii) **NETWORK**

The **NETWORK** statement is used to denote the beginning of a network description and consists of the characters **NET** entered on a line. It denotes to the SLAM II processor that the lines to follow are network statements. They must however be followed by an **ENDNETWORK** statement in order to be meaningful.

iv) **FIN**

This denotes the end of **SLAM II** input statements and causes the execution of all remaining simulation runs. This statement will complete the description of network input statements and statements for executing network models.

## II) SLAM II Network Input Statements

There are a number of basic network input statements in SLAM II, of which the following have been used in this model.

### i) CREATE

The **CREATE** node generates entities within the network and routes them into the system through activities that emanate from this node. The node is released initially at a specified time and thereafter at specified time intervals up to a maximum number of releases as indicated. Entities will continue to be created at this node until a limit is reached which will be specified by the modeller. The time between creations of entities after the first one has been created will also have to be specified in the form of a constant or a variable. The mark time is the time at which an entity is created and is stored as an attribute of the entity.

### ii) ASSIGN

This node is used to prescribe values to the attributes of an entity at each arrival of the entity to this node. These values can take a wide variety of forms. The variables to which these attributes are assigned can be used for a variety of purposes the primary ones being routing of entities and duration of activities based on assigned values. A specified maximum number of activities may be designed to emanate from this node.

### iii) EVENT

This node is used as an interface point between network models in SLAM II and FORTRAN inserts. This node causes a specified subroutine in FORTRAN to be called every time an entity arrives at this node. This allows for greater modeling flexibility as the user can model functions for which a standard node is not specified by SLAM II. The event node has been used in our model to check for proper river draught and tidal timings for ship entry and exit.

### iv) AWAIT

This node is used to store entities while waiting for any particular resource. When an entity arrives at this node and the units of the resource required are available, the entity passes directly through the node and is routed to the following node according to specifications. If on the other hand, it has to wait at the node, it is placed in a file according to the priority assigned to it. Thus, the **AWAIT** node delays an entity in a file until specified units of the resource is available.

v) **COLCT**

The **COLCT** node is used to collect statistics that are related to, either the time an entity arrives at the node or on a variable at the entity arrival time. A number of statistics on five types of variables can be collected at the **COLCT** node in the **SLAM II** network model. Four of these variables are time related such as, time of first arrival, interval statistics, etc. The fifth one is a **SLAM II** variable whose value is recorded every time an entity arrives at the **COLCT** node.

vi) **FREE**

A **FREE** node is used to release specified units of a resource type when an entity arrives at the node. The freed units of the resources may then be allocated to entities waiting at an **AWAIT** node according to priority specifications. The resources available are then decreased by the amount that is allocated. This process continues until the number of resources that are freed to be allocated are insufficient for the requirements of a waiting entity or when there is no waiting entity to be allocated to.

vii) **TERMINATE**

This node is used to destroy or delete entities from the network. It is generally used to specify the number of entities which are to be processed during a simulation run. This number of entities to be processed is called a termination count. However, if a **TERMINATE** node does not have a termination count, the entity is destroyed on arrival to the node and no further action is taken. At this node, the simulation run is terminated.

viii) **ACTIVITY**

In the **SLAM II** framework, the passage of time is depicted by a branch which is the graphical representation of an **ACTIVITY.** Activities emanating from **QUEUE** or **SELECT** nodes are referred to as service activities. They restrict the number of concurrent entities flowing through them to be equal to the number of servers represented by the activity. Activities emanating from other node types are called regular activities and have no restrictions on the number of concurrent entities. The duration of an **ACTIVITY** is the time delay encountered by an entity as it flows through the branch which represents the **ACTIVITY.** Each branch has a start node and an end node. When an entity is routed through a start node, the selection of a particular branch may be direct, probabilistic or conditional depending on the requirement of the model.

**III) The Resource Block**

A **RESOURCE** block defines a resource by its label and its initial capacity and availability. It is clear that an entity waits for a resource at the **AWAIT** node where the number of units of the resource required is specified. Resources are allocated to waiting entities in a prescribed order. This order is established through the use of a **RESOURCE** block. This block also defines the initial capacity of the resource type. Pritsker (1986) uses the term 'block ' instead of 'node' because a **RESOURCE** block has no inputs or outputs as entities do not flow through it. It is primarily used for defining the resource name or label, the available number of units of the resource and the allocation procedure for waiting entities.

So far, the various input statements of the **SLAM II** network system which have been used in the model has been discussed. We will now turn to the output report which is generated by the **SLAM II** processor at the end of each simulation run of the model. These include the input listing, echo report, trace report and **SLAM II** summary report. A brief description of the output reports is given below.

## IV) The Output Report

### i) Input statement listing and error messages

The **SLAM II** processor interprets each input statement and performs extensive checks for possible input errors. Each statement is assigned a line number and if an input error is detected, an error message is printed immediately following the statement where the error occurred. All input errors are treated as fatal errors in **SLAM II**, i.e. no execution will be attempted if even one input error is detected.

### ii) Echo Report

The Echo Report provides a summary of the simulation model as interpreted by the **SLAM II** processor. This report is extremely useful while debugging the model during the process of verification.

### iii) Trace Report

The Trace Report summarises each entity arrival event to be printed during the execution of simulation. It generates a detailed account of the progress of simulation of each arriving entity through the various nodes and activities.

### iv) Summary Report

This displays the statistical results of the simulation and is automatically printed at the end of each run. There are broadly seven categories of output statistics that are printed at the end of each simulation run giving a comprehensive picture of port operations. The first category is for variables based on discrete observations and includes those statistics collected within the network model pertaining to the **COLCT** statement. This would give the arithmetic mean, the standard deviation and the coefficient of variation of the observations. It would also give the minimum value, the maximum value and the total number of observations. The second category is for time persistent variables and would give the average value, the standard deviation and the minimum and the maximum values of the variable over time. This is followed by statistics on files and event calenders. This gives us a clear indication of how long a ship has to wait for a particular resource as well as the queue length for that resource. The next two categories correspond to statistics collected on the **ACTIVITY** branches. The last category of statistics is relevant to **RESOURCE** block and **GATE** nodes. This output report gives us a clear notion about the existing state of the port system being modelled.

The port simulation model that has been developed using the **SLAM II** network was applied to the riverine port complex of Calcutta and Haldia, in an attempt to estimate their efficiency in terms of the turnaround time of specific types of ships. This has been attempted in the following two chapters.

# CHAPTER 5

# THE PORT OF CALCUTTA: A PERFORMANCE STUDY THROUGH SIMULATION



## 5.1 Introduction

The simulation model discussed in chapter 4 was refined to estimate the turnaround time of container vessels visiting the port of Calcutta. The model so developed gave port performance data in terms of turnaround time of ships and components thereof which could then be compared with observed data in order to ascertain the accuracy of the model.

## 5.2 Choice of Container Ships

Container ships are those ships in which the cargo is carried in boxlike structures of uniform dimension called containers. Over the last few decades, containerisation has become the most efficient and popular mode of transporting sea borne general cargo all over the world. Although the concept of containerisation is relatively new to the port of Calcutta, development projects are already under way to facilitate container handling at the port complex.

Also, since containerisation involves extensive capital outlay in machinery and equipment, the importance of a quick turnaround is more critically felt. It is for these reasons that container ships were chosen for the simulation exercise.

## 5.3 The Nature of Calcutta Port

As noted earlier, the port of Calcutta is situated on the left bank of the river Hooghly about 129 km upstream from the river estuary off Saugar Islands in the Bay of Bengal. The Hooghly is characterised by a devious course, dotted by shoals and sandbanks, swirling currents and sharp bends. Accordingly, the navigation of the vessel in the river is not an easy task. All ships above 200 tons calling at the port of Calcutta, require compulsory pilotage in the river, i.e. they require the services of an experienced river pilot to guide them through the river. The pilotage distance stretches from the reporting station at Sandhead, situated 72 km downstream from the river estuary, to Calcutta harbour, covering a total distance of about 200 km. Figure 5.1 depicts a map of the river Hooghly and the location of Sandhead and the ports of Calcutta and Haldia.

An arriving ship anchors at Sandhead and waits for the allocation of a river pilot, a suitable berth and proper river conditions. A river pilot is a trained navigating officer of the port, who has complete understanding of the river and its tidal considerations. He assists the captain of the arriving ship by guiding the vessel from Sandhead to Garden Reach. When all the requirements are met, the river pilot starts the journey from Sandhead which is situated before a series of sandbars. A sandbar is a small hillock on the river bed comprising of sand deposits. A pilot must manoeuvre the vessel in such a manner and at such a depth of water so that the bottom of the vessel does not touch the sandbar. As a result the dimension of ships that can call at the port of Calcutta are restricted, although dredging is regularly carried out to maintain the navigability of the channel. The sharp bends on the river also pose problems for ships beyond a certain length.

Apart from the topography of the river bed, the tidal occurrence must also be taken into account. In Calcutta, a ship can negotiate the crucial sandbars only at specific points of time in accordance with the tidal occurrences. The current and the level of water in the river is not uniform throughout and the tidal occurrence takes place at different times at different places along the river. In general, it takes place one hour later, every 20 miles up the river. For instance, if high water takes place at Diamond Harbour at 8 a.m., high water at Calcutta, situated 40 miles upstream from Diamond Harbour will take place two hours later i.e. at 10 a.m. The pilot has to make constant calculations of the tide timings, the size and speed of the vessel, and the topography of the river bed in order to ensure safe navigation. The tidal swelling is utilised by the river pilot in order to cross a sandbar, taking advantage of the temporary rising of the water level. At Calcutta port, an incoming ship has to negotiate as many as fifteen sandbars in order to reach the harbour. Now all the fifteen bars cannot be crossed at a single tide because the speed of the tide moving upstream is far greater than the speed of the ship which generally moves at 10 to 12 knots per hour. Thus, a ship which has to cross a sandbar at high tide must start ahead of the tide and make accurate calculations of distance and speed to cross the bar at the opportune moment. This is easier said than done and the situation is even more critical for an outbound ship which has to strain against the incoming tide. Should a ship miss the tide for some reason after starting from Sandhead, it has to drop anchor at a safe anchorage and wait for the next tide.

For safety reasons night pilotage is not allowed in the upper reaches of the Hooghly as the course is extremely narrow. Thus, it has rightly been commented that, negotiating the Hooghly is a story of bars and bends and a supreme test of the river pilots professional acumen (Mistry 1980).

Before a ship can set sail in the river, a check is made to see whether the ship's draught is lesser than the river draught or not. The draught of the ship is the distance from the lowest part of the keel of the vessel to the water line at which she floats. The river draught or the depth of the river at any point is measured from a water level which is constant. The river draught varies at different locations in the river, at different points of time. Now, as a guideline for the visiting ships, which have various shapes, sizes and speed, the port authority publishes a river draught forecast, for each day of the year, six weeks in advance. This river draught forecast is actually the maximum draught available on a day, given with a clearance of two feet at high water, on the governing bar or the worst bar. The governing bar is the highest sandbar in the river. If forecast for any day is 6 metres then only those ships whose draught requirement is less than, or equal to, 6 metres will be able to negotiate the river. Otherwise, ships will have to wait at Sandhead until the river draught rises suitably. In such situations, it it said that the vessel has been neaped.

Mention must be made of the fluctuations in the river draught forecasts which follow a definite pattern in the form of periodic fluctuations at regular fortnightly intervals in keeping with the lunar and tidal phenomena. Superimposed on these fluctuations are the gradual seasonal changes in the river draught according to the prevalent wet or dry season. On studying the graph of the draught forecast for the entire year in 1988, a gradual rise in the river draught is identified during the wet season which has been taken to be from 9.5.88. to 21.10.88. The rest of the year constitutes the dry season in the present exercise. This natural phenomenon had to be taken into account as ships usually took advantage of the extra bit of river draught available during the wet season.

Within a span of twenty-four hours, each point on the river experiences two high water and two low water levels. In this model, a rule of thumb followed by pilots is used in making time calculations for negotiating the river (Mistry 1980). An incoming ship with an average speed of about 10 knots per hour, leaves Sandhead one hour after the first low water at Sandhead. Only the first low water is considered as night pilotage is not allowed in the upper reaches of the Hooghly. For an outgoing ship, leaving the harbour, the journey should commence three hours before low water at Garden Reach, given the same average vessel speed of 10 knots per hour. This rule of thumb is used for the sake of simplicity. There may well be instances where the river pilot may decide to leave earlier or later than this stipulated time depending on the speed and size of the vessel. Thus, a situation is considered where an arriving ship anchors at the reporting station or Sandhead until the following conditions are satisfied:

i) a suitable berth is available to accommodate the ship inside the harbour;
ii) river pilot is ready to guide the vessel in the river; and
iii)the river draught forecast for the day is greater than the ships draught requirement the tide timings are suitable.

Once these conditions are met, the ship commences her inward journey from Sandhead. The entire time that she spends at the reporting station is her *waiting time* or pre-berthing delay. The ship travels from Sandhead to Garden Reach under the surveillance of the river pilot. At Garden Reach the river pilot disembarks and the harbour pilot boards the vessel. He then guides the vessel from Garden Reach to the Locks with the help of two river tugs. At the Locks, the harbour pilot hands over the ship to the dock pilot or the berthing master, who berths the vessel with the help of two dock tugs. This entire time period that elapses between the time that she leaves Sandhead to the time she enters the berth constitutes her *inpilotage time*. Within this total inpilotage time, the time of travelling from Sandhead to Garden Reach may be called the river inpilotage time and the time taken to travel from Garden Reach to berth may be called harbour inpilotage time.

The entire time that the ship spends at berth constitutes her *service time*. Service time has two components, namely, *actual loading unloading time* and *idle* *time at berth*. As and when a ship is ready to deberth, an available berthing master or dock pilot is allocated. He then guides the ship from the berth to the Locks with the help of two dock tugs. There the harbour pilot takes over and with the help of two river tugs takes the ship up to Garden Reach. At Garden Reach, the ship waits until:

i) a river pilot is allocated;
ii) the river draught forecast for the day is greater than the ships draught requirement; and
iii)the tide time is suitable.

Once all these conditions are met, the river pilot takes the vessel from Garden Reach to Sandhead, after which the ship departs from the port. The journey of the ship after she deberths and up to Sandhead constitutes her *outpilotage time*. As before, the time taken by the ship to travel from berth to Garden Reach may be called the harbour outpilotage time while that taken to travel from Garden Reach to Sandhead may be termed the river outpilotage time. The entire time span beginning from and ending at Sandhead is called the *turnaround time* of the ship. Thus,

*Turnaround time = Waiting time + Inpilotage time + Service time + Outpilotage time.*

Data pertaining to Calcutta port for the year 1988-89 collected from the Planning and Research Cell of Calcutta Port Trust has been used for this modeling exercise.

## 5.4 Port Infrastructure for Handling Container Ships

The port of Calcutta has two dock systems, Netaji Subhas Docks (NSD) and Kidderpore Docks (KPD). The ship dimensions are restricted by the Locks at the entrance of each of the dock systems. The KPD can accommodate a maximum ship size of length 157 metres and breadth 21.9 metres. At NSD the corresponding figures are 172 metres and 24.4 metres respectively. Among the existing berths, one berth in KPD and four berths in NSD are regularly used for the handling of container ships. The dimensions of these berths are given below in Table 5.1.

**Table 5.1**

| *Berth* | *Length (m)* | *Width (m)* | *Depth (m)* |
|---|---|---|---|
| 3 KPD | 128.00 | 18.29 | 6.50 |
| 1 NSD | 200.00 | 13.70 | 9.15 |
| 4 NSD | 181.00 | 15.20 | 9.15 |
| 5 NSD | 183.00 | 12.30 | 7.60 |
| 7 NSD | 192.00 | 12.30 | 7.80 |

*Source: Calcutta Port Trust*

In 1988-89, the entire container cargo was loaded and unloaded with the help of shipboard cranes as the port did not possess any container handling cranes. Sometimes, if all the five container berths were occupied, a waiting container ship would be accommodated in a general cargo berth if it happened to be empty.

Apart from berths, there are certain port resources which are used by all ships irrespective of their type and class. These resources include the common pool of river pilots, harbour pilots, dock pilots, river tugs and dock tugs which are required for inpilotage and outpilotage. In the year 1988-89, which is the year of our study, there were 26 river pilots, 6 harbour pilots, 8 river tugs, 31 dock pilots, and 12 dock tugs. An approximation is made at this stage with regard to these general port resources. In 1988-89, approximately 20% of the calling ships were container vessels. As a simplifying assumption, about 20% of the said general port resources were reserved exclusively for container ships in the model. Thus, there are 5 river pilots, 1 harbour pilot, 2 river tugs, 6 dock pilots and 2 dock tugs. It may be pointed out in this connection, that Raman and Ramakumar (1988) encountered a similar problem in ascertaining the number of berths in their study on the port of Madras and tackled the problem in a similar fashion.

Given these port resources, it has been attempted to simulate the operations of container ships calling at the port in the year 1988-89, in an effort to estimate their turnaround time and components thereof.

## 5.5 Pattern of Ship Arrivals

Based on the information collected from the shipyards for all container ships calling at Calcutta in 1988-89, the pattern of ship arrivals at the port could be deciphered. Since the data was available on the precise date and time of each ship arrival, the distribution of interarrival time of consecutive ships could be computed.

Previous studies have revealed that the interarrival time of ships visiting a port generally follow exponential distribution. A Chi square test was run on the observed interarrival time of container ships visiting Calcutta in 1988-89, in order to verify the hypothesis in this particular case. The hypothesis that the observed pattern of interarrival time of ships conform to exponential distribution with mean 54.90 hours was accepted both at 5% and 1% levels of significance. In the SLAM II simulation language that has been used, ship arrivals are generated automatically at the CREATE node, once the interarrival time distribution and its mean is specified as discussed in the previous chapter.

## 5.6 Classification of Ship Types

The arriving ships were classified on the basis of their dimensions, or more specifically, their draught requirement, which happens to be the most crucial characteristic of a ship in a riverine port like Calcutta. The JICA Report (1988) specifies the following dimension relations regarding container vessels.

$$\text{Log } L = 0.6124 + 0.3825 \text{ Log } DWT \qquad \text{(i)}$$

$$\text{Log } d = -0.4500 + 0.3331 \text{ Log } DWT \qquad \text{(ii)}$$

$$\text{Log } B = 0.1201 + 0.3009 \text{ Log } DWT \qquad \text{(iii)}$$

where:

L = length over all of vessels (m)

d = full load draught (m)

B = breadth of vessel (m)

DWT = Dead Weight Tonnage (tonnes)

From the ship card or ship record available at the Planning and Research Cell of the Calcutta Port Trust, access was available to detailed data relating to all movements of container ships visiting the port in 1988-89. The first step in processing the data on container ships was to classify the ships into categories on the basis of their dimension and full load draught. From the information on the lengths of the arriving ships, the full loaded draught of the vessels was calculated from the mathematical relations (i) and (ii) mentioned above. The characteristics of container ships calling Calcutta in 1988-89 are listed in Appendix 5.1.

Then, the arriving ships were classified into two categories as below:

1) Ship type 1 included lighter and smaller ships whose full loaded draught was below or equal to 6 metres..
2) Ship type 2 included heavier and larger ships whose full loaded draught was above 6 metres.

It was observed that ships often arrived or departed in partly laden conditions. Hence, simply designating an arriving ship as type 1 on the basis of its full load draught would not suffice as an accurate representation of reality. Thus, a further subdivision of A, B and C was required within each ship type. Subtype A included those ships whose actual draught requirement was less than 50% of its fully loaded draught. Subtype B included those ships whose actual draught requirement was between 50 to 75% of its full loaded draught. For Subtype C, this was above 75%. Thus ship type 2A would indicate a ship whose full loaded draught lay above 6m but whose actual draught requirement while using the port was less than 50% of its full loaded draught. Based on this classification of ship types, the arrival and departure draught figures of all containerships visiting Calcutta in 1988-89 were noted and tabulated as percentages of the total number of observations as shown in Table 5.2.

**Table 5.2**
**Percentage of Total Number of Containerships Visiting Calcutta**

| | Ship Type | | |
|---|---|---|---|
| | *1C* | *2B* | *2C* |
| Arrival | 14.56 | 2.53 | 82.91 |
| Departure | 14.56 | 0.63 | 84.81 |

Thus we see that the ships which visited Calcutta in 1988-89, fell in the ship types 1C, 2B, and 2C. Within ship type 2, an overwhelming majority was of subtype 2C. So ship type 2C was considered to be representative of all ships belonging to ship type 2 in the model. Moreover, a ship which came in as a certain ship type, also generally departed as the same ship type. There were only a few cases where it was seen otherwise. For the sake of simplicity, it was assumed that a ship which arrives as a certain ship type, also departs as the same ship type, i.e. a ship coming in as 2C will also depart as 2C. In this model, the arrival as well as the departure percentages of the two major ship types, 1C and 2C have been approximated in Table 5.3.

**Table 5.3**
**Percent of Total Number of Containerships Visiting Calcutta**

| | Ship Type | |
|---|---|---|
| | *1C* | *2C* |
| Arrival | 15.0 | 85.0 |
| Departure | 15.0 | 85.0 |

## 5.7 Assignment of Ship Characteristics or Attributes

We then assigned the various characteristics for each ship type, in agreement with the actual observations on the characteristics of containerships visiting the port of Calcutta in 1988-89, as follows.

*1) The ships draught requirement*

Table 5.4 shows the approximate range of the draught requirement for each type of ship, during arrival and departure at the port in 1988-89, considering the dry as well as the wet seasons. A few extreme cases in the ships draught figures have been ignored in order to avoid an unnatural bias. The ships draught was found to vary within the range as given below. The discrepancy in the ships draught requirement during dry and wet seasons was due to the fact that ships often took advantage of the extra bit of river draught available during the wet season and came in with a heavier load of cargo. Moreover, it was observed that generally ships departure draught was marginally higher than their arrival draught.

**Table 5.4**
**Ship's Draught Requirement (meters )**

| | Ship Type | |
|---|---|---|
| *Season* | *1C* | *2C* |
| DRY | | |
| Arrival | 4.5 to 5.5 | 5.0 to 6.2 |
| Departure | 4.5 to 5.9 | 5.0 to 6.3 |
| WET | | |
| Arrival | 4.5 to 5.7 | 5.0 to 6.5 |
| Departure | 4.5 to 6.0 | 5.0 to 6.7 |

*2) Calculating the ships service time*

The service time or the time spent by the ship at berth is, the sum total of the ship's actual loading unloading time and its idle time. Calcutta port has, over the years, acquired the stigma of low productivity as far as handling of containers is concerned. The productivity of container handling in Calcutta is around 19 to 21 container boxes per hook, per shift. As against this, the worldwide norm is about 51 to 62 boxes per hook, per shift (JICA Report 1989).

The reasons behind this dismal performance have been summarised as follows:

a) Communication and information gap among relevant shipping interests such as shipping companies, stevedores, agents, port authorities, customs and clearing houses, labour and equipment contractors, storage and transportation agencies etc. This results in poor, uncoordinated planning involving delays in service time.

b) There is a shortage of specialised skilled labour for container handling coupled with an abundance of unskilled labour. Calcutta has one of the highest number of persons in a standard gang of labourers ranging from 51 to 57 persons. The corresponding figure for Singapore is 11 persons which is one of the lowest gang strengths in container operations.

c) The layout of berths were not originally meant to be for container operations. There is faulty area planning with narrow aprons, insufficient storage space, congested access to container sheds and inefficient ship handling methods.

The construction of the new facilities at the new container terminal in DNSD is expected to improve the current situation in ships service time.

Under the contemporary prevailing situation, it was attempted to estimate the service time of container vessels calling at the port in 1988-89. The loading – unloading time of each ship type was found to be normally distributed while the idle time at berth was exponentially distributed. Statistical goodness of fit tests were carried out to justify the hypotheses. The findings are tabulated in Table 5.5.

In this way, the attributes or characteristics of the various ship types were set on the basis of actual observations on containerships visiting the port in 1988-89. A simplifying assumption made at this stage was that a ship once allocated to a particular berth, stayed there until all the loading unloading activities were completed. In actual practice however, there could be rare instances where ships may be shifted from one berth to another during loading unloading operations. Such interberth movements were ignored in the present model for simplification.

**Table 5.5**
**The Loading-Unloading Time and Idle Time of Various Ship Types (hours)**

| | **Loading-Unloading Time** | | **Idle Time** |
|---|---|---|---|
| *Ship type* | *Mean* | *Standard Deviation* | *Mean* |
| 1C | 52.72 | 18.77 | 8.93 |
| 2C | 57.48 | 24.57 | 9.69 |

## 5.8 The Simulation Exercise

Given these specifications, the stage was set for the simulation run to commence. As the initial configuration regarding the positioning of the river pilot, it was specified that all five river pilots were initially stationed at Sandhead.

Ships were arriving to the system following the given distribution pattern of interarrival time. Then they were probabilistically routed to their respective ship types on the basis of their actual percentage of arrival in 1988-89. Once a ship's type is ascertained, its corresponding attributes relating to draught and service time were specified. Initial positioning of the resource river pilot was made. Then the ship commenced its various activities sequentially in the simulated port environment. Taking into account the various activities initiated by the arriving entity, i.e, the ship, a graphical network model was constructed using symbols and notations as specified by SLAM II. The network model was then transcribed into statement form comprehensible to the computer using SLAM II terminologies and commands. Appendix 5.2 contains the input statements of the said model. Certain modifications relating to the wet and dry season specifications, the joint allocation of harbour pilot, river tugs, dock pilot and dock tugs, calculations of draught and tide timings were coded using FORTRAN subroutines. Thus, the entire model was developed as a sequential chain of activities initiated by ship arrivals and a simulation run was given for 17520 hours of port operation.

## 5.9 Simulation Results

Various port related statistics were obtained at the end of the simulation run in the form of a summary report giving a clear representation of container ship operations in Calcutta.

These port related statistics included the following:

1) The average turnaround time for each type of ship together with its components such as:

    i) the ships waiting time at Sandhead;

    ii) inpilotage time;

    iii)the total time at berth which includes the; and

    - *loading unloading time and the*
    - *idle time*

    iv) outpilotage time.

The results also yielded the mean value, standard deviation, coefficient of variation, minimum value, maximum value and the total number of observations of the turnaround time and its various components.

2) With each of the port's resources, the SLAM II system associates a file. The file statistics for the various files denoting ships waiting in queue for the different resources were obtained. These included the average length of file for each resource, standard deviation, maximum length, current length and average waiting time giving a clear picture of how long the ship has had to wait for each port resource.

3) The resource statistics gave the capacity and utilisation rates of each port resource. They included the average utilisation, standard deviation, maximum utilisation, current utilisation, the current availability and average availability of each resource.

While considering the observed and estimated values of the turnaround time and components thereof, those ships which were neaped (N) at Sandhead, i.e. had to wait for more than 24 hours for suitable conditions for entry, were considered separately. The rest were denoted as regular (R). Unless this distinction was made, the extreme waiting times associated with neaped ships would unduly inflate the average waiting at Sandhead for all ships.

Thereafter, the estimated values of turnaround time and its components obtained at the end of the simulation run was compared with the corresponding observed values for the year 1988-89. Table 5.6 gives us the relevant comparison between average values of the components of estimated and observed turnaround time.

## 5.10 An Interpretation of the Results

A scrutiny of the results revealed a number of interesting features:

1. No ship belonging to ship type 1C was neaped, either in reality or in the simulation exercise as they were relatively smaller ships. This shows an agreement between the model and the actual port situation.

2. The results indicated that 15% of the ships in the simulated situation belonged to the category 1C while 85% belonged to the group 2C. This showed that the model was functioning exactly the way it was intended to. This is crucial for the purpose of model verification.

3. There was excellent correspondence between the observed and estimated values of total turnaround time for both ship types – the regular as well as the neaped ships. The above points indicate close agreement between the simulated and observed situations.

4. With regard to certain components of turnaround time, there were some discrepancies between the observed and estimated values, especially Total SH (Sandhead) Wait. It was found that the estimated figures were much higher than the observed values, for all ship types. This discrepancy was primarily due to the excessive waiting for the resource River in the simulated environment. On the other hand, the observed values of Inpilotage Time were found to be greater than the corresponding estimated value, irrespective of ship type. A probable reason for this discrepancy could be as follows.

In the model, the entire waiting period for river, i.e. the waiting for suitable tide timings and for draught facilities, is collected at a single point of time at Sandhead. This is done after a berth and a river pilot is allocated under the subheading River (see fig. 4.2). At this point, a check is made to see whether the river conditions are suitable for inpilotage or not. The ship is made to wait at Sandhead until such time as the conditions are deemed fit. Hence, the entire waiting for river is clubbed together once and for all under this heading. In actual practice however, a ship may start on its inward journey right after a berth and river pilot is allocated to it and may anchor at some suitable point inside the river, should the riverine conditions be unsatisfactory.

Hence, the waiting for river is often distributed at various points along the inward journey. This difference between the actual situation and the simulation exercise resulted in an upward bias in the waiting time at Sandhead in the model.

Similarly, as the total inpilotage time of the arriving ships in the model did not take into account any stoppages en route, the average estimated inpilotage time fell short of the average observed inpilotage time of the ships. Ships may start earlier or later depending on its size and speed and the river conditions of that particular day. Thus, Sandhead wait has been overestimated while Inpilotage time has been underestimated in the simulation exercise. Therefore, if the Total SH Wait and the inpilotage time is added up and then the observed and estimated figures are compared, better correspondence between the two can be expected.

Another reason for the discrepancy is that the shipowners, in actual practice have prior knowledge of the river draught far in advance. Hence, utmost caution is taken by them to ensure that there is no undue waiting due to draught restrictions. This is more so in the case of containerships where time deadlines are of crucial importance. The fortnightly cycles of draught fluctuations are carefully considered and ships draught adjusted accordingly. Captains of vessels often resort to deballasting at Sandhead in order to match the draught of the day.

**Table 5.6**
**Average Values of Components of Turnaround Time (hours)**

| | Ship Type 1C | | | | Ship Type 2C | | | |
|---|---|---|---|---|---|---|---|---|
| | *Observed* | | *Estimated* | | *Observed* | | *Estimated* | |
| | (N) | (R) | (N) | (R) | (N) | (R) | (N) | (R) |
| **Sandhead wait** | **0.00** | **4.09** | **0.00** | **12.59** | **40.53** | **4.00** | **49.53** | **10.90** |
| a) Berth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| b) RPILOT | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.11 |
| c) River | 0.00 | 0.00 | 0.00 | 12.42 | 0.00 | 0.00 | 0.00 | 10.74 |
| **Inpilotage** | **0.00** | **19.92** | **0.00** | **12.29** | **24.00** | **16.86** | **12.52** | **12.12** |
| a) River " | 0.00 | 0.00 | 0.00 | 8.98 | 0.00 | 0.00 | 9.22 | 8.98 |
| b) Harbour " | 0.00 | 0.00 | 0.00 | 3.31 | 0.00 | 0.00 | 3.30 | 3.14 |
| **Berth Time** | **0.00** | **64.61** | **0.00** | **64.10** | **75.38** | **70.09** | **74.32** | **66.22** |
| a) Working | 0.00 | 55.09 | 0.00 | 54.04 | 56.96 | 59.08 | 65.42 | 57.20 |
| b) Idle | 0.00 | 9.52 | 0.00 | 10.06 | 18.42 | 11.01 | 8.90 | 9.02 |
| **Outpilotage** | **0.00** | **20.96** | **0.00** | **20.02** | **20.90** | **20.58** | **20.93** | **23.26** |
| a) River " | 0.00 | 0.00 | 0.00 | 9.02 | 0.00 | 0.00 | 9.02 | 9.03 |
| b) Harbour " | 0.00 | 0.00 | 0.00 | 3.03 | 0.00 | 0.00 | 2.98 | 3.05 |
| c) RPILOT | 0.00 | 0.00 | 0.00 | 0.36 | 0.00 | 0.00 | 0.00 | 0.04 |
| d) River | 0.00 | 0.00 | 0.00 | 7.61 | 0.00 | 0.00 | 8.93 | 11.14 |
| **Turnaround** | **0.00** | **109.59** | **0.00** | **109.00** | **160.81** | **111.53** | **157.30** | **112.50** |

These practical and shrewd hedging tactics to counter the tricky draught situation could not be incorporated in the model. A straightforward situation has been considered where ships arrive at random and depending on the ship class, pick a value of the ships arrival draught at random from within a specified range. If the river draught of the day is greater than the ships draught so chosen, the ship enters the river, otherwise it waits in a file named River thus resulting in an inflated value as compared to the real situation.

Considered below in Table 5.7 is the combined value of Waiting Time at Sandhead and Inpilotage time of all ship types and compare the observed and estimated values. It is found that there is a good correspondence between the simulated and observed results.

5. There was almost no waiting for berth, irrespective of ship type. Only in the case of the regular ships falling in the category 2C, there was an average waiting for berth of 3 minutes which can be considered to be quite negligible. This implied that given the existing rate of traffic, the existing number of berths was quite sufficient.

**Table 5.7**
**Average Values of Sandhead Waiting and Inpilotage Time (hours)**

| | **Ship Type 1C** | | | | **Ship Type 2C** | | | |
|---|---|---|---|---|---|---|---|---|
| | *Observed* | | *Estimated* | | *Observed* | | *Estimated* | |
| | **(N)** | **(R)** | **(N)** | **(R)** | **(N)** | **(R)** | **(N)** | **(R)** |
| Total SH Wait | - | 4.09 | - | 12.59 | 40.53 | 4.0 | 49.53 | 10.90 |
| Inpilotage | - | 19.92 | - | 12.29 | 24.00 | 16.86 | 12.52 | 12.12 |
| **SUM** | - | 24.01 | - | 24.88 | 64.53 | 20.86 | 62.05 | 23.02 |

6. The waiting for the resource river pilot also was insignificant which had similar implications as the previous one.

7. The estimate of total time at berth estimates corresponded reasonably well with reality. In case of ship type 2C however, the estimated average value was marginally lower than the corresponding observed figures.

8. In case of Outpilotage Time also, there is quite a close correspondence between observed and estimated values.

In the preceding paragraphs, the model estimates have been compared with observed values in an attempt to validate the model. In this context, Raman and Ramakumar (1988) have remarked:

> The acceptable level of reasonableness and approximation may vary from system to system and simulation to simulation. There is no universally accepted criterion for accepting a simulation model as a valid representation. When the simulated system

exists in real life the most obvious and the best approach is to compare the results of the model with that of the real system.

In this simulated port situation a similar attempt has been made at validation by comparing the estimated and observed values of turnaround time and components thereof of containerships visiting the port of Calcutta. Two test run situations have also been compared for two different simulation run lengths, namely, 7884 hours and 17520 hours. The results obtained at the end of the three runs are tabulated in Table 5.8. It is found that as the run length increases, there is a closer correspondence between observed and estimated values of the average turnaround time of ships, which is a crucial point in favour of model validation.

## 5.11 Experiments on the Model

So far the current situation of operational efficiency has been simulated at the container port of Calcutta, given the existing constraints. However, there exist a number of factors that influence the efficiency of a container terminal. Hwang (1978) broadly divides these factors into two categories.

a) The operational factors, such as, the distribution pattern of ship arrivals, berth assignment policy of port authorities, service schedule for loading unloading operations, composition of ship categories etc.
b) The physical factors, such as, the number and sizes of berths, handling equipment, pilots, tugs, terminal storage capacity and other physical conditions of the port.

In order to investigate the effect of some of these factors on the ports efficiency (expressed in terms of ship turnaround time) a number of experiments were carried out. The experiments are listed below.

1) Increase the number of berths.
2) Increase the number of river pilots.
3) Increase the number of harbour pilots.

4) Replace the river draught data of 1988-89 with the corresponding figures of 1991-92.
5) Change the arrival pattern of ships with a greater percentage of heavier ships, with river draught figures of 1991-92.
6) Consider enhanced future traffic with new mean interarrival time and river draught data of 1991-92.
7) Consider increased ships draught requirement with river draught figures of 1991-92.
8) A comparison of experiments 6 and 7. Enhanced ships traffic is considered with lower mean interarrival time, with deeper draughted ships calling at the port using the river draught figures of 1991-92. Each experiment is conducted under the assumption that except for the parameter in question, all other conditions remain unchanged.

The objective behind carrying out these experiments is to study the behaviour of the port system under various operational and physical conditions. Since the primary motive is to compare and assess the alternatives, it is desirable to run the model in such a manner that each alternative can be studied under identical conditions. This is done by using the same series of random numbers for each alternative experiment. This is also an added advantage of computer simulation, as identical conditions can be reproduced in the model for an unbiased assessment of policy alternatives. Judging from the results of the three test runs summarised in Table 5.8, 17520 hours was used as the run length of each experiment, as this compared best with the actual turnaround time and its components in the port. Scenarios which may arise due to the expansion of certain port facilities have been considered. The results obtained are discussed below:

a) The first three experiments involved an increase in the ports facilities, namely:

(i) an increase in the number of berths from 5 to 7;

(ii) an increase in the number of river pilots from 5 to 7; and

(iii) an increase in the number of harbour pilots from 3 to 5.

Each of the experiments was carried out one at a time, all other things remaining constant. The findings of these experiments are summarised in Tables 5.9 (a) and 5.9 (b). The original set of estimated results are denoted by S1 and those obtained at the end of the experiments (i), (ii) and (iii), are denoted by S2, S3 and S4 respectively. It is found that in the case of ship type 1C, none of these experiments have had any effect whatsoever. We have completely identical results in S1, S2, S3 and S4 as far as ship type 1C is concerned. Thus, Table 5.9 (a) gives us no new insight apart from the fact that the existing port infrastructure is quite sufficient to handle the present volume of traffic falling in category 1C.

Table 5.9 (b) gives a similar picture for the ship types. However, there is a very slight decline in Sandhead waiting time from 10.90 hours to 10.80 hours and a resultant decline in turnaround time when the number of berths increased from 5 to 7. In the case of the other two experiments, there was no impact on the performance of ship type 2C, as is clear from Table 5.9 (b).

b) It is evident from the previous discussion, that, the problem of navigability is of utmost importance at the riverine port of Calcutta. Thus, what the future holds for the port in terms of navigability must be investigated. Using new river draught figures of the year 1991-92 which were marginally higher than that of 1988-89, the model was run under other identical conditions. Table 5.10 gives a comparative picture of the original estimates S1 and those obtained from this experiment, namely S5. As an outcome of this experiment, the following interesting points were noted

**Table 5.8**
**Comparison Of Average Turnaround Time Obtained From Two Test Runs**

| **Ship Type** | **Observed** | **Estimated** | |
|---|---|---|---|
| | | *Run 1 (a)* | *Run 2 (b)* |
| 1C | 109.59 | 104.1 | 109.0 |
| 2C(R) | 111.53 | 109.8 | 112.5 |
| 2C(N) | 160.81 | 156.5 | 157.3 |

Notes: (a) Run 1 is a test run for 7884 hours.
(b) Run 2 is a test run for 17520 hours.

**Table 5.9 (a)**
**Comparison of Performance of Ship Type 1C**

| | S1 | | S2 | | S3 | | S4 | |
|---|---|---|---|---|---|---|---|---|
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **12.59** | **0.00** | **12.59** | **0.00** | **12.59** |
| a) Berth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 0.17 | 0.00 | 0.17 | 0.00 | 0.17 |
| c) River | 0.00 | 12.42 | 0.00 | 12.42 | 0.00 | 12.42 | 0.00 | 12.42 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **12.29** | **0.00** | **12.29** | **0.00** | **12.29** |
| a) River | 0.00 | 8.98 | 0.00 | 8.98 | 0.00 | 8.98 | 0.00 | 8.98 |
| b) Harbour | 0.00 | 3.31 | 0.00 | 3.31 | 0.00 | 3.31 | 0.00 | 3.31 |
| **Time at Berth** | **0.00** | **64.10** | **0.00** | **64.10** | **0.00** | **64.10** | **0.00** | **64.10** |
| a) Work Time | 0.00 | 54.04 | 0.00 | 54.04 | 0.00 | 54.04 | 0.00 | 54.04 |
| b) Idle | 0.00 | 10.06 | 0.00 | 10.06 | 0.00 | 10.06 | 0.00 | 10.06 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **20.02** | **0.00** | **20.02** | **0.00** | **20.02** |
| a) River " | 0.00 | 9.02 | 0.00 | 9.02 | 0.00 | 9.02 | 0.00 | 9.02 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.03 | 0.00 | 3.03 | 0.00 | 3.03 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 0.36 | 0.00 | 0.36 | 0.00 | 0.36 |
| d) River | 0.00 | 7.61 | 0.00 | 7.61 | 0.00 | 7.61 | 0.00 | 7.61 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **109.00** | **0.00** | **109.00** | **0.00** | **109.00** |

There was a fall in the average Sandhead waiting of neaped ships by about 9 hours. This implied that:

i) fewer ships were being neaped; and
ii) neaped ships were detained for a shorter stretch of time at Sandhead.

This resulted in a smoother flow of traffic in the system and as a result, time savings were made in areas such as, total time at berth, irrespective of ship type. A plausible explanation for this is that, earlier on, when more ships were getting neaped, they were bunched at Sandhead until such time when the draught was right. This detainment of ships and later flooding of the system put an unnatural pressure on the ports facilities which affected all ship types. As a result, the average service time was affected. However, with the new draught data input, the flow of traffic was smoothened out, with fewer ships being neaped, lesser occasional spurts and sluggishness, and fewer output of service time.

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**Table 5.9 (b)**
**Comparison of Performance of Ship Type 2 C**

| | S1 | | S2 | | S3 | | S4 | |
|---|---|---|---|---|---|---|---|---|
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **49.53** | **10.90** | **49.53** | **10.80** | **49.53** | **10.90** | **49.53** | **10.90** |
| a) Berth | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 |
| b) RPILOT | 0.00 | 0.11 | 0.00 | 0.10 | 0.00 | 0.11 | 0.00 | 0.11 |
| c) River | 0.00 | 10.74 | 0.00 | 10.70 | 0.00 | 10.74 | 0.00 | 10.74 |
| **Inpilotage** | **12.52** | **12.12** | **12.52** | **12.12** | **12.52** | **12.12** | **12.52** | **12.12** |
| a) River " | 9.22 | 8.98 | 9.22 | 8.98 | 9.22 | 8.98 | 9.22 | 8.98 |
| b) Harbour " | 3.30 | 3.14 | 3.30 | 3.14 | 3.30 | 3.14 | 3.30 | 3.14 |
| **Berth Time** | **74.32** | **66.22** | **74.32** | **66.22** | **74.32** | **66.22** | **74.32** | **66.22** |
| a) Working | 65.42 | 57.20 | 65.42 | 57.20 | 65.42 | 57.20 | 65.42 | 57.20 |
| b) Idle | 8.90 | 9.02 | 8.90 | 9.02 | 8.90 | 9.02 | 8.90 | 9.02 |
| **Outpilotage** | **20.93** | **23.26** | **20.93** | **23.26** | **20.93** | **23.26** | **20.93** | **23.26** |
| a) River " | 9.02 | 9.03 | 9.02 | 9.03 | 9.02 | 9.03 | 9.02 | 9.03 |
| b) Harbour " | 2.98 | 3.05 | 2.98 | 3.05 | 2.98 | 3.05 | 2.98 | 3.05 |
| c) RPILOT | 0.00 | 0.04 | 0.00 | 0.04 | 0.00 | 0.04 | 0.00 | 0.04 |
| d) River | 8.93 | 11.14 | 8.93 | 11.14 | 8.93 | 11.14 | 8.93 | 11.14 |
| **Turnaround** | **157.30** | **112.50** | **157.30** | **112.40** | **157.30** | **112.50** | **157.30** | **112.50** |

It was also found that in the new scenario, a good number of ships which had earlier belonged to the 2C(N), i.e. neaped category, now constituted the 2C(R), i.e. regular category. As a result, the greatest lowering of service time was seen in the 2C(N) category, by about 9 hours. On the other hand, in the 2C(R) category, there was a marginal fall in service time which was less than 1 hour only, indicating that, in spite of the smoother flow of traffic, ship type 2C(R) had to cope with a higher number of ships which had earlier on been neaped. In the case of ship type 1C, it is found that a marginal fall in the waiting for river which is a component of total Sandhead wait. There were marginal falls in the inpilotage time and outpilotage time as well. The average time at berth also fell by about 5 hours.

**Table 5.10**
**Comparison of Original Results With Altered River Draught Results**

| | Ship Type 2C | | | | Ship Type 1C | | | |
|---|---|---|---|---|---|---|---|---|
| | S1 | | S5 | | S1 | | S5 | |
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **13.97** | **49.53** | **10.90** | **40.09** | **12.27** |
| a) Berth | 0.00 | 0.00 | 0.00 | 2.26 | 0.00 | 0.05 | 0.00 | 0.84 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 0.17 | 0.00 | 0.11 | 0.00 | 0.39 |
| c) River | 0.00 | 12.42 | 0.00 | 11.54 | 0.00 | 10.74 | 0.00 | 11.04 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **12.26** | **12.52** | **12.12** | **12.19** | **12.31** |
| a) River " | 0.00 | 8.98 | 0.00 | 8.94 | 9.22 | 8.98 | 8.83 | 9.00 |
| b) Harbour " | 0.00 | 3.31 | 0.00 | 3.32 | 3.30 | 3.14 | 3.36 | 3.31 |
| **Berth Time** | **0.00** | **64.10** | **0.00** | **59.06** | **74.32** | **66.22** | **65.57** | **64.79** |
| a) Working | 0.00 | 54.04 | 0.00 | 50.43 | 65.42 | 57.20 | 58.51 | 55.43 |
| b) Idle | 0.00 | 10.96 | 0.00 | 8.63 | 8.90 | 9.02 | 7.06 | 9.36 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **19.61** | **20.93** | **23.26** | **21.55** | **22.33** |
| a) River " | 0.00 | 9.02 | 0.00 | 8.88 | 9.02 | 9.03 | 9.05 | 9.00 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.04 | 2.98 | 3.05 | 3.21 | 2.98 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.39 |
| d) River | 0.00 | 7.61 | 0.00 | 7.69 | 8.93 | 11.14 | 9.29 | 9.96 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **104.90** | **157.30** | **112.50** | **139.40** | **111.70** |

c) A probable outcome of better draught facilities could mean greater arrival of larger ships at Calcutta. Such a possibility is considered in the present scenario. Previously, 85% of the arriving ships fell in the category 2C. This was now increased to 95% and the river draught figures of 1991-92 were also used as inputs. Table 5.11 summarises the original set of estimates S1 and the new one, S6. A comparison of S1 and S6 brings into focus, the following observations.

Due to the change in the river draught figures and in spite of a higher percentage of ships belonging to the heavier category, the average waiting at Sandhead for neaped ships fell by about 13 hours. This fall in waiting time resulted in a smoother flow of traffic in the system which lowered the service time of ships. This lowering of average waiting time and service time was less pronounced in case of ship type 2C(R) as more ships came under this category as a direct consequence of the experimental design and a shift from the neaped category due to improved draught conditions. In the case of ship type 1C, which now accounted for a smaller slice of traffic a lowering of the average service time by about 4 hours is noted which is reflected in the turnaround time. There were minor changes in the other components of turnaround time, which eventually cancelled out.

d) A case using the draught figures of 1991-92 is now considered where ship traffic is greatly enhanced. The new interarrival mean of 24.90 hours has replaced the old mean of 54.90 hours and the new set of results is denoted by S7. Table 5.12 gives a comparative study of S1 and S7.

**Table 5.11**
**Comparison of Original Results With Those After Altering River Draught and Arrival Pattern**

| | Ship Type 2C | | | | Ship Type 1C | | | |
|---|---|---|---|---|---|---|---|---|
| | S1 | | S6 | | S1 | | S6 | |
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **15.07** | **49.53** | **10.90** | **36.15** | **11.48** |
| a) Berth | 0.00 | 0.00 | 0.00 | 1.36 | 0.00 | 0.05 | 0.00 | 0.79 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.10 |
| c) River | 0.00 | 12.42 | 0.00 | 13.71 | 0.00 | 10.74 | 0.00 | 10.59 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **12.44** | **12.52** | **12.12** | **12.14** | **12.28** |
| a) River " | 0.00 | 8.98 | 0.00 | 9.01 | 9.22 | 8.98 | 8.82 | 9.04 |
| b) Harbour " | 0.00 | 3.31 | 0.00 | 3.43 | 3.30 | 3.14 | 3.32 | 3.24 |
| **Berth Time** | **0.00** | **64.10** | **0.00** | **59.94** | **74.32** | **66.22** | **68.35** | **66.66** |
| a) Working | 0.00 | 54.04 | 0.00 | 52.07 | 65.42 | 57.20 | 60.30 | 57.46 |
| b) Idle | 0.00 | 10.06 | 0.00 | 7.87 | 8.90 | 9.02 | 8.05 | 9.20 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **18.25** | **20.93** | **23.26** | **19.86** | **20.69** |
| a) River " | 0.00 | 9.02 | 0.00 | 8.65 | 9.02 | 9.03 | 9.29 | 9.11 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.15 | 2.98 | 3.05 | 2.96 | 3.00 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.11 |
| d) River | 0.00 | 7.61 | 0.00 | 6.45 | 8.93 | 11.14 | 7.61 | 8.47 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **105.70** | **157.30** | **112.50** | **136.50** | **111.11** |

In situation S7, where the traffic intensity is much higher, it is found that the turnaround time has increased considerably, primarily due to excessive waiting for berth. It is clear therefore, that the number of berths at the Calcutta Port willhave to be increased, should the container traffic increase significantly in the future.

e) In this case, the river draught figures of 1991-92 are used and a situation considered where the ships draught requirement is higher than before, all other things remaining the same. Let the new situation be denoted by S8. In Table 5.13 below, the ships draught requirement is given for the dry and wet seasons, both during arrival and departure, for the two situations S1 and S8.

**Table 5.12**
**Comparison of Original Results With Those After Altering Mean Interarrival Time**

| | **Ship Type 1C** | | | | **Ship Type 2C** | | | |
|---|---|---|---|---|---|---|---|---|
| | S1 | | S7 | | S1 | | S7 | |
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **60.02** | **49.53** | **10.90** | **70.08** | **54.23** |
| a) Berth | 0.00 | 0.00 | 0.00 | 47.54 | 0.00 | 0.05 | 0.00 | 42.22 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 0.64 | 0.00 | 0.11 | 0.00 | 1.25 |
| c) River | 0.00 | 12.42 | 0.00 | 11.84 | 0.00 | 10.74 | 0.00 | 10.76 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **14.15** | **12.52** | **12.12** | **12.79** | **12.89** |
| a) River " | 0.00 | 8.98 | 0.00 | 8.99 | 9.22 | 8.98 | 8.79 | 8.91 |
| b) Harbour " | 0.00 | 3.31 | 0.00 | 5.16 | 3.30 | 3.14 | 4.00 | 3.98 |
| **Berth Time** | **0.00** | **64.10** | **0.00** | **58.84** | **74.32** | **66.22** | **70.03** | **67.45** |
| a) Working | 0.00 | 54.04 | 0.00 | 50.00 | 65.42 | 57.20 | 60.23 | 58.49 |
| b) Idle | 0.00 | 10.06 | 0.00 | 8.84 | 8.90 | 9.02 | 9.80 | 8.96 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **20.69** | **20.93** | **23.26** | **22.40** | **22.23** |
| a) River " | 0.00 | 9.02 | 0.00 | 9.13 | 9.02 | 9.03 | 8.70 | 9.02 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.12 | 2.98 | 3.05 | 3.27 | 3.08 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 1.05 | 0.00 | 0.04 | 2.06 | 1.52 |
| d) River | 0.00 | 7.61 | 0.00 | 7.39 | 8.93 | 11.14 | 8.37 | 8.61 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **153.70** | **157.30** | **112.50** | **175.30** | **156.80** |

**Table 5.13**

| Ship Type 1C | | | | Ship Type 2C | | | |
|---|---|---|---|---|---|---|---|
| *Arrival* | | *Departure* | | *Arrival* | | *Departure* | |
| (Dry) | (Wet) | (Dry) | (Wet) | (Dry) | (Wet) | (Dry) | (Wet) |
| (4.5-5.5) | (4.5-5.7) | (4.5-5.9) | (4.5-6.0) | (5.0-6.2) | (5.0-6.5) | (5.0-6.3) | (5.0-6.7) |
| (5.5-5.8) | (5.5-5.9) | (5.5-5.9) | (5.5-6.0) | (6.0-6.9) | (6.5-7.4) | (6.0-7.0) | (6.5-7.5) |

Table 5.14 gives a comparative picture between the original model results and those after the latest experimentation. It is found that in the case of ship type 2C, there is considerable waiting for the river. The total Sandhead wait for the neaped ships also increased considerably. This happened in spite of incorporating the improved river draught data of 1991-92. A logical conclusion from the above experiment is that a great deal of further dredging will have to be carried out in order to improve the river draught situation considerably, if deeper draughted vessels are to be accommodated in the port. Otherwise, unnecessary time will be lost in waiting for suitable navigational conditions and a great number of vessels will be neaped.

f) In this case, a combination of experiments (d) and (e) have been considered and the resultant estimates S9 compared with the original set S1 in Table 5.15. The river draught data of 1991-92 has been used with enhanced mean interarrival time of 24.90 hours and higher ships draught requirement as in the previous case. As a result, an excessive increase is found in the total turnaround time of all ship types. As expected, the lion's share of the increase in turnaround time is due to the rise in waiting for berth and waiting for river.

**Table 5.14**
**Comparison of Original Estimates With Those After Enhancing Ship's Draught**

| | Ship Type 2C | | | | Ship Type 1C | | | |
|---|---|---|---|---|---|---|---|---|
| | S1 | | S8 | | S1 | | S8 | |
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **15.72** | **49.53** | **10.90** | **77.74** | **17.01** |
| a) Berth | 0.00 | 0.00 | 0.00 | 1.91 | 0.00 | 0.05 | 0.00 | 4.50 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 1.62 | 0.00 | 0.11 | 0.00 | 1.83 |
| c) River | 0.00 | 12.42 | 0.00 | 12.19 | 0.00 | 10.74 | 0.00 | 10.68 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **12.43** | **12.52** | **12.12** | **14.19** | **13.62** |
| a) River " | 0.00 | 8.98 | 0.00 | 8.91 | 9.22 | 8.98 | 8.89 | 8.89 |
| b) Harbour " | 0.00 | 3.31 | 0.00 | 3.52 | 3.30 | 3.14 | 5.30 | 4.73 |
| **Berth** | **0.00** | **64.10** | **0.00** | **61.99** | **74.32** | **66.22** | **66.86** | **62.22** |
| a) Working | 0.00 | 54.04 | 0.00 | 53.84 | 65.42 | 57.20 | 57.60 | 53.74 |
| b) Idle | 0.00 | 10.06 | 0.00 | 8.15 | 8.90 | 9.02 | 9.26 | 8.48 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **25.06** | **20.93** | **23.26** | **29.91** | **43.05** |
| a) River " | 0.00 | 9.02 | 0.00 | 9.05 | 9.02 | 9.03 | 9.07 | 9.01 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.07 | 2.98 | 3.05 | 3.03 | 3.03 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 3.56 | 0.00 | 0.04 | 0.67 | 1.71 |
| d) River | 0.00 | 7.61 | 0.00 | 9.38 | 8.93 | 11.14 | 17.14 | 29.30 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **115.20** | **157.30** | **112.50** | **188.70** | **135.90** |

## Table 5.15

**Comparison of Original Estimates With Those After Altering Ship's Draught Requirement and Mean Interarrival Time**

| | Ship Type 2C | | | | Ship Type 1C | | | |
|---|---|---|---|---|---|---|---|---|
| | S1 | | S9 | | S1 | | S9 | |
| | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* | *(N)* | *(R)* |
| **SH Wait** | **0.00** | **12.59** | **0.00** | **96.77** | **49.53** | **10.90** | **167.60** | **119.29** |
| a) Berth | 0.00 | 0.00 | 0.00 | 78.28 | 0.00 | 0.05 | 0.00 | 101.80 |
| b) RPILOT | 0.00 | 0.17 | 0.00 | 8.13 | 0.00 | 0.11 | 0.00 | 6.95 |
| c) River | 0.00 | 12.42 | 0.00 | 10.36 | 0.00 | 10.74 | 0.00 | 10.54 |
| **Inpilotage** | **0.00** | **12.29** | **0.00** | **14.12** | **12.52** | **12.12** | **14.05** | **20.44** |
| a) River " | 0.00 | 8.98 | 0.00 | 9.01 | 9.22 | 8.98 | 9.09 | 9.02 |
| b) Harbour " | 0.00 | 3.31 | 0.00 | 5.11 | 3.30 | 3.14 | 4.96 | 11.42 |
| **Berth Time** | **0.00** | **64.10** | **0.00** | **59.10** | **74.32** | **66.22** | **63.36** | **66.87** |
| a) Working | 0.00 | 54.04 | 0.00 | 49.87 | 65.42 | 57.20 | 54.34 | 57.29 |
| b) Idle | 0.00 | 10.06 | 0.00 | 9.23 | 8.90 | 9.02 | 9.02 | 9.58 |
| **Outpilotage** | **0.00** | **20.02** | **0.00** | **35.31** | **20.93** | **23.26** | **29.89** | **46.20** |
| a) River " | 0.00 | 9.02 | 0.00 | 8.98 | 9.02 | 9.03 | 9.15 | 8.98 |
| b) Harbour " | 0.00 | 3.03 | 0.00 | 3.07 | 2.98 | 3.05 | 3.04 | 3.08 |
| c) RPILOT | 0.00 | 0.36 | 0.00 | 15.65 | 0.00 | 0.04 | 7.98 | 7.98 |
| d) River | 0.00 | 7.61 | 0.00 | 7.61 | 8.93 | 11.14 | 9.72 | 26.16 |
| **Turnaround** | **0.00** | **109.00** | **0.00** | **205.30** | **157.30** | **112.50** | **274.90** | **252.80** |

## 5.12 Conclusions

The present model enables us to predict, in precise quantitative terms, the areas where further investments would reap maximum benefits in terms of enhanced turnaround time. The objective function chosen was to evaluate the overall performance of the system in terms of the total time that a container ship spends in Calcutta port. An examination of the results obtained so far indicates that with the existing volume of traffic, the number of berths assigned for containerships are quite sufficient. So are the number of river pilots handling the container vessels. It is indeed, the waiting for proper riverine conditions that occupy the lion's share of the ships waiting time. This reveals the critical need for improving the navigability of the river if the turnaround time at Calcutta port is to be reduced.

Thus, under the existing facilities and volume of traffic, the simulation exercise indicated that it is the improvement of river draught that should be of prime concern to the port authorities. Once this is achieved and the number of ships calling at the port increase, time shortages may be felt in other port resources such as, berths and pilots. The impact of these changes can then be studied with the help of the model. The various experiments tried on the model point to the fact that if in future, with improvements in the river draught conditions, a greater volume of ships do call at the port, there will be a need to increase the resource berth. If with greater volume of traffic, the port has to accommodate deeper draughted vessels, then once again attention will have to be paid towards further improvement of river draught.

In the case of the port of Calcutta, where the stigma of inefficiency has tarnished its earlier reputation, this kind of a simulation technique may well serve as a useful tool in the hands of the port authorities in pinpointing the critical weaknesses and taking appropriate steps to improve the situation. The model provides quantitative assessment of the severity of the problem and is an important tool in pinpointing the specific areas where improvement is required. The simulated results obtained after considering the alternative policy measures need to be carefully analysed. The model can be used to study other riverine ports as well, with suitable parametric adjustments.

# Appendix 5.1
## Dimensions and Characteristics of Containerships Calling (Calcutta 1988-89)

| Shipping line | Name | Length *(m)* | Draught *(m)* | Ship Type | Capacity *(20 ft containers)* |
|---|---|---|---|---|---|
| Orient Express | Orient Success | 89.00 | 5.18 | 1C | 96 |
| Oceanic Spirit | Lhotse | 117.45 | 6.59 | 2C | 233 |
| T.S.S. | Theodore Fontaine | 110.00 | 6.23 | 2C | 190 |
| I.S.S. | Indian Courier | 119.00 | 6.67 | 2C | 242 |
| Shangri La | Bengal Progress | 135.30 | 7.50 | 2C | 357 |
| BentNielson | Edel Scheel | 102.50 | 5.86 | 1C | 152 |
| Veb Davtfracht | Halbert Stadt | 122.00 | 6.82 | 2C | 262 |
| Seagrave Shipping | Navigare | 17.02 | 6.57 | 2C | 230 |
| Bengal TigerLine | Tiger Bay | 110.00 | 6.23 | 2C | 190 |
| Seagadua Shipping | Manaslu | 104.50 | 5.96 | 1C | 161 |
| BSC | BanglarUrmi | 144.00 | 7.88 | 2C | 429 |
| BSC | Banglar Rabi | 140.00 | 7.68 | 2C | 395 |
| BSC | Banglar Shova | 144.00 | 7.88 | 2C | 429 |
| BSC | Banglar Doot | 169.16 | 8.28 | 2C | 676 |
| Zep Pacific Pvt Ltd | Pumori | 117.45 | 6.59 | 2C | 233 |
| Mars Navigation | Marianne Schultz | 135.30 | 7.50 | 2C | 357 |
| Yugo Arab Shipping | Susak | 99.60 | 5.71 | 1C | 138 |
| Irano HindShipping | Mowlavi | 166.00 | 8.90 | 2C | 642 |
| S.C.I. | Bhaba Bhuti | 152.50 | 8.28 | 2C | 506 |
| V.I.A.Shipping | Marivia | 127.70 | 7.09 | 2C | 299 |
| Black Sea Shipping | Yamburenko | 125.60 | 6.70 | 2C | 286 |
| Hoyo Kaiyun Co. Ltd | Kumul Express | 118.00 | 6.60 | 2C | 236 |
| Forbes Campbell Co. | Eagle Breeze | 126.52 | 7.04 | 2C | 292 |
| K.I. Larsen | Catherine Sif | 101.30 | 5.80 | 1C | 146 |
| K.I. Larsen | Bravo Sif | 115.50 | 6.50 | 2C | 221 |

Source: Calcutta Port Trust, Planning and Research Cell

# Appendix 5.2
## Statement Form of Basic Calcutta Model

```
GEN,MADHUBANI,CALCUTTA PORT,19/7/95
    LIMITS,8,26,400;
    NETWORK;
        RESOURCE/KBRTH(1),1;
        RESOURCE/NBRTH(4),1,6;
        RESOURCE/RPILOT(5),2,8;
        RESOURCE/HPILOT(1),3,7;
        RESOURCE/RTUG(2),3,7;
        RESOURCE/DPILOT(6),4,5;
        RESOURCE/DTUG(2),4,5;
;
;       SHIP ARRIVAL SEGMENT
;       ---------------------
        CREATE,EXPON(54.90),8,,,1;
        ACT,,.15,ARV1;
        ACT,,.85,ARV2;
ARV1      ASSIGN,ATRIB(5)=EXPON(8.93),ATRIB(6)=RNORM(52.72,18.77),
        ATRIB(7)=1;
        EVENT(1);
        ACT,,ATRIB(26).EQ.0.,AR11;
        ACT,,ATRIB(26).EQ.1.,AR12;
AR11      ASSIGN,ATRIB(1)=UNFRM(4.5,5.5),ATRIB(2)=UNFRM(4.5,5.9);
        ACT,,XX(1).NE.0.,POR1;
        ACT,,XX(1).EQ.0.,ERST;
AR12      ASSIGN,ATRIB(1)=UNFRM(4.5,5.7),ATRIB(2)=UNFRM(4.5,6.0);
        ACT,,XX(1).NE.0.,POR1;
        ACT,,XX(1).EQ.0.,ERST;
ARV2      ASSIGN,ATRIB(5)=EXPON(9.69),ATRIB(6)=RNORM(57.48,24.57),
        ATRIB(7)=2;
        EVENT(1);
        ACT,,ATRIB(26).EQ.0.,AR21;
        ACT,,ATRIB(26).EQ.1.,AR22;
AR21      ASSIGN,ATRIB(1)=UNFRM(5.0,6.2),ATRIB(2)=UNFRM(5.0,6.3);
        ACT,,XX(1).NE.0.,POR1;
        ACT,,XX(1).EQ.0.,ERST;
AR22      ASSIGN,ATRIB(1)=UNFRM(5.0,6.5),ATRIB(2)=UNFRM(5.0,6.7);
        ACT,,XX(1).NE.0.,POR1;
        ACT,,XX(1).EQ.0.,ERST;
        EVENT(1);



;
;       INITIALIZATION SEGMENT
;       ---------------------
ERST      ASSIGN,XX(1)=1;       INITIALIZATION OVER
        ASSIGN,XX(2)=5;     NUMBER OF RPILOT AT SANDHEADS
        ASSIGN,XX(3)=0;     NUMBER OF RPILOT AT HARBOUR
        ACT,,,POR1;


;       PORT OPERATION SEGMENT
;       --------------------------
POR1      ASSIGN,ATRIB(9)=TNOW;
       AWAIT(1),ALLOC(1);   WAIT FOR AN AVAILABLE BERTH
```

```
        ACT,,ATRIB(7).EQ.1,T01;
        ACT,,ATRIB(7).EQ.2,T02;
T01     COLCT,INT(9),T01 WT FOR BERTH;
        ACT,,,PORT;
T02     COLCT,INT(9),T02 WT FOR BERTH;
        ACT,,,PORT;
PORT    ASSIGN,ATRIB(11)=TNOW;
        AWAIT(2),ALLOC(2);   WAIT FOR AN AVAILABLE RPILOT
        ACT,,ATRIB(12).EQ.0,COL1;
        ACT,,ATRIB(12).EQ.1,DUM1;
DUM1    ASSIGN,ATRIB(13)=UNFRM(7.5,10.5);
        ACT,ATRIB(13),,COL1;
COL1    ASSIGN,ATRIB(13)=UNFRM(7.5,10.5);
        ACT,,ATRIB(7).EQ.1,T11;
        ACT,,ATRIB(7).EQ.2,T12;
T11     COLCT,INT(11),T11  WT FOR RPILOT;
        ACT,,,IRIVER;
T12     COLCT,INT(11),T12  WT FOR RPILOT;
        ACT,,,IRIVER;
IRIVER  ASSIGN,ATRIB(14)=TNOW;
        EVENT(2);
        ACT,ATRIB(15),,COL2; DELAY FOR TIDE  AND DRAFT
COL2    ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
        ACT,,ATRIB(7).EQ.1,T21;
        ACT,,ATRIB(7).EQ.2,T22;
        ACT,,ATRIB(7).EQ.3,T23; SPECIAL TYPE CHANGE FOR NEAPED SHIPS
T21     COLCT,INT(14),T21  WT FOR RIVER;
        ACT,,,INPLOT;
T22     COLCT,INT(14),T22  WT FOR RIVER;
        ACT,,,INPLOT;
T23     COLCT,INT(14),T23  WT FOR RIVER;
        ACT,,,INPLOT;
INPLOT  ASSIGN,ATRIB(16)=TNOW;
        ACT/1,ATRIB(13);     RIVER INPILOTAGE TIME
        FREE,RPILOT/1;      RELEASE THE RPILOT
        ASSIGN,XX(3)=XX(3)+1;
COL4    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,,ATRIB(7).EQ.1,T31;
        ACT,,ATRIB(7).EQ.2,T32;
        ACT,,ATRIB(7).EQ.3,T33;
T31     COLCT,INT(16),T31 RIVER INPILOTAGE TIME;
        ACT,,,STAY;
T32     COLCT,INT(16),T32 RIVER INPILOTAGE TIME;
        ACT,,,STAY;
T33     COLCT,INT(16),T33 RIVER INPILOTAGE TIME;
        ACT,,,STAY;
STAY    AWAIT(3),ALLOC(3); WAIT FOR AVAILABLE HPILOT AND TUGS
TRBE    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,UNFRM(1.,2.); TRAVEL TO LOCKS
        FREE,HPILOT/1; RELEASE THE HPILOT
        FREE,RTUG/2; RELEASE THE RTUGS
        ACT,,,COL3;
COL3    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        AWAIT(4),ALLOC(4); WAIT FOR AVAILABLE DPILOT AND DTUGS
URBE    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,UNFRM(1.,2.);
        FREE,DPILOT/1; RELEASE THE DPILOT
        FREE,DTUG/2;  RELEASE THE DTUGS
        ACT,,,BERTH;
BERTH   ASSIGN,ATRIB(17)=TNOW;
        ACT,ATRIB(6),,SCOL;
SCOL    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,,ATRIB(7).EQ.1,S1;
        ACT,,ATRIB(7).EQ.2,S2;
```

```
       ACT,,ATRIB(7).EQ.3,S3;
S1       COLCT,INT(17),S1 CARGO HANDLING TIME;
       ACT,,,BER2;
S2       COLCT,INT(17),S2 CARGO HANDLING TIME;
       ACT,,,BER2;
S3       COLCT,INT(17),S3 CARGO HANDLING TIME;
       ACT,,,BER2;
BER2     ASSIGN,ATRIB(23)=TNOW;
       ACT,ATRIB(5),,ICOL;
ICOL     ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       ACT,,ATRIB(7).EQ.1,I1;
       ACT,,ATRIB(7).EQ.2,I2;
       ACT,,ATRIB(7).EQ.3,I3;
I1       COLCT,INT(23),I1 IDLE TIME;
       ACT,,,BER3;
I2       COLCT,INT(23),I2 IDLE TIME;
       ACT,,,BER3;
I3       COLCT,INT(23),I3 IDLE TIME;
       ACT,,,BER3;
BER3     ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       AWAIT(5),ALLOC(5); WAIT FOR AVAILABLE DPILOT AND DTUGS
COL5     ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       ACT,,ATRIB(18).EQ.1,RELKB;
       ACT,,ATRIB(18).EQ.2,RELNB;
RELKB    FREE,KBRTH/1;          RELEASE A BERTH,KPD
       ACT,,,ENREL;
RELNB    FREE,NBRTH/1;          RELEASE A BERTH,NSD
       ACT,,,ENREL;
ENREL    ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       ACT,,ATRIB(7).EQ.1,T41;
       ACT,,ATRIB(7).EQ.2,T42;
       ACT,,ATRIB(7).EQ.3,T43;
T41      COLCT,INT(17),T41 TIME AT BERTH;
       ACT,,,OUPLOT;
T42      COLCT,INT(17),T42 TIME AT BERTH;
       ACT,,,OUPLOT;
T43      COLCT,INT(17),T43 TIME AT BERTH;
       ACT,,,OUPLOT;
OUPLOT   ASSIGN,ATRIB(25)=TNOW;
       ACT,UNFRM(1.,2.),,DPREL; TRAVEL TO LOCK
DPREL    FREE,DPILOT/1; RELEASE THE DPILOT
       FREE,DTUG/2; RELEASE THE DTUGS
       ACT,,,WAIT;
WAIT     AWAIT(7),ALLOC(6); WAIT FOR AVAILABLE HPILOT AND RTUGS
COL6     ASSIGN,ATRIB(8)=0;  DUMMY ASSIGNMENT
       ACT,UNFRM(1.,2.),,HPREL; TRAVEL TO GARDEN REACH
HPREL    FREE,HPILOT/1; RELEASE THE HPILOT
       FREE,RTUG/2; RELEASE THE RTUGS
       ACT,,,COL7;
COL7     ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
       ACT,,ATRIB(7).EQ.1,H1;
       ACT,,ATRIB(7).EQ.2,H2;
       ACT,,ATRIB(7).EQ.3,H3;
H1       COLCT,INT(25),H1 HARBOUR OUTPILOTAGE TIME;
       ACT,,,GRDH;
H2       COLCT,INT(25),H2 HARBOUR OUTPILOTAGE TIME;
       ACT,,,GRDH;
H3       COLCT,INT(25),H3 HARBOUR OUTPILOTAGE TIME;
       ACT,,,GRDH;
GRDH     ASSIGN,ATRIB(19)=TNOW;
       AWAIT(8),ALLOC(7); WAIT FOR AVAILABLE RPILOT
       ACT,,ATRIB(24).EQ.0,DUM2;
       ACT,,ATRIB(24).EQ.1,DUM3;
DUM3     ASSIGN,ATRIB(24)=UNFRM(7.5,10.5);
```

```
      ACT,ATRIB(24),,DUM2;
DUM2     ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
      ACT,,ATRIB(7).EQ.1,T51;
      ACT,,ATRIB(7).EQ.2,T52;
      ACT,,ATRIB(7).EQ.3,T53;
T51     COLCT,INT(19),T51  WT FOR RPILOT;
      ACT,,,ORIVER;
T52     COLCT,INT(19),T52  WT FOR RPILOT;
      ACT,,,ORIVER;
T53     COLCT,INT(19),T53  WT FOR RPILOT;
      ACT,,,ORIVER;
ORIVER   ASSIGN,ATRIB(20)=TNOW;
      EVENT(3);
      ACT,ATRIB(21),,COL8;  DELAY FOR TIDE AND DRAFT
COL8     ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
      ACT,,ATRIB(7).EQ.1,T61;
      ACT,,ATRIB(7).EQ.2,T62;
      ACT,,ATRIB(7).EQ.3,T63;
T61     COLCT,INT(20),T61  WT FOR RIVER;
      ACT,,,TROUT;
T62     COLCT,INT(20),T62  WT FOR RIVER;
      ACT,,,TROUT;
T63     COLCT,INT(20),T63  WT FOR RIVER;
      ACT,,,TROUT;
TROUT    ASSIGN,ATRIB(22)=TNOW;
      ASSIGN, ATRIB(23)=UNFRM(7.5,10.5); TIME TO REACH SH
      ACT/2,ATRIB(23);  RIVER OUTPILOTAGE TIME
      FREE,RPILOT/1;    RELEASE A RPILOT
      ASSIGN,XX(2)=XX(2)+1;
      ACT,,,COL9;
COL9     ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT;
      ACT,,ATRIB(7).EQ.1,OPT1;
      ACT,,ATRIB(7).EQ.2,OPT2;
      ACT,,ATRIB(7).EQ.3,OPT3;
OPT1     COLCT,INT(22),O1 RIVER OUTPILOTAGE TIME;
      ACT,,,DPT1;
OPT2     COLCT,INT(22),O2 RIVER OUTPILOTAGE TIME;
      ACT,,,DPT2;
OPT3     COLCT,INT(22),O3 RIVER OUTPILOTAGE TIME;
      ACT,,,DPT3;
DPT1     COLCT,INT(9),T1 IN PORT TIME;
      TERM;
DPT2     COLCT,INT(9),T2 IN PORT TIME;
      TERM;
DPT3     COLCT,INT(9),T3 IN PORT TIME;
      TERM;
      ENDNETWORK;
INIT,0,17520;
FIN;
```

# CHAPTER 6

# THE PORT OF HALDIA: A PERFORMANCE STUDY THROUGH SIMULATION



## 6.1 Introduction

In the present chapter, the simulation model used to represent tanker handling at Haldia will be discussed, using the special purpose simulation language SLAM II. In order to do so, a clear understanding of the port situation at Haldia is essential. In the past few decades, the shipping and ports sector underwent a veritable technical revolution with mechanised cargo handling, modern facilities and gigantic ships. Thus, port authorities across the seas faced a common problem of adaptation to the new scheme of things. The severe draught problem at Calcutta, which seriously impacted upon the size of the calling vessels, left the authorities no other alternative but to embark upon the construction of the subsidiary deepwater port of Haldia.

Haldia was planned with the following two objectives:

a) to respond to the enlargement of contemporary ship size by providing better draught conditions; and

b) to develop coastal ancillary industries such as petrochemical and fertiliser production.

It has been noted above that the Haldia dock system is located on the right bank of the Hooghly river, 104 km downstream from Calcutta. Construction work began in 1964 and the port was formally opened in 1977. The first construction in Haldia was a jetty for the handling of POL (Petroleum and Other Lubricants) in order to feed the Barauni Refinery. The construction of the oil jetty commenced in June 1965 and was completed in July 1968; and a pipeline connected the jetty and the refinery. Eventually Haldia emerged as an important deep water port under the jurisdiction of Calcutta Port Trust whose primary cargo was POL.

## 6.2 Ship Handling at the Port of Haldia

Earlier traffic studies have revealed that, POL has always accounted for the lions share of the port's traffic. At present, tankers call at Haldia with an average load of 30,000 to 35,000 tonnes after discharging part of their cargo at ports like Madras so that the ship's draught requirement is lessened. The crude POL which is usually imported from the Gulf countries is refined by the Indian Oil Corporation at Haldia which has a refining capacity of 2,500,000 tonnes per year.

An arriving tanker waits at Sandhead until a river pilot is allocated to her. Then she checks for suitable river conditions and tide timings before starting on her inward journey. The time criterion for entry into the river from Sandhead for a ship of average speed is 5 hours before high water at Sagar or 1 hour after low water at Sagar. The time criterion for exit from Haldia is during low water at Diamond Harbour or 45 minutes after low water at Haldia. Once, this time criterion is met, an arriving ship is then guided by a river pilot on its journey up the Hooghly. When it is still about an hour or so to reach the Haldia jetty, two river tugs join the ship. Then the river pilot, with the help of the two tugs, berths the vessel, provided a berth is available. At the berth, the ship completes her loading-unloading operations. Thereafter, during departure, the river pilot guides the vessel into the river, on its outward journey, with the help of the two river tugs. After about an hour or so, the river tugs are released and they return to the jetty area. The river pilot then guides the vessel right up to

Sandhead. The ship handling procedure is therefore, quite similar compared to Calcutta but on a somewhat simpler scale.

Actual port data pertaining to tanker handling at Haldia in 1988-89 is used for the simulation exercise. In that particular year, the interarrival time of tankers visiting the port was calculated to be exponentially distributed with mean 27.37 hours. In the model, two types of ships are considered:

1. Ship Type 1 includes those requiring a full load draught of less than 10 metres; and
2. Ship Type 2 includes those requiring a full load draught greater than or equal to 10 metres .

Within each ship type there are two subtypes – A and B. Subtype A includes those having an actual draught which is half of or less than half of the fully loaded draught requirement. Subtype B includes those ships which have an actual draught greater than half of the fully loaded draught. As in the Calcutta model, ships which had to wait for more than 24 hours at Sandheads due to draught restrictions formed a separate category called neaped ships. On the basis of the observed data of 1988-89, the following parameters were set for each ship type.

*Ship Type 1A*

This particular type accounted for 12% of all tanker arrivals in 1988-89. The loading unloading time was found to be exponentially distributed with mean 12.84 hours while the idle time at berth was found to be exponentially distributed with mean 10.43 hours. The ship's draught requirement was found to be between 4 metres to 5 metres.

*Ship Type 1B*

15% of tanker arrivals at Haldia in 1988-89 fell in this category. The loading-unloading time was exponentially distributed with mean 17.26 hours while idle time was exponentially distributed with mean 11.06 hours. The ship's draught requirement was between 5 metres to 7 metres.

*Ship Type 2A*

This category accounted for the lion's share covering 52% all tanker arrivals at Haldia in 1988-89. The loading unloading time was exponentially distributed with mean 15.21 hours and idle time was exponentially distributed with mean 10.48 hours. The ship's draught requirement was between 6 metres to 7 metres.

*Ship Type 2B*

This category accounted for the remaining 21% of total tanker arrivals. The loading unloading time was exponentially distributed with mean 23.89 hours and idle time was exponentially distributed with mean 11.23 hours. The ship's draught requirement was between 7 metres to 8 metres.

At the very outset, the port resources at Haldia available for the handling of tankers in 1988-89 were specified. Although, there was just one oil jetty to handle tankers at that time, an ore berth was often made available to accommodate tankers in the event of heavy tanker traffic. As a result, the port facilities, in our model consisted of two berths to accommodate the tankers. Also, there were five river pilots and four river tugs to assist the tankers during inpilotage and outpilotage. As in the case of Calcutta, the Haldia model was coded in SLAM II with FORTRAN subroutines which replicated the sequential chain of activities and events which were initiated by a ship arrival to the system. The model was run for 17,520 hours of simulation time and the model results agreed quite well with reality. Table 6.1 gives a comparative picture of the observed values and estimates of turnaround time and its components.

**Table 6.1**
**Comparison of Observed and Estimated Turnaround Time and Components**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Obs* | *Est* | *Obs* | *Est* | *Obs* | *Est* | *Obs* | *Est* | *Obs* | *Est* |
| **1. SH Wait** | **4.5** | **7.4** | **6.3** | **8.52** | **7.24** | **8.93** | **7.73** | **8.75** | **74.96** | **75.51** |
| a) RPILOT | 0.00 | 0.85 | 0.00 | 1.62 | 0.00 | 2.48 | 0.00 | 1.94 | 0.00 | 0.00 |
| b) River | 0.00 | 6.51 | 0.00 | 6.90 | 0.00 | 6.45 | 0.00 | 6.81 | 0.00 | 0.00 |
| **2. Inpilotage** | **15.5** | **11.1** | **11.2** | **9.35** | **14.02** | **12.28** | **16.93** | **11.99** | **14.74** | **6.24** |
| a) River " | 0.00 | 5.02 | 0.00 | 4.96 | 0.00 | 5.08 | 0.00 | 4.98 | 0.00 | 4.98 |
| b) Berth wait | 0.00 | 6.12 | 0.00 | 4.39 | 0.00 | 7.20 | 0.00 | 7.01 | 0.00 | 1.26 |
| **1 + 2** | **20.0** | **18.5** | **17.5** | **17.87** | **21.26** | **21.21** | **24.66** | **20.74** | **89.70** | **81.20** |
| **3. Berth** | **25.7** | **27.0** | **30.5** | **28.00** | **26.97** | **26.09** | **41.03** | **32.75** | **31.81** | **31.19** |
| a) Working | 13.7 | 14.8 | 19.1 | 18.29 | 15.76 | 14.53 | 25.35 | 20.90 | 19.44 | 22.62 |
| b) Idle | 11.9 | 12.1 | 11.3 | 9.71 | 11.21 | 11.56 | 15.68 | 11.85 | 12.37 | 8.57 |
| **4. Outpilotage** | **6.90** | **11.7** | **9.5** | **11.02** | **8.77** | **11.77** | **10.27** | **16.01** | **11.75** | **15.21** |
| a) River " | 0.00 | 3.54 | 0.00 | 3.49 | 0.00 | 3.52 | 0.00 | 3.53 | 0.00 | 3.41 |
| b) Harbour " | 0.00 | 1.54 | 0.00 | 1.28 | 0.00 | 1.38 | 0.00 | 1.15 | 0.00 | 4.92 |
| c) River wait | 0.00 | 6.62 | 0.00 | 6.25 | 0.00 | 6.87 | 0.00 | 11.33 | 0.00 | 6.88 |
| **Turnaround** | **52.6** | **57.2** | **57.5** | **56.89** | **57.06** | **59.07** | **75.70** | **69.50** | **133.1** | **127.60** |

A comparison of the observed values and their corresponding estimates brings into focus the following observations:

a) There was quite a close correspondence between the observed and estimated values of total turnaround time. This was particularly pronounced in the case of ship type 2A, which accounted for the majority of all ship arrivals (52%). Here, the discrepancy was as low as 2 hours only.

b) There are 4 major components which were again subdivided. They are as follows:

1) Total Sandhead wait

i) wait for river pilot

ii) wait for river

This included the time that a ship waits at Sandhead for the above mentioned requirements. Once a river pilot is allocated to the ship and the river conditions deemed suitable, the ship commenced its inward journey.

2) Total inpilotage

i) river inpilotage

ii) wait for berth

This includes the time that a ship spends navigating in the riverine stretch and the time she spends outside the locks waiting for an available berth.

3) Total time at berth

i) cargo handling time

ii) idle time

This includes the time that the ship spends in the berth, either involved in actual loading-unloading operations or lying idly. Idle time may be encountered due to any of the following reasons: non-availability of labour/gangs, no night navigation, shortage of equipment, vessels option, tidal constraint, weather, recess, strike, holiday, customs formalities, time lost in hatch opening, electricity failures etc.

4) Total outpilotage

i) harbour outpilotage

ii) waiting for river

iii)river outpilotage

This includes the time that a ship spends to get out of the locks, the waiting for suitable riverine conditions and the time taken for the ship for outbound navigation.

## 6.3 Results

1. In the component 'Total Sandhead wait', it is found that the estimated values are marginally higher than their observed counterparts, the discrepancy ranging between 1 to about 3 hours.

This overestimation was present in the case of all ship types, but was almost negligible for ship types 2A and 2B which, together accounted for about 73% of all tanker arrivals in that year.

2. In the case of the component 'Total inpilotage' a slight underestimation is found, i.e. the estimated values are marginally lower than the observed values.

As a result, the sum total of 1 and 2, i.e. the total time taken by a ship from arrival at Sandhead to arrival at berth, shows very close correspondence between the model results and reality. The discrepancy is the least in the case of ship type 2A, which accounts for the majority of all ship arrivals. This is an encouraging sign.

3. The total time at berth shows a close correspondence between observed and estimated values. The estimations of both the components, i.e. loading unloading time and idle time are close approximations of observed values. Only in the case of ship type 2B, which accounted for only 21% of all ship arrivals, the estimated value was somewhat lower than that observed in actual practice.

4. There were some minor discrepancies between the estimated and observed values of total outpilotage time. In all the cases, the estimated value was somewhat higher than the observed value. It may be pointed out that the main component of the outpilotage time was the waiting for river. However, in the case of ship type 2A accounting for 52% of all tanker arrivals, this discrepancy was marginal.

5. As mentioned above, there was quite a close correspondence between the observed and estimated values of total turnaround time. This shows that the simulated model results were quite encouraging as they were a good approximation of reality.

Certain alternative scenarios on the model were also tried, to test its sensitivity to various parametric changes.

### *Scenario 1: Increasing the Number of Berths*

The model was run for 17,520 hours of simulation time after increasing the number of berths from 2 to 4. This was the first sensitivity analysis that was undertaken to estimate the effect of an increase in the resource berth on the turnaround time and its components of tankers visiting the port of Haldia. Table 6.2 gives a comparative picture of the original estimates (oe) and the model estimates after the parametric change (s1).

**Table 6.2**
**Comparison of Original Estimated Turnaround Time (oe) and Components With New Estimates (s1) After Increasing Number of Berths**

| | **1A** | | **1B** | | **2A** | | **2B** | | **Neaped** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s1* | *oe* | *s1* | *oe* | *s1* | *oe* | *s1* | *oe* | *s1* |
| **1. SH Wait** | **7.36** | **7.43** | **8.52** | **7.61** | **8.93** | **6.40** | **8.75** | **6.79** | **75.51** | **81.01** |
| a) RPILOT | 0.85 | 0.26 | 1.62 | 0.43 | 2.48 | 0.26 | 1.94 | 0.28 | 0.00 | 0.00 |
| b) River | 6.51 | 7.17 | 6.90 | 7.18 | 6.45 | 6.14 | 6.81 | 6.51 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.1** | **5.04** | **9.35** | **5.06** | **12.28** | **5.07** | **11.99** | **5.05** | **6.24** | **5.16** |
| a) River " | 5.02 | 5.04 | 4.96 | 5.06 | 5.08 | 5.07 | 4.98 | 5.05 | 4.98 | 5.16 |
| b) Berth wait | 6.12 | 0.04 | 4.39 | 0.00 | 7.20 | 0.05 | 7.01 | 0.04 | 1.26 | 0.00 |
| **3. Berth** | **27.0** | **24.6** | **28.0** | **31.13** | **26.09** | **23.35** | **32.75** | **34.53** | **31.19** | **35.14** |
| a) Working | 14.8 | 12.2 | 18.2 | 19.46 | 14.53 | 13.88 | 20.90 | 23.86 | 22.62 | 25.41 |
| b) Idle | 12.1 | 12.4 | 9.71 | 11.67 | 11.56 | 9.47 | 11.85 | 10.67 | 8.57 | 9.73 |
| **4. Outpilotage** | **11.7** | **12.2** | **11.0** | **11.50** | **11.77** | **12.27** | **16.01** | **17.76** | **15.21** | **10.99** |
| a) River " | 3.54 | 3.46 | 3.49 | 3.47 | 3.52 | 3.46 | 3.53 | 3.47 | 3.41 | 3.61 |
| b) Harbour " | 1.54 | 1.57 | 1.28 | 1.53 | 1.38 | 1.53 | 1.15 | 1.81 | 4.92 | 1.52 |
| c) River wait | 6.62 | 7.18 | 6.25 | 6.50 | 6.87 | 7.28 | 11.33 | 12.48 | 6.88 | 5.86 |
| **Turnaround** | **57.2** | **49.3** | **56.8** | **55.30** | **59.07** | **47.09** | **69.50** | **64.13** | **127.6** | **132.30** |

It is found that as a direct consequence of increasing the resource berth, the waiting for berth diminished considerably for all ship types. The maximum average waiting for any ship type was encountered by type 2A and that too for 0.05 hours only. As a result, the total turnaround time also fell except in the case of the neaped variety. This was caused by about a 4 hour rise on an average in the 'Total time at berth' of ships belonging to the neaped category. There were marginal changes in the other components of turnaround time. Thus it is found that due to parametric changes incorporated in the model, the resultant estimates have changed in the right direction, i.e. the waiting for berth has diminished for all ship types. However, due to the inherent randomness in the variables of the model, a simulation run with even a small parametric change may cause unexpected variations in model output.

### *Scenario 2: Increasing the Number of River Pilots*

The second parametric change that was incorporated on the Haldia model was to increase the number of river pilots from 5 to 7. Table 6.3 gives a comparison of the original model estimates (oe) and estimates after making this parametric change (s2). It is found that the component 'Wait for river pilot' was originally a very small part of the total turnaround time. The longest a ship type waited on an average for this resource, was ship type 2A, which waited for 2.48 hours only. Thus, it is quite clear that given the existing volume of traffic, the existing number of river pilots were quite sufficient to handle tankers calling at Haldia. A rise in the number of river pilots would at best, cause marginal improvements in turnaround time. A comparison of the estimates confirmed this observation.

It is observed that on increasing the number of river pilots, the estimated average waiting for river pilot for ship type 2A decreased to 0.83 hours. Similar decreases were noted in the case of other ship types as well. As a consequence, there were marginal declines in the total turnaround time of ship types 1A, 1B and 2A. However, in the case of ship type 2B, the turnaround time increased by about 5 hours due to a corresponding rise in a particular component namely, cargo handling time. In the case of neaped ships, there was a fall in the turnaround time estimates from 127.60 hours to 106.70 hours. This was due to decreases in the waiting for river and cargo handling time. Thus, it appears that the parametric changes coupled with the inherent randomness of the model may sometimes cause the estimates to deviate to a certain extent. In spite of this, the general pattern of deviation caused by a parametric change is apparent from the model.

**Table 6.3**
**Comparison of Original Estimated Turnaround Time (oe) and Components With New Estimates (s2) After Increasing Number of River Pilots**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s2* | *oe* | *s2* | *oe* | *s2* | *oe* | *s2* | *oe* | *s2* |
| **1. SH Wait** | **7.4** | **6.0** | **8.5** | **6.65** | **8.93** | **6.93** | **8.75** | **8.04** | **75.51** | **63.47** |
| a) RPILOT | 0.85 | 0.0 | 1.6 | 0.71 | 2.48 | 0.83 | 1.94 | 1.19 | 0.00 | 0.00 |
| b) River | 6.51 | 6.0 | 6.9 | 5.94 | 6.45 | 6.10 | 6.81 | 6.85 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.1** | **12.3** | **9.3** | **12.65** | **12.28** | **14.51** | **11.99** | **13.09** | **6.24** | **9.81** |
| a) River " | 5.02 | 5.0 | 4.9 | 4.97 | 5.08 | 5.01 | 4.98 | 4.05 | 4.98 | 5.10 |
| b) Berth wait | 6.12 | 7.3 | 4.3 | 7.68 | 7.20 | 9.50 | 7.01 | 8.04 | 1.26 | 4.71 |
| **1 + 2** | **18.5** | **18.3** | **17.8** | **19.30** | **21.21** | **21.44** | **20.74** | **21.13** | **81.20** | **73.28** |
| **3. Berth** | **27.0** | **24.7** | **28.0** | **24.64** | **26.09** | **25.78** | **32.75** | **36.71** | **31.19** | **21.35** |
| a) Working | 14.8 | 12.3 | 18.2 | 14.25 | 14.53 | 14.78 | 20.90 | 25.46 | 22.62 | 15.69 |
| b) Idle | 12.1 | 12.4 | 9.71 | 10.39 | 11.56 | 11.00 | 11.85 | 11.25 | 8.57 | 5.66 |
| **4. Outpilotage** | **11.7** | **11.6** | **11.0** | **11.83** | **11.77** | **11.09** | **16.01** | **16.25** | **15.21** | **12.07** |
| a) River " | 3.54 | 3.5 | 3.49 | 3.54 | 3.52 | 1.08 | 3.53 | 3.61 | 3.41 | 3.39 |
| b) Harbour " | 1.54 | 1.5 | 1.28 | 1.54 | 1.38 | 3.66 | 1.15 | 0.51 | 4.92 | 1.52 |
| c) River wait | 6.62 | 6.6 | 6.25 | 6.75 | 6.87 | 6.35 | 11.33 | 12.13 | 6.88 | 7.16 |
| **Turnaround** | **57.2** | **54.5** | **56.8** | **55.77** | **59.07** | **58.31** | **69.50** | **74.09** | **127.60** | **106.70** |

### *Scenario 3: Increasing the Number of River Tugs*

A look at the earlier tables will show that the waiting for a river tug, if any, is not shown separately as a component of turnaround time but is implicitly included during inpilotage and outpilotage. Just like a berth or a river pilot, a river tug is also a port resource and hence the effect of an increase or decrease in the resource on the turnaround time of ships require special attention. Table 6.4 gives a comparison of the original estimates (oe) and the estimates in the new scenario (s3), after increasing the number of river tugs from 4 to 6.

**Table 6.4**
**Comparison of Original Estimated Turnaround Time (oe) and Components Thereof With New Estimates (s3) After Increasing Number of River tugs**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s3* | *oe* | *s3* | *oe* | *s3* | *oe* | *s3* | *oe* | *s3* |
| **1. SH Wait** | **7.36** | **7.36** | **8.52** | **8.52** | **8.93** | **8.93** | **8.75** | **8.75** | **75.51** | **75.51** |
| a) RPILOT | 0.85 | 0.85 | 1.62 | 1.62 | 2.48 | 2.48 | 1.94 | 1.94 | 0.00 | 0.00 |
| b) River | 6.51 | 6.51 | 6.90 | 6.90 | 6.45 | 6.45 | 6.81 | 6.81 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.1** | **11.1** | **9.35** | **9.33** | **12.28** | **12.26** | **11.99** | **11.98** | **6.24** | **6.24** |
| a) River " | 5.02 | 5.02 | 4.96 | 4.94 | 5.08 | 5.08 | 4.98 | 4.99 | 4.98 | 4.98 |
| b) Berth wait | 6.12 | 6.10 | 4.39 | 4.39 | 7.20 | 7.18 | 7.01 | 6.99 | 1.26 | 1.26 |
| **3. Berth** | **27.0** | **27.0** | **28.0** | **27.99** | **26.09** | **26.09** | **32.75** | **32.75** | **31.19** | **31.19** |
| a) Working | 14.8 | 14.8 | 18.2 | 18.29 | 14.53 | 14.53 | 20.90 | 20.90 | 22.62 | 22.62 |
| b) Idle | 12.1 | 12.1 | 9.71 | 9.70 | 11.56 | 11.56 | 11.85 | 11.85 | 8.57 | 8.57 |
| **4. Outpilotage** | **11.7** | **11.7** | **11.0** | **11.05** | **11.77** | **11.73** | **16.01** | **16.02** | **15.21** | **14.66** |
| a) River " | 3.54 | 3.53 | 3.49 | 3.52 | 3.52 | 3.53 | 3.53 | 3.53 | 3.41 | 3.41 |
| b) Harbour " | 1.54 | 1.52 | 1.28 | 1.26 | 1.38 | 1.37 | 1.15 | 1.14 | 4.92 | 4.37 |
| c) River wait | 6.62 | 6.66 | 6.25 | 6.27 | 6.87 | 6.83 | 11.33 | 11.35 | 6.88 | 6.88 |
| **Turnaround** | **57.2** | **57.2** | **56.8** | **56.89** | **59.07** | **59.01** | **69.50** | **69.50** | **127.6** | **127.60** |

It is found that in the changed situation, both inpilotage time as well as outpilotage time have remained more or less unchanged. The total turnaround time, together with its other components, has also remained almost unchanged.

This implies that the original number of river tugs are quite sufficient to handle the existing volume of traffic. As a result, an increase in this particular resource had almost no impact on the turnaround time and its components for tankers visiting Haldia.

## *Scenario 4: Increased Arrival Rate of Ships*

In this new experiment, a situation where tanker traffic at Haldia is greatly increased is considered. In the original model, the interarrival time of ships was exponentially distributed with a mean of 27.37 hours. This mean now was reduced to 17.37 hours, and with all the other things remaining identical, the model was run for

17,520 hours of simulation time. A comparison of the original estimates (oe) and those in the new scenario (s4) are shown in Table 6.5.

**Table 6.5**
**Comparison of Original Estimated Turnaround Time (oe) and Components Thereof With New Estimates (s4) With Higher Arrival Rate of Ships**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s4* | *oe* | *s4* | *oe* | *s4* | *oe* | *s4* | *oe* | *s4* |
| **1. SH Wait** | **7.36** | **29.86** | **8.52** | **27.95** | **8.93** | **28.82** | **8.75** | **27.00** | **75.51** | **88.33** |
| a) RPILOT | 0.85 | 22.90 | 1.62 | 21.51 | 2.48 | 22.75 | 1.94 | 20.24 | 0.00 | 20.00 |
| b) River | 6.51 | 6.86 | 6.90 | 6.44 | 6.45 | 6.32 | 6.81 | 6.76 | 0.00 | 68.33 |
| **2. Inpilotage** | **11.14** | **20.10** | **9.35** | **20.48** | **12.28** | **20.66** | **11.99** | **17.21** | **6.24** | **22.18** |
| a) River " | 5.02 | 5.04 | 4.96 | 5.03 | 5.08 | 5.03 | 4.98 | 5.02 | 4.98 | 5.06 |
| b) Berth wait | 6.12 | 15.10 | 4.39 | 15.45 | 7.20 | 15.63 | 7.01 | 12.19 | 1.26 | 17.12 |
| **1 + 2** | **18.5** | **49.9** | **17.8** | **48.43** | **21.21** | **49.48** | **20.74** | **44.21** | **81.20** | **110.51** |
| **3. Berth** | **27.03** | **22.40** | **28.00** | **29.47** | **26.09** | **25.74** | **32.75** | **34.50** | **31.19** | **33.10** |
| a) Working | 14.85 | 12.69 | 18.29 | 18.64 | 14.53 | 15.05 | 20.90 | 23.55 | 22.62 | 23.47 |
| b) Idle | 12.18 | 9.77 | 9.71 | 10.83 | 11.56 | 10.69 | 11.85 | 10.95 | 8.57 | 9.63 |
| **4. Outpilotage** | **11.70** | **11.8** | **11.00** | **11.49** | **11.77** | **11.52** | **16.01** | **18.06** | **15.21** | **18.69** |
| a) River " | 3.54 | 3.52 | 3.49 | 3.48 | 3.52 | 3.52 | 3.53 | 3.50 | 3.41 | 3.53 |
| b) Harbour " | 1.54 | 1.73 | 1.28 | 1.73 | 1.38 | 1.92 | 1.15 | 0.54 | 4.92 | 9.29 |
| c) River wait | 6.62 | 6.56 | 6.25 | 6.28 | 6.87 | 6.08 | 11.33 | 14.02 | 6.88 | 5.87 |
| **Turnaround** | **57.2** | **84.2** | **56.89** | **89.39** | **59.07** | **86.74** | **69.50** | **96.77** | **127.6** | **162.30** |

As an obvious consequence, this resulted in a tremendous pressure on the existing port resources. Thus, the average waiting for river pilot in the case of ship type 2A, which accounted for the maximum number of arrivals, rose from 2.48 hours to 22.75 hours. Similar time enhancements took place for other ship types as well. The corresponding estimate for waiting for berth rose from 7.20 hours to 15.63 hours respectively. As a direct consequence of such increases in the components, the turnaround time of ship type 2A rose from 59.07 hours to 86.74 hours. As is evident from the table, all ship types experienced similar increases in turnaround time and its components relating to waiting for the ports resources. Thus, it may be concluded that, although for the existing volume of traffic the port facilities are just about sufficient, there will be shortages should the traffic increases in future, other things remaining the same.

### *Scenario 5: Higher Arrival Percentage of Deeper Draughted Ships*

In this new scenario, the original model is altered to include more ships belonging to the deeper draughted variety. As a result, the arrival percentages of the various ship types have been changed as follows:

| | *Original Arrival Percentage* | *New Arrival Percentage* |
|---|---|---|
| 1A | 12 | 02 |
| 1B | 15 | 05 |
| 2A | 52 | 52 |
| 2B | 21 | 41 |

A comparative idea about the estimates of the original model (oe) and those after the proposed change (s5) are shown in Table 6.6.

As a direct consequence of the change, it is found that the total turnaround time has increased for all ship types. In the case of ship types 1A and 1B, whose arrival percentages had declined, a very small number of entities were now arriving to the system. As a result, the extreme values of their estimates were giving an upward bias to the average turnaround time of these ships. Thus, ship type 1A and 1B showed an increase in turnaround time from 57.23 hours to 71.12 hours and from 56.89 hours to 65.20 hours respectively.

Turning to the other ship types, similar increases in total turnaround time were noticed. Due to greater arrival of heavier ships, larger number of ships got neaped, i.e. they got detained at Sandheads due to draught restrictions. As a result, a river pilot which already was allocated to a particular ship, got held up at Sandhead along with the vessel, until the draught situation was deemed favourable. Thus, there was considerable pressure on the port facilities under the new scenario and total Sandhead waiting was greatly increased. This caused the total turnaround time to increase. Thus, it is concluded that, given the existing river draught conditions, a higher percentage of deeper draughted vessels will result in a larger number of ships getting neaped, a greater pressure on existing port resources especially the river pilot and as a result, greater average turnaround time of ships.

**Table 6.6**
**Comparison of Original Estimated Turnaround Time (oe) and Components Thereof With New Estimates (s5) With Higher Arrival Rate of Deeper Draughted Ships**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s5* | *oe* | *s5* | *oe* | *s5* | *oe* | *s5* | *oe* | *s5* |
| **1. SH Wait** | **7.36** | **21.62** | **8.52** | **12.71** | **8.93** | **26.13** | **8.75** | **26.51** | **75.51** | **108.05** |
| a) RPILOT | 0.85 | 16.54 | 1.62 | 6.71 | 2.48 | 19.87 | 1.94 | 19.82 | 0.00 | 0.00 |
| b) River | 6.51 | 5.08 | 6.90 | 6.00 | 6.45 | 6.26 | 6.81 | 6.69 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.14** | **14.92** | **9.35** | **10.00** | **12.28** | **14.47** | **11.99** | **14.32** | **6.24** | **9.78** |
| a) River " | 5.02 | 4.95 | 4.96 | 4.98 | 5.08 | 5.02 | 4.98 | 5.03 | 4.98 | 4.94 |
| b) Berth wait | 6.12 | 9.97 | 4.39 | 5.08 | 7.20 | 9.45 | 7.01 | 9.29 | 1.26 | 4.84 |
| **1 + 2** | **18.50** | **36.54** | **17.87** | **22.77** | **21.21** | **40.60** | **20.74** | **40.83** | **81.20** | **117.83** |
| **3. Berth** | **27.03** | **23.96** | **28.00** | **28.81** | **26.09** | **25.74** | **32.75** | **32.77** | **31.19** | **44.79** |
| a) Working | 14.85 | 13.76 | 18.29 | 13.47 | 14.53 | 15.50 | 20.90 | 21.30 | 22.62 | 33.52 |
| b) Idle | 12.18 | 10.20 | 9.71 | 15.34 | 11.56 | 10.24 | 11.85 | 11.47 | 8.57 | 11.27 |
| **4. Outpilotage** | **11.70** | **10.62** | **11.02** | **13.62** | **11.77** | **11.86** | **16.01** | **13.98** | **15.21** | **16.28** |
| a) River " | 3.54 | 3.82 | 3.49 | 3.63 | 3.52 | 3.51 | 3.53 | 3.50 | 3.41 | 3.57 |
| b) Harbour " | 1.54 | 1.07 | 1.28 | 5.01 | 1.38 | 1.59 | 1.15 | 0.32 | 4.92 | 6.35 |
| c) River wait | 6.62 | 5.73 | 6.25 | 4.98 | 6.87 | 6.76 | 11.33 | 10.16 | 6.88 | 6.36 |
| **Turnaround** | **57.23** | **71.12** | **56.89** | **65.20** | **59.07** | **78.20** | **69.50** | **87.58** | **127.6** | **178.90** |

### *Scenario 6: More Ships and Heavier Ships*

From the previous two exercises it was observed how the turnaround time of tankers visiting Haldia increased in the event of greater traffic pressure and higher arrival of heavier ships, all other things remaining the same. A combination of scenarios 4 and 5 were tried to see the effect of a greater arrival of ships together with greater arrival percentages of heavier ships on the estimated turnaround time. Table

6.7 gives a comparison of the original estimates (oe) and those (s6) after the new parametric adjustments.

It is found that in the case of ship types 1A, 1B, 2A and 2B, the turnaround time estimates almost trebled. The main contribution towards this massive increase came from the components 'wait for river pilot' and 'wait for berth'. A greater number of ships were neaped due to excessive arrival of heavier ships. This clearly indicates that the existing port resources will prove to be greatly inadequate in the event of an increase in the existing volume of traffic and greater arrival of bigger ships.

**Table 6.7**
**Comparison of Original Estimated Turnaround Time (oe) and Components Thereof With New Estimates (s6)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s6* | *oe* | *s6* | *oe* | *s6* | *oe* | *s6* | *oe* | *s6* |
| **1. SH Wait** | **7.36** | **88.53** | **8.52** | **81.31** | **8.93** | **105.9** | **8.75** | **102.7** | **75.51** | **194.36** |
| a) RPILOT | 0.85 | 81.50 | 1.62 | 74.19 | 2.48 | 99.2 | 1.94 | 95.8 | 0.00 | 0.00 |
| b) River | 6.51 | 7.03 | 6.90 | 7.12 | 6.45 | 6.7 | 6.81 | 6.9 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.14** | **26.74** | **9.35** | **20.97** | **12.28** | **23.79** | **11.99** | **24.63** | **6.24** | **16.51** |
| a) River " | 5.02 | 5.18 | 4.96 | 4.98 | 5.08 | 4.99 | 4.98 | 5.01 | 4.98 | 5.03 |
| b) Berth wait | 6.12 | 21.56 | 4.39 | 15.99 | 7.20 | 18.80 | 7.01 | 19.62 | 1.26 | 11.48 |
| **1 + 2** | **18.50** | **115.3** | **17.87** | **102.3** | **21.21** | **129.7** | **20.74** | **127.4** | **81.20** | **210.87** |
| **3. Berth** | **27.03** | **20.72** | **28.00** | **27.37** | **26.09** | **24.56** | **32.75** | **33.73** | **31.19** | **40.62** |
| a) Working | 14.85 | 13.15 | 18.29 | 17.82 | 14.53 | 14.68 | 20.90 | 22.45 | 22.62 | 29.94 |
| b) Idle | 12.18 | 7.57 | 9.71 | 9.55 | 11.56 | 10.08 | 11.85 | 11.28 | 8.57 | 10.68 |
| **4. Outpilotage** | **11.70** | **11.61** | **11.02** | **15.15** | **11.77** | **16.01** | **16.01** | **15.28** | **15.21** | **15.81** |
| a) River " | 3.54 | 3.54 | 3.49 | 3.53 | 3.52 | 3.53 | 3.53 | 3.00 | 3.41 | 3.53 |
| b) Harbour " | 1.54 | 1.07 | 1.28 | 5.01 | 1.38 | 1.59 | 1.15 | 0.32 | 4.92 | 6.35 |
| c) River wait | 6.62 | 5.73 | 6.25 | 4.98 | 6.87 | 6.76 | 11.33 | 10.16 | 6.88 | 6.36 |
| **Turnaround** | **57.23** | **147.6** | **56.89** | **144.8** | **59.07** | **166.1** | **69.50** | **176.4** | **127.6** | **267.30** |

### *Scenario 7: The Original Haldia Model with New Draught Data of 1991-92*

A simulation exercise was run for 17,520 hours of port operations on the original Haldia model using a new set of river draught data, pertaining to the year 1991-92. The purpose was to see if any marked improvement had taken place in the draught data over the years and whether, this had any impact on the turnaround time of tankers visiting Haldia. Table 6.8 gives a comparison of the original estimates (oe) and that of (s7) after the introduction of new draught data.

On comparison it is found that, in the case of ship types 1A, 2A and 2B, there was a slight decline in the total turnaround time due to this parametric change. In the case of ship type 1B however, there was a marginal increase in turnaround time. This was caused by an increase in the component 'total time at berth'. In the case of all ship types, the component 'wait for river' underwent a decline in the new scenario, which indicated that the draught situation had marginally improved between 1988-89 and 1991-92. In the case of neaped ships, the wait for river was about 7 hours lesser as compared to the original estimates. However, there was excessive waiting for berth as well as total time spent at berth. This resulted in an enhancement in the turnaround time estimates of this ship type. Due to the randomness attached to the model variables under this new parametric change, on an average the estimated time spent by neaped ships at berth increased. As a result, neaped ships on an average, were waiting longer for a free berth, resulting in higher turnaround time estimates. On the whole, it is found that in 1991-92, the river draught situation improved slightly, as compared to that of 1988-89 and as a result turnaround time showed marginal declines in the cases of certain ship types due to a fall in the waiting for river. In the case of other ship categories, this marginal fall was overshadowed by enhancements in some other component of turnaround time as a result of the stochastic nature of simulation variables.

Table 6.8
**Comparison of Original Estimated Turnaround Time (oe) and Components Thereof With New Estimates (s7)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *oe* | *s7* | *oe* | *s7* | *oe* | *s7* | *oe* | *s7* | *oe* | *s7* |
| **1. SH Wait** | **7.36** | **8.03** | **8.52** | **7.39** | **8.93** | **7.36** | **8.75** | **6.76** | **75.51** | **67.92** |
| a) RPILOT | 0.85 | 1.23 | 1.62 | 1.26 | 2.48 | 0.99 | 1.94 | 0.35 | 0.00 | 0.00 |
| b) River | 6.51 | 6.80 | 6.90 | 6.13 | 6.45 | 6.37 | 6.81 | 6.41 | 0.00 | 0.00 |
| **2. Inpilotage** | **11.14** | **10.88** | **9.35** | **9.24** | **12.28** | **10.52** | **11.99** | **10.08** | **6.24** | **20.89** |
| a) River " | 5.02 | 4.97 | 4.96 | 4.99 | 5.08 | 5.05 | 4.98 | 5.04 | 4.98 | 4.89 |
| b) Berth wait | 6.12 | 5.91 | 4.39 | 4.25 | 7.20 | 5.47 | 7.01 | 5.04 | 1.26 | 16.00 |
| **1 + 2** | **18.50** | **18.91** | **17.87** | **16.63** | **21.21** | **17.88** | **20.74** | **16.84** | **81.20** | **88.81** |
| **3. Berth** | **27.03** | **20.72** | **28.00** | **27.37** | **26.09** | **24.56** | **32.75** | **33.73** | **31.19** | **40.62** |
| a) Working | 14.85 | 13.15 | 18.29 | 17.82 | 14.53 | 14.68 | 20.90 | 22.45 | 22.62 | 29.94 |
| b) Idle | 12.18 | 7.57 | 9.71 | 9.55 | 11.56 | 10.08 | 11.85 | 11.28 | 8.57 | 10.68 |
| **4. Outpilotage** | **11.70** | **11.97** | **11.02** | **12.25** | **11.77** | **10.94** | **16.01** | **11.25** | **15.21** | **13.21** |
| a) River " | 3.54 | 3.53 | 3.49 | 3.57 | 3.52 | 3.48 | 3.53 | 3.52 | 3.41 | 3.51 |
| b) Harbour " | 1.54 | 1.60 | 1.28 | 1.55 | 1.38 | 1.53 | 1.15 | 1.46 | 4.92 | 4.60 |
| c) River wait | 6.62 | 6.84 | 6.25 | 7.13 | 6.87 | 5.93 | 11.33 | 6.27 | 6.88 | 5.10 |
| **Turnaround** | **57.23** | **54.25** | **56.89** | **59.51** | **59.07** | **53.69** | **69.50** | **63.07** | **127.6** | **139.00** |

### *Scenario 8: Higher Traffic of Ships with River Draught of 1991-92*

Taking into account the marginal improvement in river draught between 1988-89 and 1991-92, the effect of a rise in the volume of traffic on the efficiency parameters of the port of Haldia's tanker trade, has been studied. A situation is considered where ships are arriving with an interarrival mean time of 17.37 hours. The draught data of 1991-92 is oncorporated and the model run for 17,520 hours of port time, all other things remaining the same. Table 6.9 gives a comparison of the estimates of Scenario 4 (s4), where a similar situation was modelled with draught data of 1988-89 and the present one (s8).

**Table 6.9**
**Comparison of Estimated Turnaround Time of Scenario 4 (s4) and Components Thereof With New Estimates (s8)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *s4* | *s8* | *s4* | *s8* | *s4* | *s8* | *s4* | *s8* | *s4* | *s8* |
| **1. SH Wait** | **29.81** | **31.43** | **27.95** | **36.34** | **28.82** | **39.43** | **27.00** | **37.46** | **88.33** | **74.80** |
| a) RPILOT | 22.95 | 24.59 | 21.51 | 29.57 | 22.75 | 32.55 | 20.24 | 31.05 | 0.00 | 0.00 |
| b) River | 6.86 | 6.84 | 6.44 | 6.77 | 6.32 | 6.88 | 6.76 | 6.41 | 0.00 | 0.00 |
| **2. Inpilotage** | **20.17** | **19.36** | **20.48** | **18.77** | **20.66** | **19.12** | **17.21** | **20.01** | **22.18** | **11.01** |
| a) River " | 5.04 | 5.01 | 5.03 | 4.96 | 5.03 | 5.05 | 5.02 | 5.08 | 5.06 | 4.75 |
| b) Berth wait | 15.13 | 14.35 | 15.45 | 13.81 | 15.63 | 14.07 | 12.19 | 14.93 | 17.12 | 6.26 |
| **1 + 2** | **49.98** | **50.79** | **48.43** | **55.11** | **49.48** | **58.55** | **44.21** | **57.47** | **110.5** | **85.81** |
| **3. Berth** | **22.46** | **23.15** | **29.47** | **26.85** | **25.74** | **25.25** | **34.50** | **33.50** | **33.10** | **33.86** |
| a) Working | 12.69 | 12.02 | 18.64 | 15.48 | 15.05 | 14.20 | 23.55 | 23.22 | 23.47 | 24.81 |
| b) Idle | 9.77 | 11.13 | 10.83 | 11.37 | 10.69 | 11.05 | 10.95 | 10.28 | 9.63 | 9.05 |
| **4. Outpilotage** | **11.81** | **11.54** | **11.49** | **11.43** | **11.52** | **11.65** | **18.06** | **12.43** | **18.69** | **11.33** |
| a) River " | 3.52 | 3.58 | 3.48 | 3.51 | 3.52 | 3.49 | 3.50 | 3.48 | 3.53 | 3.61 |
| b) Harbour " | 1.73 | 1.80 | 1.73 | 1.51 | 1.92 | 1.69 | 0.54 | 2.09 | 9.29 | 3.00 |
| c) River wait | 3.52 | 3.58 | 3.48 | 3.51 | 3.52 | 3.49 | 3.50 | 3.48 | 3.53 | 3.61 |
| **Turnaround** | **84.25** | **85.48** | **89.39** | **93.41** | **86.74** | **95.45** | **96.77** | **103.4** | **162.3** | **131.00** |

It is found that in the present situation, the turnaround time was quite high for all ship types. However, due to improvements in the draught situation between 1988-89 and 1991-92, the situation of the neaped ships improved and showed lower turnaround time estimates falling from 162.30 hours to 131.00 hours. This was primarily due to a fall in the component 'Total Sandhead wait.' Thus it is found that in spite of the tremendous pressure of enhanced tanker traffic on the existing port resources, the marginal improvement in the river draught situation, actually lowered the turnaround time estimates of the neaped ships.

However, an interesting feature was that, in the case of all types of regular ships, the turnaround time actually rose in the new scenario, due to a corresponding increase in the component 'Wait for river pilot'. This was particularly apparent in the case of ship types 2A and 2B which accounted for the lions share of the traffic. Thus, there is a conflicting situation where, on one hand, marginal improvements in river draught have reduced the turnaround time of neaped ships through a reduction in the component 'Total Sandhead wait', while on the other hand, the turnaround time estimates of all other regular ship types have risen due to a rise in the same time component, due to a shortage of river pilots. It is concluded that the draught improvement between 1988-89 and 1991-92 was too meagre to bring about any foreseeable reduction in the turnaround time of all ships visiting Haldia. Eventually, the shortage of river pilots will stand in the way of higher port efficiency, should the traffic increase in the future.

***Scenario 9: Greater Arrival of Heavier Ships with River Draught Data of 1991-92***

As in scenario 5, a situation where the percentage of arrival of deeper draughted vessels is higher compared to the original model has been simulated. This time the river draught data of 1991-92 is incorporated. Table 6.10 gives a comparison of the earlier estimates (s5) and the present one (s9). It is noticed that compared to the earlier similar situation of greater percentage of heavier ships, in the new scenario using river draught data of 1991-92, there has been an across the board decline in the turnaround time of all ships, including the neaped variety. This was caused by a fall in the total Sandhead wait due to a substantial decline in waiting for river pilot. It is found that due to the small improvement in the river draught situation, the port was able to cope better with a situation of greater arrival of heavier ships. The turnaround time of neaped ships also improved in the new scenario, due to a substantial fall in the component 'Total Sandhead wait'. Thus, improvements in the river draught situation can go a long way towards enhancing port efficiency and accommodating heavier traffic of deeper draughted tankers at Haldia.

**Table 6.10**
**Comparison of Estimated Turnaround Time of Scenario 5 (s5) and Components Thereof With New Estimates (s9)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *s5* | *s9* | *s5* | *s9* | *s5* | *s9* | *s5* | *s9* | *s5* | *s9* |
| **1. SH Wait** | **21.62** | **10.19** | **12.71** | **7.61** | **26.13** | **8.70** | **26.51** | **7.94** | **108.0** | **63.57** |
| a) RPILOT | 16.54 | 4.62 | 6.71 | 0.56 | 19.87 | 2.33 | 19.82 | 1.57 | 0.00 | 0.00 |
| b) River | 5.08 | 5.57 | 6.00 | 7.05 | 6.26 | 6.37 | 6.69 | 6.37 | 0.00 | 0.00 |
| **2. Inpilotage** | **14.92** | **18.32** | **10.06** | **10.63** | **14.47** | **13.36** | **14.32** | **12.09** | **9.78** | **10.35** |
| a) River " | 4.95 | 5.00 | 4.98 | 4.96 | 5.02 | 5.04 | 5.03 | 5.02 | 4.94 | 4.86 |
| b) Berth wait | 9.97 | 13.32 | 5.08 | 5.67 | 9.45 | 8.32 | 9.29 | 7.07 | 4.84 | 5.49 |
| **1 + 2** | **36.54** | **28.51** | **22.77** | **18.24** | **40.60** | **22.06** | **40.83** | **20.03** | **117.8** | **73.92** |
| **3. Berth** | **23.96** | **24.96** | **28.81** | **25.13** | **25.74** | **24.59** | **32.77** | **35.86** | **44.79** | **37.06** |
| a) Working | 13.76 | 11.62 | 13.47 | 14.60 | 15.50 | 14.83 | 21.30 | 23.59 | 33.52 | 29.25 |
| b) Idle | 10.20 | 13.34 | 15.34 | 10.53 | 10.24 | 9.76 | 11.47 | 12.27 | 11.27 | 7.81 |
| **4. Outpilotage** | **10.62** | **10.96** | **13.62** | **11.19** | **11.86** | **11.45** | **13.98** | **12.00** | **16.28** | **13.62** |
| a) River " | 3.82 | 3.46 | 3.63 | 3.59 | 3.51 | 3.49 | 3.50 | 3.51 | 3.57 | 3.49 |
| b) Harbour " | 1.07 | 1.60 | 5.01 | 1.82 | 1.59 | 1.46 | 0.32 | 1.50 | 6.35 | 1.55 |
| c) River wait | 5.73 | 5.90 | 4.98 | 5.78 | 6.76 | 6.50 | 10.16 | 6.99 | 6.36 | 8.58 |
| **Turnaround** | **71.12** | **64.43** | **65.20** | **54.56** | **78.20** | **58.10** | **87.58** | **67.89** | **178.9** | **124.60** |

### *Scenario 10: Combination Of Scenario 8 and Scenario 9*

A situation is considered where ship interarrivals were exponentially distributed with mean 17.37 hours and as before, the original arrival percentages of tankers were altered to include more deeper draughted vessels. The river draught data of 1991-92 is incorporated and the model run for 17,520 hours of simulated port operations. Table 6.11 gives a comparative picture of the similar situation using the draught data of 1988-89 (s6) and the present one (s10). In the case of ship types 1A and 2B the turnaround time estimates under the new scenario were lower as compared with the earlier one. For ship types 1B and 2A however, the converse was true. On the whole, it is noted that a tremendous pressure is exerted on the ports resources such as river pilot and berth due to enhanced traffic. The waiting for river has shown minor changes between the two situations. The turnaround time of the neaped ships massively declined under the new scenario. This was caused by a similar fall in the time component, waiting at Sandhead. Thus it is found that, even a marginal improvement in the river draught can cause marked differences in the turnaround time of neaped vessels.

**Table 6.11**
**Comparison of Estimated Turnaround Time of Scenario 6 (s6) and Components Thereof With New Estimates (s10)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *s6* | *s10* | *s6* | *s10* | *s6* | *s10* | *s6* | *s10* | *s6* | *s10* |
| **1. SH Wait** | **88.53** | **76.50** | **81.31** | **78.3** | **105.95** | **103.7** | **102.7** | **98.26** | **194.4** | **158.32** |
| a) RPILOT | 81.50 | 69.70 | 74.19 | 71.77 | 99.21 | 96.70 | 95.80 | 91.23 | 0.00 | 0.00 |
| b) River | 7.03 | 6.89 | 7.12 | 6.53 | 6.74 | 7.03 | 6.94 | 7.03 | 0.00 | 0.00 |
| **2. Inpilotage** | **26.74** | **25.52** | **20.97** | **31.08** | **23.79** | **29.16** | **24.63** | **26.45** | **16.51** | **18.43** |
| a) River " | 5.18 | 4.94 | 4.98 | 5.08 | 4.99 | 5.04 | 5.01 | 5.00 | 5.03 | 5.00 |
| b) Berth wait | 21.56 | 20.58 | 15.99 | 26.00 | 18.80 | 24.12 | 19.62 | 21.45 | 11.48 | 13.43 |
| **1 + 2** | **115.3** | **102.0** | **102.3** | **109.4** | **129.74** | **132.9** | **127.4** | **124.7** | **210.9** | **176.75** |
| **3. Berth** | **20.72** | **27.09** | **27.37** | **31.60** | **24.56** | **26.17** | **33.73** | **36.33** | **40.62** | **37.32** |
| a) Working | 13.15 | 14.62 | 17.82 | 21.19 | 14.68 | 15.83 | 22.45 | 24.86 | 29.94 | 29.00 |
| b) Idle | 7.57 | 12.47 | 9.55 | 10.41 | 10.08 | 10.34 | 11.28 | 11.47 | 10.68 | 8.32 |
| **4. Outpilotage** | **11.61** | **10.89** | **15.15** | **11.02** | **11.88** | **10.94** | **15.28** | **11.76** | **15.81** | **12.24** |
| a) River " | 3.54 | 3.52 | 3.53 | 3.55 | 3.53 | 3.52 | 3.00 | 3.49 | 3.53 | 3.39 |
| b) Harbour " | 1.51 | 1.63 | 5.09 | 1.42 | 1.59 | 0.53 | 0.50 | 1.27 | 2.50 | 1.90 |
| c) River wait | 6.56 | 5.74 | 6.53 | 6.05 | 6.72 | 6.89 | 11.78 | 7.00 | 9.78 | 6.95 |
| **Turnaround** | **147.6** | **140.0** | **144.8** | **162.0** | **166.1** | **170.0** | **176.4** | **172.8** | **267.3** | **216.90** |

### *Scenario 11: Greater Ship Draught Requirement with River Draught of 1991-92*

In the present scenario, the river draught data of 1991-92 is incorporated. However, the ships draught requirement in metres has been enhanced as compared to the original model. Below are the ships draught requirements as given in the original model, vis-a-vis, those in the new model.

**Ship's Draught Requirement**

| | Original model | | New Scenario | |
|---|---|---|---|---|
| | *Arrival* | *Departure* | *Arrival* | *Departure* |
| 1A | (4.0,5.0) | (4.0,5.0) | (4.0,5.0) | (4.0,5.0) |
| 1B | (5.0,7.0) | (5.0,7.0) | (6.0,8.0) | (6.0,8.0) |
| 2A | (6.0,7.0) | (6.0,7.0) | (7.0,8.0) | (7.0,8.0) |
| 2B | (7.0,8.0) | (7.0,8.0) | (8.0,9.0) | (8.0,9.0) |

**Table 6.12**
**Comparison of Estimated Turnaround Time of Scenario 6 (s7) and Components Thereof With New Estimates (s11)**

| | 1A | | 1B | | 2A | | 2B | | Neaped | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *s7* | *s11* | *s7* | *s11* | *s7* | *s11* | *s7* | *s11* | *s7* | *s11* |
| **1. SH Wait** | **8.03** | **175.4** | **7.39** | **109.5** | **7.36** | **148.4** | **6.76** | **137.0** | **67.92** | **438.80** |
| a) RPILOT | 1.23 | 169.1 | 1.26 | 102.8 | 0.99 | 141.8 | 0.35 | 130.0 | 0.00 | 0.00 |
| b) River | 6.80 | 6.34 | 6.13 | 6.73 | 6.37 | 6.59 | 6.41 | 7.01 | 0.00 | 0.00 |
| **2. Inpilotage** | **10.88** | **10.22** | **9.24** | **8.86** | **10.52** | **10.11** | **10.08** | **11.77** | **20.89** | **8.29** |
| a) River " | 4.97 | 4.94 | 4.99 | 5.03 | 5.05 | 5.01 | 5.04 | 5.01 | 4.89 | 5.01 |
| b) Berth wait | 5.91 | 5.28 | 4.25 | 3.83 | 5.47 | 5.10 | 5.04 | 6.76 | 16.00 | 3.28 |
| 1 + 2 | **18.91** | **185.7** | **16.63** | **118.4** | **17.88** | **158.5** | **16.84** | **148.8** | **88.81** | **447.09** |
| **3. Berth** | **23.37** | **23.14** | **30.63** | **27.16** | **24.87** | **21.90** | **34.98** | **40.34** | **36.98** | **31.04** |
| a) Working | 12.97 | 13.20 | 19.43 | 17.04 | 14.67 | 13.75 | 25.10 | 27.54 | 32.27 | 22.35 |
| b) Idle | 10.40 | 9.94 | 11.20 | 10.12 | 10.20 | 8.15 | 9.88 | 12.80 | 4.71 | 8.69 |
| **4. Outpilotage** | **11.97** | **11.30** | **12.25** | **10.85** | **10.94** | **7.30** | **11.25** | **100.6** | **13.21** | **149.9** |
| a) River " | 3.53 | 3.29 | 3.57 | 3.41 | 3.48 | 2.51 | 3.52 | 3.55 | 3.51 | 3.50 |
| b) Harbour " | 1.60 | 1.80 | 1.55 | 1.55 | 1.53 | 0.60 | 1.46 | 0.50 | 4.60 | 2.27 |
| c) River wait | 6.84 | 6.21 | 7.13 | 5.89 | 5.93 | 4.19 | 6.27 | 96.55 | 5.10 | 144.10 |
| **Turnaround** | **54.25** | **220.1** | **59.51** | **156.4** | **53.69** | **188.0** | **63.07** | **289.7** | **139.0** | **628.00** |

Table 6.12 gives a comparison of the estimates (s7) observed by using the river draught figures of 1991-92 on the original model and s11, that obtained from the present experiment. It is found that as a result of the current parametric changes, there is a massive rise in the turnaround time estimates of all ship types including the neaped ships. The 'waiting for river' component assumes a very high value for the neaped ships. Thus it is concluded that marginal improvements in the river draught

situation are certainly not enough to accommodate higher ship draught requirements of the calling vessels. The port authorities must make a sincere attempt to improve the river draught situation if they wish to accommodate deeper draughted vessels at Haldia, which was the prime motive behind its inception.

## 6.5 Conclusions

The above simulation exercise gives a fair idea about the handling of tankers at Haldia. The model results are quite a close approximation of observed data for average turnaround time and its components for such ships visiting Haldia in 1988-89. This, proves the validity of the model that has been developed. Sensitivity of the model with respect to various changes in port facilities and operating conditions was observed through the above experiments. The insight gained from these experiments should give the policymaker a fair idea about the best possible mix of future port investment in order to improve turnaround time.

In conclusion it may be stated that appreciable improvements must be made in the river draught situation at Haldia in order to accommodate the deeper draughted ships which are the order of the day. The creation of the second oil jetty will bring down the turnaround time of tankers by reducing the traffic pressure on existing berths. Although, the existing port facilities are more or less sufficient to handle the current tanker traffic, the resource river pilot, followed by berth, will prove insufficient, should the traffic increase in the future. The port authorities should keep this in their planning perspective while chalking out the future of the port of Haldia.

# CHAPTER 7

# DEMAND ESTIMATION OF PORT SERVICES AND OPTIMAL PRICING: THE CASE OF CALCUTTA



## 7.1 Introduction

This chapter attempts to estimate the demand for port services which can be viewed as a queuing system. It then investigates whether the pricing strategy for these services in the past decade has been optimal, given the performance and cost recovery potential of Calcutta port.

Much has been written on the issue of optimal configuration of a queuing system in different applied contexts. Such projects often assume a given interarrival rate of entities into the system determined from actual past data, decide on some performance parameters such as queue length, waiting time or total time in the system and then either through exact algebraic optimisation or through numerical estimates obtained from various simulation runs, determine what the optimal resource configurations are.

Quite often, the objective is to attain an engineering measure, rather than an economic one, of system performance. Moreover, in many instances, it may be clearly inappropriate to assume that the interarrival rates are going to be independent of the system performance measures. There is obviously a feedback loop going from the latter to the former which needs to be taken into account when the system is reconfigured to improve one's objective(s). When a fast food restaurant is in the process of deciding whether the cost of an extra drive-through window is going to balance the benefit of not turning away customers unwilling to wait beyond a certain period of time, it must take into account that the publicity that customers are rarely turned away, thanks to that extra window, is probably going to affect the *demand* and hence the interarrival rate. Similarly when a telephone company expands its communication facilities, at least to an extent, the cost may be offset as more customers are attracted by the fact that with the added facilities, the lines are rarely busy.[1] Thus it may be accurate to say that while these studies have concentrated on the *technology* side of the picture, where arrivals are the cause and performances are the effect, it is more appropriate to consider their *joint determination through an equilibrating process*, much the same way as prices and quantities are jointly

[1] This is to be distinguished from baulking or reneging. In the latter phenomena, no change in the interarrival rate due to congestion is implied. Customers decide not to wait any further, depending on queue length or the amount of wait already incurred, *after they have arrived.* A matter of interest is situations where the reputation of queue performance travels quickly and affects the arrival rate almost instantaneously. Steady state (assuming that disequilibrium dynamics is short lived) occurs when there is no pressure on the arrival rate to change. Baulking or reneging are not feasible options for a large vessel arriving at a port; yet shipowners do react to port performance *ex ante* in deciding whether or not to send their ships to the port in the first place.

determined in microeconomics through the combined influence of supply and demand. This clearly necessitates consideration of a simultaneous equations model.

Although there exists an important strand of work in the queuing theoretical literature treating interarrival rates as endogenous, there has been no attempt made to combine demand estimation with the simulation of large scale queuing systems in a meaningful way taking this simultaneity into account [Park and Noh(1987), Pope(1995)]. This is because, practitioners do not usually consider the effect of performance on arrival rates when recommending policy changes with regard to queue discipline or configuration.

To understand the problems involved in doing this consider the situation of a monopolist service provider trying to decide what prices should be charged for the services and how many facilities should be provided.

The problem is to:

Max $R = P(\lambda) - C(F)$

sub to $\lambda = D(\tau, P, X)$ Demand Relation

$\tau = T(\lambda, F, Y)$ Technology Relation

where:

R is the revenue function;

C is the cost function;

$\lambda$ is a vector denoting arrival patterns;

P is a vector for prices charged for services;

F is the vector of facilities;

$\tau$ is a vector of performance measures;

X is a vector of variables affecting 'demand'; and

Y is a vector of variables affecting 'technology'.

The monopolist may be interested in predicting P* and F*, the optimal price and facility configuration that will maximise the profits. Alternatively, he may be interested in finding out, historically, to what extent the prices charged had deviated from their optimal levels from a profit maximisation point of view, given the levels of facilities provided. Obviously he needs to estimate the D and the T functions. While one could estimate the latter using simulation data, one might try to estimate the former by means of OLS using historical data on $\lambda$, $\tau$, P and X. But this would be an incorrect procedure as Working (1927) had pointed out long ago and as discussed in all standard econometrics texts (Johnston 1984). In a system such as this one, the endogenous variables are *simultaneously* determined via the exogenous variables, which will lend bias to OLS estimates.

One may then abandon the use of simulation techniques altogether and take full recourse to econometric procedures such as 3SLS (Three Stage Least Squares) for estimating the coefficients of all the equations in the system using historical data on all endogenous variables ($\lambda$ and $\tau$) and all exogenous variables (P, the various components of F, X and Y). However, there are some drawbacks of this approach as well. First of all, if theoretical considerations suggest the use of a large number of variables in one of these equations (typically, this will be the technology equation) then it may be under-identified.[2] This problem arises when different sets of structural coefficients are compatible with the same set of data. For example, in the regression of price on quantity alone, one may not know whether it is the demand or the supply function that is being estimated as price and quantity enter both these functions. In the present context, if such a situation arises, there will be no means of discussing the optimality of prices or resources. Second, even if the model was identified, it might not be simple to develop a good functional form for the technology equation if it has too many arguments and the relevant queuing system is difficult to analyse theoretically. This will typically wreak havoc on the estimation of the demand equation even though its specification might be fully correct. Finally, it

[2] A particular equation in a model of simultaneous equation systems is not econometrically identifiable if given the specifications, more than one set of parameters in that equation can generate the same probability distributions over the endogenous variables given the exogenous variables (Johnston 1984), implying that the original coefficients in that particular equation will therefore be unrecoverable from the data.

seems unfortunate to discard the prospect of extra gain in efficiency and accuracy that a trustworthy simulation model might provide.

This chapter makes the methodological point that there is a simple yet unexplored way to combine simulation modeling with traditional simultaneous equation econometrics which answers all of the above criticisms. The two-stage approach is as follows. In stage 1, for each period in the sample (for which historical data are available), several simulation runs are prformed with F and Y for that period fixed in place and $\tau$ values are collected for various values of $\lambda$. Next, a functional relationship is specified between various components of $\tau$ and $\lambda$ (the reduced dimensionality should help here in obtaining accuracy in specification) and the parameters of this relation are estimated *for each period* by means of simple OLS or preferably by SURE (Seemingly Unrelated Regression Equations).[3] The effect of the changes in the technology curve from one period to another due to changes in F and Y are thus captured in the changes of the parameters of the OLS or SURE estimates. Next, in stage 2, a 3SLS is performed with a demand group and a supply group of equations. The supply equations use the same specifications as used in the first stage but now treat the parameters estimated from stage 1 as exogenous variables which typically necessitates the use of non-linear 3SLS.

The technique mentioned above is applied in the case of the riverine port system of Calcutta, to estimate the demand for its services and to ask whether in the last decade the port authorities had optimally priced their services (given resources). The exercise revealed that they had not. All indications point to the conclusion that services were largely underpriced.

It must be emphasised that this is a stylised illustration of a methodological tool. Attention is focused on only certain port resources, assuming others to be fixed

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[3] The reason SURE might be a better bet than straightforward OLS is as follows. Typically, each observation in a simulation run for a particular year will be carried out with a particular seed which will govern the pattern of creation of the entities. This might induce cross-equation correlations where each equation pertains to a period. Generalised Least Squares methods such as SURE corrects this.

or unalterable for the purpose of the study.[4] Also, as a port charges its users on many different accounts, there are at least several hundred 'prices'; and since it does not make sense to use all of them or to use some selectively, an aggregate price measure is used, namely, the total real ship related income in a year divided by the total cargo traffic of that year.[5] The period of analysis used for estimation purposes is limited to the ten years: 1986-87 through 1995-96. This was the longest period for which all the information on all the relevant variables was available on recent data.

The rest of the chapter is organised as follows. In the next section, some background information on the port of Calcutta is provided describing first the physical characteristics of the queue environment which was captured in painstaking details through the simulation model. Details of this has been provided in earlier chapters. Next in the same section, some figures show how the port has been performing in recent times both physically and financially. Section 7.3 discusses the full model employed for the purpose of the study while section 7.4 discusses the simulation model, presenting some evidence depicting the match between actual and simulated turnaround times. Section 7.5 presents the two stage econometric technique used and the results thereof. Section 7.6 is devoted to discussing the theoretical underpinning's behind the expected signs of the various coefficients in the demand equation(s). Section 7.7 discusses the results of the non-linear programs written to examine a) the validity of the full model and b) the similarity between the optimal and the actual prices. Section 7.8 concludes by outlining the possibilities of extending this model in diverse directions.

## 7.2 Background

In Chapter 5, a simulation model was developed to estimate the turnaround time of a specific type of ship namely, containers visiting the port of Calcutta using actual port data for the year 1988-89. In order to estimate the technology relationship

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[4] As we will see from the simulation results, the turnaround times are mostly determined by the resources considered.

[5] A ship pays a port on many accounts other than just cargo handling. The use of an aggregative measure for prices can be justified under either of the two following assumptions a) cargo handling charges constitute the major portion of all payouts, and b) a ship's contribution through other accounts is roughly proportional to its size, which, in turn, is roughly proportional to the cargo it carries.

discussed above which expresses turnaround time as a function of interarrival time and facilities provided, the first step was to generalise the model to include all ship types. The sequential nature of ship handling by the various port facilities remained unaltered. However, suitable changes had to be made in the interarrival time of ships, the cargo handling and idle time distributions and the quantity of port's resources available for those ships.

The river plays a crucial role in the ship handling process at Calcutta. The problem of river draught in the Hooghly has been discussed earlier on. The arrival and departure of ships were critically dependant on the available river draught which fluctuated daily and was forecast weeks in advance by the port authorities. Superimposed on the daily fluctuations were the seasonal fluctuations in the river draught spread over the entire year.

As discussed earlier, the total time that a ship spends in port, i.e. the time between arrival at the reporting station or Sandhead and departure from the reporting station is called the ship's turnaround time. In the case of a riverine port like Calcutta, turnaround time has the following components:

*Turnaround time = Sandhead waiting time + Inpilotage time + Service time*
*+ Outpilotage time*

where,

*Service time = Loading Unloading time + Idle time*

Table 7.1 lists the various facility configuration at the port of Calcutta for the period 1986-87 to 1995-96. The facilities include, river pilot (RPILOT), harbour pilot (HPILOT), dock pilot (DPILOT), river tug (RTUG) and dock tug (DTUG). There was not much variation among the resources except perhaps the number of river pilots. The number of berths, usually viewed as the most important port resource was kept at a constant value of 33 for the entire period. One recalls that an HPILOT is always employed in unison with two RTUGS; therefore when there are 8 of each available for instance, effectively there are only 4 HPILOTS available. The same is true about

DPILOTS and DTUGS. More than proportional numbers of pilots often help out when there is a shortage in the nearby port of Haldia; while more than proportional tugs often reflect the fact that some of them are rather old and the port may be unwilling to incur too rapid a depreciation on them.

**Table 7.1 Resource Availability for Calcutta Port 1987-1996**

| *Year* | *RPILOT* | *HPILOT* | *DPILOT* | *RTUG* | *DTUG* | *BERTH* |
|---|---|---|---|---|---|---|
| 1986-87 | 28 | 8 | 33 | 8 | 12 | 33 |
| 1987-88 | 27 | 5 | 31 | 8 | 12 | 33 |
| 1988-89 | 26 | 6 | 31 | 8 | 12 | 33 |
| 1989-90 | 25 | 10 | 27 | 8 | 10 | 33 |
| 1990-91 | 24 | 10 | 26 | 8 | 10 | 33 |
| 1991-92 | 25 | 7 | 29 | 8 | 10 | 33 |
| 1992-93 | 24 | 5 | 31 | 8 | 10 | 33 |
| 1993-94 | 24 | 5 | 36 | 10 | 10 | 33 |
| 1994-95 | 23 | 3 | 37 | 10 | 10 | 33 |
| 1995-96 | 33 | 11 | 44 | 10 | 10 | 33 |

*Source: Calcutta Port Trust.*

Table 7.2 gives for the corresponding period, the total number of ships calling at Calcutta port, their average turnaround time, the average ship related income earned by the port authorities, the inbound, outbound and total cargo handled by the port. Though not shown here, the port of Calcutta suffered a drastic decline in all categories of performance measures since the mid 1960s, with only very modest signs of recovery showing in the early and mid 1990s. To give some idea about the extent of this decline, total traffic handled at this port in mid sixties was well over 10 million tonnes; in the mid eighties this had trickled down to less than half of that value. This does not reflect on the general trend of sea traffic through other Eastern Indian seaports; ports like Vizag has more than doubled its traffic during the same period. In terms of turnaround time, the picture is equally dismal. In 1970-71, Calcutta had an average turnaround time of 7.4 days; in 1990-91 this figure rose to 11.23 days. This is 30 to 40 percent above corresponding values for other Eastern Indian ports.

While everything from labor unrest to lack of facilities have been blamed for this, the one issue that has avoided scrutiny is the price structure. Apart from the rather arbitrary assignment of numbers to waiting costs, demand has not been seriously addressed. This analysis however shows that, given the traffic volume, concern about berths are misplaced, and both profits and turnaround time could be improved by adjusting prices instead. This assumes some significance in the wake of the currently occurring liberalisation movement in India where proposals for privatising many public sector undertakings are being raised and seriously discussed.

**Table 7.2 Performance Measures for the Port of Calcutta 1987-1996**

| *Year* | *Total number of ships* | *Average Turnaround time (days)* | *Average ship related income (Rs Crores)* | *Inbound cargo (thousand tonnes)* | *Outbound cargo (thousand tonnes)* | *Total cargo (thousand tonnes)* |
|---|---|---|---|---|---|---|
| 1986-87 | 898 | 11.38 | 0.0438 | 2983 | 1054 | 4047 |
| 1987-88 | 933 | 10.76 | 0.0427 | 3513 | 880 | 4393 |
| 1988-89 | 840 | 9.62 | 0.0697 | 3408 | 930 | 4338 |
| 1989-90 | 808 | 10.53 | 0.0778 | 3394 | 955 | 4349 |
| 1990-91 | 781 | 11.23 | 0.0782 | 3162 | 968 | 4130 |
| 1991-92 | 703 | 10.28 | 0.0858 | 2932 | 1225 | 4157 |
| 1992-93 | 764 | 10.05 | 0.1037 | 3677 | 1480 | 5157 |
| 1993-94 | 736 | 9.31 | 0.1154 | 3374 | 1795 | 5169 |
| 1994-95 | 755 | 9.17 | 0.1102 | 4106 | 1698 | 5804 |
| 1995-96 | 805 | 8.63 | 0.1256 | 4250 | 1874 | 6124 |

*Source: Administrative Reports, Calcutta Port Trust.*

## 7.3 The Full Model

The full model which has been used in this study and the estimation strategy will now be specified. Let the average turnaround time in time t ($T_t$) be the index of performance of the system. $T_t$ is 'determined' in the technology side by the number of ships arriving each year ($n_t$) and the average cargo traffic per ship ($c_t$) given the number of each type of facility in each time period. Thus, besides interarrival rates, in $c_t$ there is an extra attribute for the entities which influence turnaround time. Cargo amounts can influence turnaround times in two ways: the first obvious is by affecting the cargo handling time (given a fixed cargo handling rate) and the second is by affecting the weight of the ships and thereby draught requirements. It so happens that the second influence is negligible. For a representative sample of ships, the draught requirements were regressed on various ship characteristics including cargo on board. It turns out that most of the dependent variable is explained by what is known as the ship's 'full-load draught' which is related to its dimensions and deadweight tonnage; the cargo coefficient turns out to be insignificant and has thus been ignored. $c_t$ is also a left-hand side variable on the demand side assumed to be affected by the same set of variables which affect number of ships calling per period ($n_t$).

There are five types of explicit facilities: namely berths, river pilots, harbour resource, dock resource and cargo handling facility. Harbour resource is the combination of a harbour pilot and two river tugs and similarly one unit of dock resource is the combination of one dock pilot and two dock tugs. Cargo handling facility is directly proxied by the inverse handling rate *h,* which is expressed in terms of time required to handle unit weight. These are referred to as explicit resources as the port has full control over their magnitudes (though the costs of unit expansion and contraction could be asymmetric) as opposed to one implicit resource: river draught. The port cannot determine this precisely, but has some control over its size through dredging and other 'river training programs'.

The full model is specified by the following 4 equation system, divided into a technology group and a demand group:

<u>*Technology*</u>

$$T_t = f_{1t} \ (n_t, c_t) \tag{1}$$

$$T_t \equiv d_t + c_t \ h_t \tag{2}$$

<u>*Demand*</u>

$$n_t = f_2 \ (d_t, h_t, p_t) \tag{3}$$

$$c_t = f_3 \ (d_t, h_t, p_t) \tag{4}$$

where:

$t$ refers to the relevant period;

$T_t$ is the turnaround time in period $t$(hours);

$p_t$ is the real price paid to the port (Rupees thousands per hundred tonnes in 1981

prices);

$n_t$ is the number of ships sent;

$c_t$ is the traffic per ship (hundred tonnes);

$d_t$ is the non cargo handling time (hours);

$h_t$ is the time required per unit cargo handled (hours per hundred tonnes).

Equation (1) captures the effect of number and cargo on turnaround time; the subscript $t$ in $f_{1t}$ is to reflect the fact that because of changing resource configurations, $n_t$ and $c_t$ affect $T_t$ differently in each t. Equation (2) is simply an identity: turnaround time is the sum of cargo handling time and non-cargo handling time. The reason for this decomposition is obvious; while shipowners are adversely affected by large turnaround times, they are clearly aware that they can raise/lower their turnaround time by carrying more/less cargo. So on the demand side (equations (3) and (4)) they decide their frequency of visit and the amount of cargo carried in each visit as functions of *d, p* and *h.* Note that they take *d* as an exogenous variable when making these decisions – to reflect the belief that that they are one among many ships in this market and have small influence on *d*.

It is postulated that equations (1), (2), (3) and (4) *simultaneously determine* *T, d, n* and *c* (the endogenous variables) through *p, h* and *t* (the exogenous variables). According to Johnston(1984), a necessary condition for identifiability of each equation is:

*Number of variables excluded in that equation ≥ Total number of equations – 1*

This tells us that that in equation (1) if the subscript $t$ was omitted and facilities were directly brought in, i.e. if the equation was specified in the form $T_t = f_1 \ (n_t, c_t, F_{1t}, F_{2t} ..., F_{kt} \ )$ where $F_{1t}, F_{2t} ,..., F_{kt}$ were the amounts of the various port resources used, it would result in too few variables excluded and hence the equation would not be identified. For instance in this model, excluding river draught and berth, there are 4 resources (river pilot, harbour resource, dock resource and cargo handling facility) which will have to be included in this equation as should be $h$ along with $T$, $n$ *and* $c$; thus $p$ would be the only variable excluded from the list of all exogenous and endogenous variables. The number of equations is 3 (consider equation (2) above as an identity rather than an equation and substitute for $d$ in equations (3) and (4) using this identity); thus the identifiability condition will not be satisfied for (1).

In order to deal with this problem, the simulation model for the port was run for each year with different $n$ and $c$ while the resources were specified as they were for that year. The inverse cargo handling rate $h$ was also fixed at the level of the actual rate used for that year. This allows one to obtain a direct relationship between $n$ and $c$ on the one hand and $T$ on the other. More importantly this allows one to exclude $h$ besides $p$ from the first equation thus enabling to obtain identifiability. Unfortunately, although figures were obtained for all the explicit resources for each year, day by day river draught data were only avialable for 1988-89 and 1995-96. The first set of numbers were used for the first 5 years and the second set for the next five. Given that river draughts have actually changed somewhat over time this will imply a bias (unless corrected for). This and other time-varying factors not accounted for in the simulation model are taken care of by introducing a non-linear time trend in equation (1). Thus that equation should essentially be rewritten as:

$$T_t = g(t) + f_{1t}(n_t, c_t) \qquad (1')$$

In $f_{1t}(n_t, c_t)$ the time dependence is only through the fact that the coefficients on $n_t$ and $c_t$ are different in each period t. In the next section, the simulation model instrumental in obtaining the expression for $f_{1t}(n_t, c_t)$ is discussed and it is shown that even without the correction term, the fit between simulated and actual turnaround times is quite good.

## 7.4 Simulating the Queue Technology

The first step towards simulating the queue technology was to construct a generalised model of ship movement through the port system to be captured using a special purpose language. A sample was picked at random out of the total number of ships that visited the port in 1988-89. The actual observed ship characteristics with regard to various waiting and service times as well as the total turnaround time has been tabulated in Appendix 7.1. The entire process of ship-handling at the riverine port, from ship arrival to departure has been replicated in the simulation model. A map of Calcutta port (Figure 7.1) and a schematic flow chart (Figure 7.2) representing the model are presented below.

The next step involved figuring out the appropriate distributions for all the pertinent random variables such as interarrival time, draught requirements, loading-unloading, idle time, inpilotage and outpilotage time, etc. Since this information was required for every year in the sample and detailed ship logs for only one particular year (1988-89) could be accessed, they had to be deduced from reasonable assumptions. For the 1988-89 data the interarrival rate was found to be exponentially distributed with a mean of 10.43 hours. Using the input program in SIMAN, observed ship characteristics from 102 randomly drawn ships were then fitted with distributions (Appendix 7.2) as follows.

The idle time was found to follow lognormal distribution with parameters given by [1 + Lognormal (54.8,71.8)] while the loading unloading time followed Gamma distribution given by [7 + Gamma (68.4,1.37) ]. The ship's draught requirement for the inward journey was found to be normally distributed given by [Normal (5.46,.8385) ] while that for the outward journey was normally distributed given by [Normal (5.42,0.7843)]. Various components of inpilotage time (i.e. time required to travel from Sandhead to Garden Reach; from Garden Reach to the locks and from the locks to the berths) had to be estimated on the basis of the distances involved and ship speeds. On the distribution of the latter there was no information apart from the range; hence uniform distributions were used. The same strategy was used with regards to the outpilotage time components. Both in the incoming phase and outgoing phase before the ship was allowed to navigate up (or down) the river, the program checked whether the river draught was appropriate and whether the time of the day was suitable to make the worst sandbar at high tide. As mentioned earlier, these distributions could be directly obtained from actual data for only one year (1989). For other years only average values were available. To derive the actual distributions for these other years, the assumption was made that the form and the variance of the distribution remained the same each year and that only the mean (on which information was obtained) had changed. To illustrate, it was known that the average handling rate (time required per unit cargo handled) in 1987 was 2.54400 hours per hundred tonnes while that for 1989 was 1.93385 hours.

Given that average cargo size in 1987 and 1989 were 45 and 52 (hundred tonnes) respectively and that the distribution for cargo handling time in 1989 was [7 + Gamma (68.4,1.37)], it was assumed that the distribution of cargo handling time in 1987 was also of the form [7 + Gamma ($\alpha$, $\beta$)]. $\alpha$ and $\beta$ were calculated by the formulae: $(7+\alpha\beta)/(45*2.5440) = 75.4/(52*1.93385)$ and $\alpha\beta^2 = 68.4*1.37^2$. In the absence of knowledge regarding the distribution of cargo size, handling time and handling rate, this was thought to be the only reasonable approximation one could use.

A special purpose simulation package SLAM II was run on a RISC 6000 machine to simulate the port operations. User-inserted FORTRAN subroutines were used to allocate resources depending on where they were physically in the system. Subroutines were also used to check whether river draught conditions were being met. The complete program and its output are listed in Appendices 7.3 and 7.4 respectively. The model was eventually run for 17520 hours or two years of port operations which was when a moving average of simulated output a) began to converge and b) also began to correspond quite closely with actual observations.[6]

[6] Because initial conditions were determined by last year's resources, it might be appropriate to run the model for the entire 10 years, changing resources at the end of each year and not clear the arrays before collecting statistics. However, this would treat the years differently in the sense that runs for the latter years would be 'more close to steady state'. It was felt that the best thing to do was to re-run the model for long enough to get steady state like values even though this entailed runs longer than actual run time.

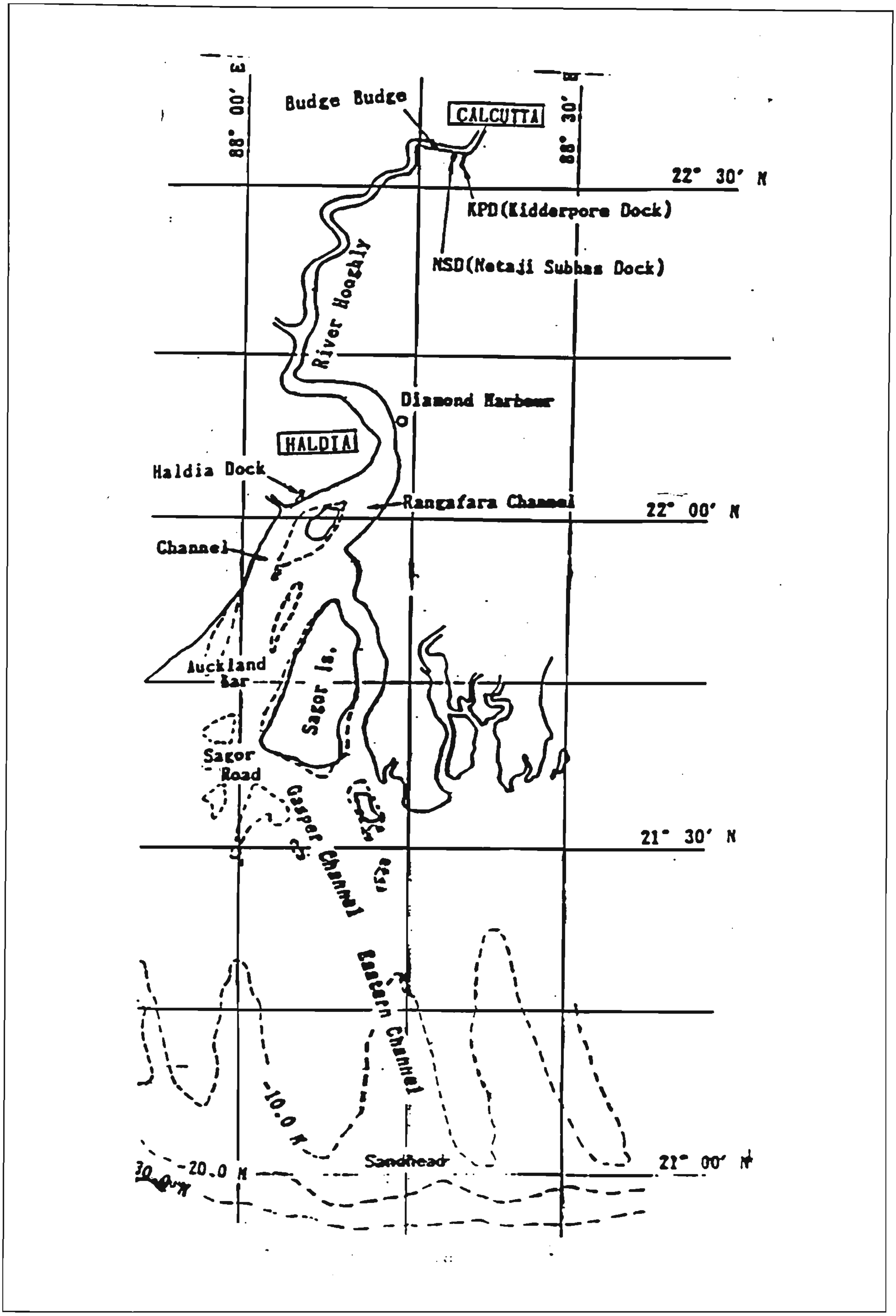
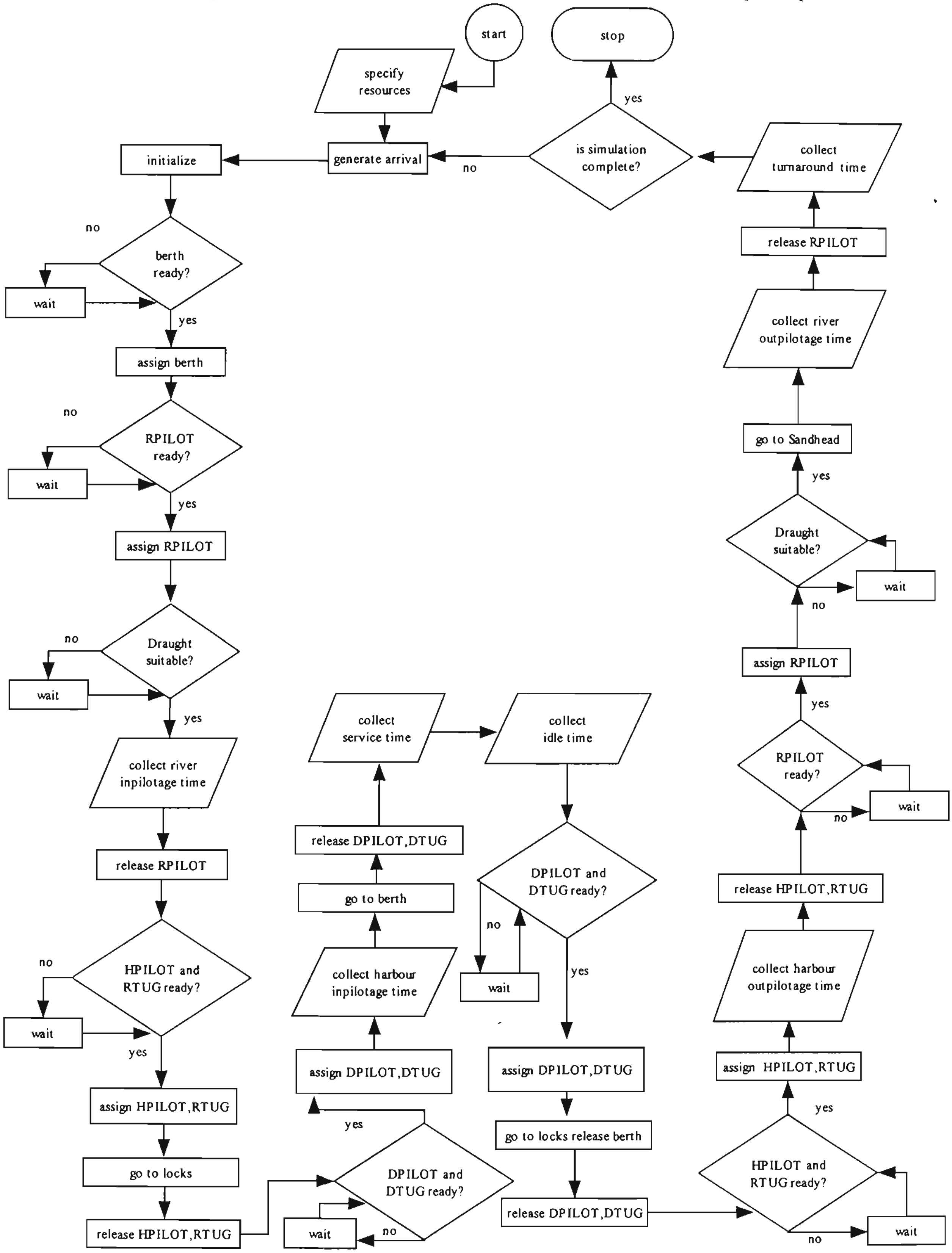



Figure 7.1: Map of the Hooghly River and the Port of Calcutta

**Figure 7.2 : Flowchart for the SLAM II simulation model for port operations**



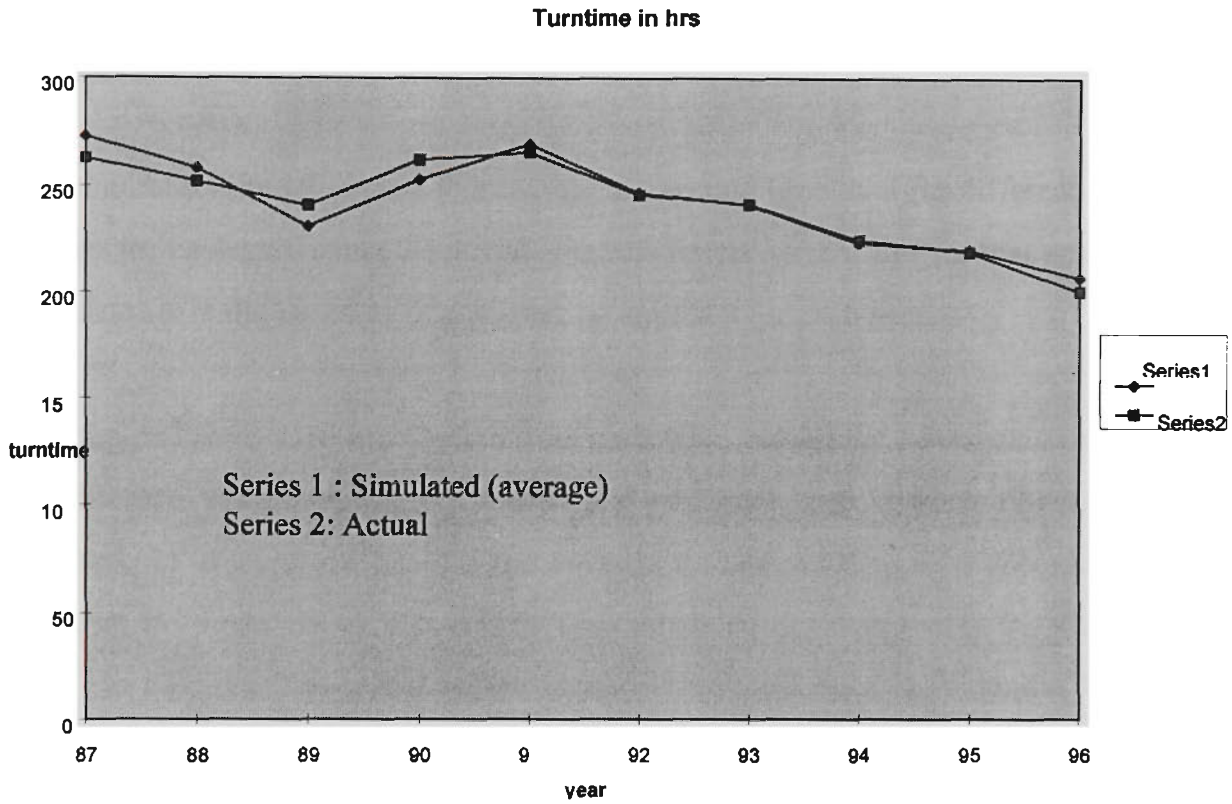



**Figure 7.3**

To understand the validity of the model, it was first run for each year using actual values of $n$ and $c$. A pictorial presentation of the average turnaround times is shown in Figure 7.3. It can be observed that there was a close correspondence between observed and estimated values. Although eventually 450 replications were used for each year to obtain the regression equation of the 'technology curve' ($T$ against $n$ and $c$); here only 3 different seeds are used (and averaged upon). The predictive power of the full model is discussed in the next two sections. It was observed that ships did not have to wait for berths. Usually, it was the unavailability of river pilots and unsuitability of river conditions which caused the delay.

## 7.5 Estimating Demand

The two step process of demand estimation is discussed below. In step 1 we consider the technology aspect of the port with the help of the simulation model and estimate the relevant parameters. In the next step, the demand equations are estimated using as inputs, the estimated parameters obtained from step 1.

*Step 1*: In this step,

a) the simulation model is used to generate turnaround time data for different $n$ and $c$ values for each year using the actual numbers for resource usage for that year, and
b) this data set is then used to fit a regression equation for each year.

The functional form used was the same for each year, though the parameters estimated were different. For generating the data set for each year, three random number seeds were used, 15 $n$'s and 10 $c$'s and the average turnaround time was recorded, thus generating 450 replications. The results were tabulated chronologically for the period 1986-87 to 1995-96. The output for the year 1995-96 is attached as Appendix 7.5. The first column gives the random number seed, the second column is an index for interarrival time (where 1 is an interarrival time of 9 hours, 2 is 9.25 hours, 3 implies 9.5 hours and so on). The third column is traffic while the last column gives the turnaround time. Thereafter, the econometric package LIMDEP (Greene 1996) was used to conduct a SURE (Seemingly Unrelated Regression Equations) estimation procedure to estimate the regression equation(s). The specification that yielded the best explanatory power was a log-log form namely:

$$ln\, T_t = \alpha_t + \beta_t\, ln\, n_t + \gamma_t\, ln\, c_t \qquad (5.1)$$

The estimated $\alpha_t$ , $\beta_t$ and $\gamma_t$ for each time period, as well as the $R^2$, and Durbin-Watson statistics are all listed in Table 7.3. As is expected, the coefficients on $n$ and $c$ are always positive, and apart from one instance are also highly significant. The $R^2$ values are moderate (55%) to high (89%), something not expected to be achieved with such a simple specification in a model as complex as this one . A simple OLS model was run for each year; the log likelihood did decline but not dramatically (by about 0.1% in most cases) which means that OLS estimates, at least for this study, would have worked almost as well.

Step 2:

Next, the system is specified,

$$ln\, T_t = y_0 + y_1 t + y_2 t^2 + \alpha_t + \beta_t \, ln\, n_t + \gamma_t \, ln\, c_t \qquad (5.2)$$

$$T_t \equiv d_t + c_t \; h_t \qquad (5.3)$$

$$ln\, n_t = k_1 + k_2 \; ln\, d_t + k_3 \; p_t + k_4 \, h_t \qquad (5.4)$$

$$ln\, c_t = k_5 + k_6 \; ln\, d_t + k_7 \; p_t + k_8 \, h \qquad (5.5)$$

Where, now $\alpha$, $\beta$, $\gamma$ are entered as *variables* and $t$ denotes time or year. The choice of functional forms and explanatory variables[7] were arrived at after much experimentation. Finally, the whole system is estimated by NL3SLS ( Non Linear 3 Stage Least Squares) using LIMDEP (Appendices 7.6 and 7.7). The estimated equations appear in Table 7.4.

Apart from the good fit and the high levels of significance, some characteristics of the estimated coefficients require comment. First, the correction to the technology equation is small but statistically significant. For instance, for the year 1987, the first three correction terms would add to -0.092 approximately. Without the correction turnaround, time is predicted by the last three terms to be 269.62; with the correction term it is 245.89, a difference of less than 10% (the corrections get smaller as the years increase). As far as the coefficients in the two demand equations are concerned, most of them appear to have the right signs. One might think that a higher value of any of the three explanatory variables (*d, p* and *h*) is not suitable for shipowners and should have contractionary effect on both *n* and *c*. This is true for four of the six relevant coefficients but one might wonder whether to expect that *c* will actually increase with a rise in *d* and whether *n* could rise with a higher *h.* It turns out that such signs can indeed follow from rational behaviour and will be seen in the next section. Also, the two equations enable us to predict what will happen to *total cargo (nc)* as *d, p* and *h* rise. In all cases total cargo decreases as can be found out by simply adding coefficients of the explanatory variables from the two equations.

[7] In particular, lagged *d, p and h* turned out to have little explanatory power and were therefore dropped.

**Table 7.3 Results from Step 1 in Demand Estimation**

| *Year (t)* | $\alpha_t$ | $\beta_t$ | $\gamma_t$ | $R^2$ | *Log likelihood* | *DW statistic* |
|---|---|---|---|---|---|---|
| 1986-87 | 2.8291 (0.080) | 0.1434 (0.009) | 0.4711 (0.013) | 0.77 | 1136.843 | 1.92 |
| 1987-88 | 3.1357 (0.091) | 0.1049 (0.011) | 0.4608 (0.015) | 0.69 | 1085.371 | 1.88 |
| 1988-89 | 3.4931 (0.044) | 0.0590 (0.005) | 0.4130 (0.008) | 0.87 | 1443.886 | 1.87 |
| 1989-90 | 2.4820 (0.129) | 0.1701 (0.014) | 0.5018 (0.023) | 0.59 | 966.583 | 1.92 |
| 1990-91 | 1.6663 (0.145) | 0.3079 (0.016) | 0.4807 (0.025) | 0.63 | 909.303 | 1.95 |
| 1991-92 | -0.6649 (0.222) | 0.5989 (0.022) | 0.5708 (0.040) | 0.67 | 748.594 | 1.67 |
| 1992-93 | 3.9516 (0.043) | 0.0015 (0.004) | 0.3771 (0.008) | 0.82 | 1524.982 | 1.90 |
| 1993-94 | 3.3826 (0.049) | 0.0899 (0.004) | 0.3432 (0.009) | 0.79 | 1478.689 | 1.49 |
| 1994-95 | 3.6444 (0.060) | 0.0524 (0.005) | 0.3323 (0.011) | 0.67 | 1403.683 | 1.67 |
| 1995-96 | 3.6523 (0.074) | 0.0462 (0.006) | 0.3140 (0.014) | 0.55 | 1331.923 | 1.05 |

Note: Standard errors are in parenthesis.

**Table 7.4 Estimated Equations from Step 2 in Demand Estimation**

$$\ln T_t = 13.368 - 0.30175\,t + 0.00169\,t^2 + \alpha_t + \beta_t \ln n_t + \gamma_t \ln c_t$$

(5.6)

(0.00985) (0.00022) (0.00001) $R^2 = 0.76$

$$\ln n_t = 7.4883 - 0.17586 \ln d_t - 0.029007\,p_t + 0.13723\,h_t$$

(5.7)

(0.00317) (0.00064) (0.00004) (0.00009) $R^2 = 0.94$

$$\ln c_t = 3.7927 + 0.17392 \ln d_t - 0.002135\,p_t - 0.33312\,h_t$$

(5.8)

(0.00119) (0.00024) (0.00002) (0.00004) $R^2 = 0.78$

Log Likelihood for the entire model: -11.82254; McElroy's $R^2 = 0.97899$.

Note: The number in parenthesis is the standard error; all coefficients are significant at 0.1% level.

## 7.6 Microeconomic Models of Demand Behaviour

In this section the determinants of the number of ships sent to the port and the average cargo carried in them are considered. For simplicity, a 'representative ship' model is considered, fully cognisant of other individual and general factors not captured here that may contribute to these decisions but choosing not to involve them in this simple framework. The sole objective of this exercise is to show that the signs of the coefficients in the demand equations make sense by building very simple models which yield similar results. In what follows, the shipowner and the cargo sender will be considered as one entity (as they may be expected to seek the most efficient arrangement between themselves) simply called the decision maker.

The decision maker's profit function is given by:

$$\pi\ (n,c) = (\alpha - p)nc - k_1(d + hc)n - k_2(nc)^2 - k_3c \qquad (6.1)$$

where:

$\alpha$ is the unit of margin on the cargo;

$p$ is the unit price paid to the port for cargo handling inclusive of all costs;

$n$ is the number of ships sent;

$c$ is the cargo amount per ship;

$d$ is the component of turnaround time *not* spent in cargo handling;

$h$ is the time required per unit cargo handled; and

$k_1$ , $k_2$ , $k_3$ are constants.

In this formulation, the first term on the right hand side represents the amount of money he makes in selling his goods after paying the port all the charges. This will be the net revenue term. The second term explicitly captures the cost of 'delay'; it can be thought in opportunity cost terms, as money that could have been earned by using the ship for other purposes. This will be the delay cost term. To some extent the total delay is controlled by the decision maker, in so far as it is affected by the amount of cargo he decides to send. The third term is the production cost term; to reflect the standard assumption that unit marginal cost may be rising a quadratic cost function is used.[8] Finally, there is the inventory cost term. One should think of this as stemming from the sawtooth inventory pattern that results from the periodic transfer of material from the place of production to its destination; the inventory level drops to zero right after every voyage and builds up to $c$ continuously until the next voyage. Thus the inventory cost is directly linked to $c$.

The decision maker chooses $n$ and $c$ optimally to maximise his profits. It is required, of course, that both decision variables be non-negative. Also at the optimum, for the decisionmaker to be effectively not shut out, one must have $(\alpha - p - k_1 h) > 0$ as otherwise, the profit function can not be positive.

To obtain an idea about the optimal $n^*$ and $c^*$ interior solutions are assumed and the first order conditions are:

[8] It may be checked that the optimising problem solved subsequently does not have a solution if the production cost is assumed to be linear in total production. However, incorporating a linear term along with a quadratic term will not change any of the comparative statics results as can be easily verified.

$$\frac{\partial \pi}{\partial n} = (\alpha - p)c - k_1(d + hc) - 2k_2nc^2 = 0 \tag{6.2}$$

$$\frac{\partial \pi}{\partial c} = (\alpha - p)n - k_1nh - 2k_2n^2c - k_3 = 0 \tag{6.3}$$

In addition, so that the second order condition for a maximum may be satisfied the Hessian matrix:

$$\begin{bmatrix} -2k_2c^2 & (\alpha - p - k_1h) - 4k_2nc \\ (\alpha - p - k_1h) - 4k_2nc & -2k_2n^2 \end{bmatrix}$$

must be negative definite. As is well known this is assured when the first principal minor (that is the first row-first column term) is negative – which is clearly the case – and the second principal minor (the determinant in this case) is positive.

Equations (2) and (3) together imply:

$$n = \frac{k_3}{k_1d}c \tag{6.4}$$

Substituting for the expression for $n$ in equation (6.2) and a little rearrangement yields

$$-c^3 + \frac{(\alpha - p - k_1h)k_1d}{2k_2k_3}c - \frac{k_1^2d^2}{2k_2k_3} = 0 \tag{6.5}$$

Also, the requirement that the second principal minor of the above mentioned Hessian matrix is positive can be rewritten using (6.4) as:

$$(\alpha - p - k_1h) < \frac{6k_2k_3}{k_1d}c^2 \tag{6.6}$$

So the question arises: Does there exist a root of (6.5) obeying (6.6), and if so what is its expression? The answer is yes, there is such a root under an appropriate condition and no, an algebraic expression for such a root cannot be provided. To gain better understanding of the situation, consider Figure 7.5 where:

$c^3$ and $\frac{(\alpha - p - k_1h)k_1d}{2k_2k_3}c - 9\frac{k_1^2d^2}{2k_2k_3}$

as functions of $c$ are plotted. Clearly, any solution to (6.5) is given by the intersection of the cubic and the linear curves. Since $(\alpha - p - k_1 h)$ is positive, of course, there is a negative root that may be ignored, and if there are positive roots, they must occur in a pair (unless the straight line is exactly tangent to the cubic curve). Theory of algebraic equations tells us that this happens when:[9]

$$(\alpha - p - k_1 h) > 3(.5\, k_1 k_2 k_3 d)^{\frac{1}{3}} \tag{6.7}$$

Since a positive root is needed to seriously discuss the solution of the optimisation problem, it is assumed that (6.7) holds.

Continuing on the discussion of Figure 7.5, next we need to know which of the two positive roots is the maximum (or satisfies (6.6) ). It is claimed to be the larger one. It is at this larger root that the derivative of equation (6.5) is negative (because the expression changes from positive to negative at this point). It may be checked that taking the derivative of (6.5) and setting it less than 0, is exactly the same as the inequality in (6.6).

The graphical characterisation of the solution also allows quick comparative statics for the case of changes in $p$ and $h$. Figure 7.6 shows that a *rise in* $p$ lowers the slope of the straight line without changing its intercept; hence the new intersection between the line and the (cubic) curve takes place at a *lower* $c$. Exactly the same reasoning applies with $h$ and hence *a rise in* $h$ *lowers* $c$. To see the effect of $d$, unfortunately the diagram does not suffice as a rise in $d$ at once raises the slope and lowers the intercept.

To this end the first order condition is differentiated (6.5) with respect to $d$. This results in:

---

[9] Any cubic equation is expressible in the form $y^3 + py + q = 0$; for such an equation the *Discriminant* is defined as $-4p^3 - 27q^2$. The cubic equation will have 3 distinct real roots only when the discriminant is positive. It is a fairly intricate result that in such a situation, also known as the *irreducible case*, the roots cannot be expressed in terms of p, q and their radicals (unlike in the case of quadratic equations) (Uspensky 1948).

$$-3c^2 \frac{dc}{dd} + \frac{(\alpha - p - k_1 h)}{2k_2 k_3} k_1 \left(c + d \frac{dc}{dd}\right) - \frac{2k_1^2 d}{2k_2 k_3} = 0 \qquad (6.8)$$

or $$\frac{dc}{dd} = \frac{((\alpha - p - k_1 h)\, k_1 c - 2k_1^2 d) / 2k_2 k_3}{3c^2 - \dfrac{(a - p - k_1 h)\, k_1 d}{2k_2 k_3}} \qquad (6.9)$$

That the numerator is > 0 follows from manipulating the first order condition; that the denominator too is > 0 follows from the second order condition. Hence, this corroborates the somewhat paradoxical result that a *rise in d* actually leads to a *higher c*. Using equation (6.4), the effect of $p$ and $h$ on $n$ is seen as well. Clearly, $n$ gets lowered with a rise in either $h$ or $p$. Although in the empirical section a negative coefficient on $p$ is obtained, a positive coefficient on $h$ is obtained. However, there *is* an explanation of this which will be detailed later in this section.

Unfortunately, (6.4) cannot be used to deduce the effect of $d$ on $n$ as $d$ enters into that expression in the denominator. However, one can show that a higher $d$ lowers $nc$ and therefore must lower $n$. One way to do this is to use equation (6.4) to express all terms in the original objective function (1) in terms of $nc$ which is hereafter refered to as $q$. The objective function then can be written as:

$$(\alpha - p - k_1 h)q - k_2 q^2 - (k_1 k_3 d)^{.5} q^{.5} \qquad (6.10)$$

and the first order condition for its maximisation is:

$$(\alpha - p - k_1 h) - 2k_2 q = .5(k_1 k_3 d)^{.5} q^{-.5} \qquad (6.11)$$

In Figure 7.7, the optimal q is characterised by the *larger* of the two intersections of the downward sloping straight line representing the left hand side of (6.11) and the convex downward sloping curve representing the right hand side of

(6.11)[10]. A rise in $d$ raises this latter curve and hence shifts the larger point of intersection leftward, signifying a decrease in the optimal $q$.

To recapitulate, there are the following predictions: *i)* higher $p$ lowers $n$, $c$ and $q$, *ii)* higher $h$ lowers $n$, $c$ and $q$, and *iii)* higher $d$ raises $c$, lowers $n$ and $q$. Of the nine comparative statics signs only one is not in agreement with empirical findings: namely the effect of $h$ on $n$. This is because the foregone model was too simplistic – in fact a small alteration of it can tackle the discrepancy.

It is assumed that a number of decision makers are either producing at full capacity (which is another way of saying that the marginal cost of production rises up to infinity from the present level) or that they have already made their decision on the total quantity to be supplied based on some contract. This can happen when the decisionmaker is only the shipowner operating under a contract from the cargo sender – a separate entity. In either case a drop in $h$ does not allow him to adjust his $q$ to a higher level; although he can change the $n$-$c$ mix. Also it is assumed that the marginal cost of delay per voyage, instead of being a constant is actually increasing in the delay; more specifically, in addition to the linear term, a quadratic term is assumed as well in the expression for delay cost. These two changes are able to produce the observed effect. To see how this comes about the decisionmaker's problem is rewritten as:

$$\text{Min } Cost\ (n,c) = k_{11}(d+hc)n - k_{12}(d+hc)^2 n - k_3 c \qquad (6.12)$$

$$\text{sub to } nc = \bar{q}. \qquad (6.13)$$

Thus, the terms in (6.1) which contain the product $nc$ have been ignored. By substituting for $c$ in terms of $n$ and then writing out the first order condition, one may easily verify that the optimal $n$ is given by $\left.\dfrac{k_{12}h^2\bar{q} + k_3\bar{q}}{k_{11}d + k_{12}d^2}\right)^{.5}$. (6.14)

[10] It is only at the larger value that the derivative of the objective changes sign from positive to negative, satisfying second order condition.

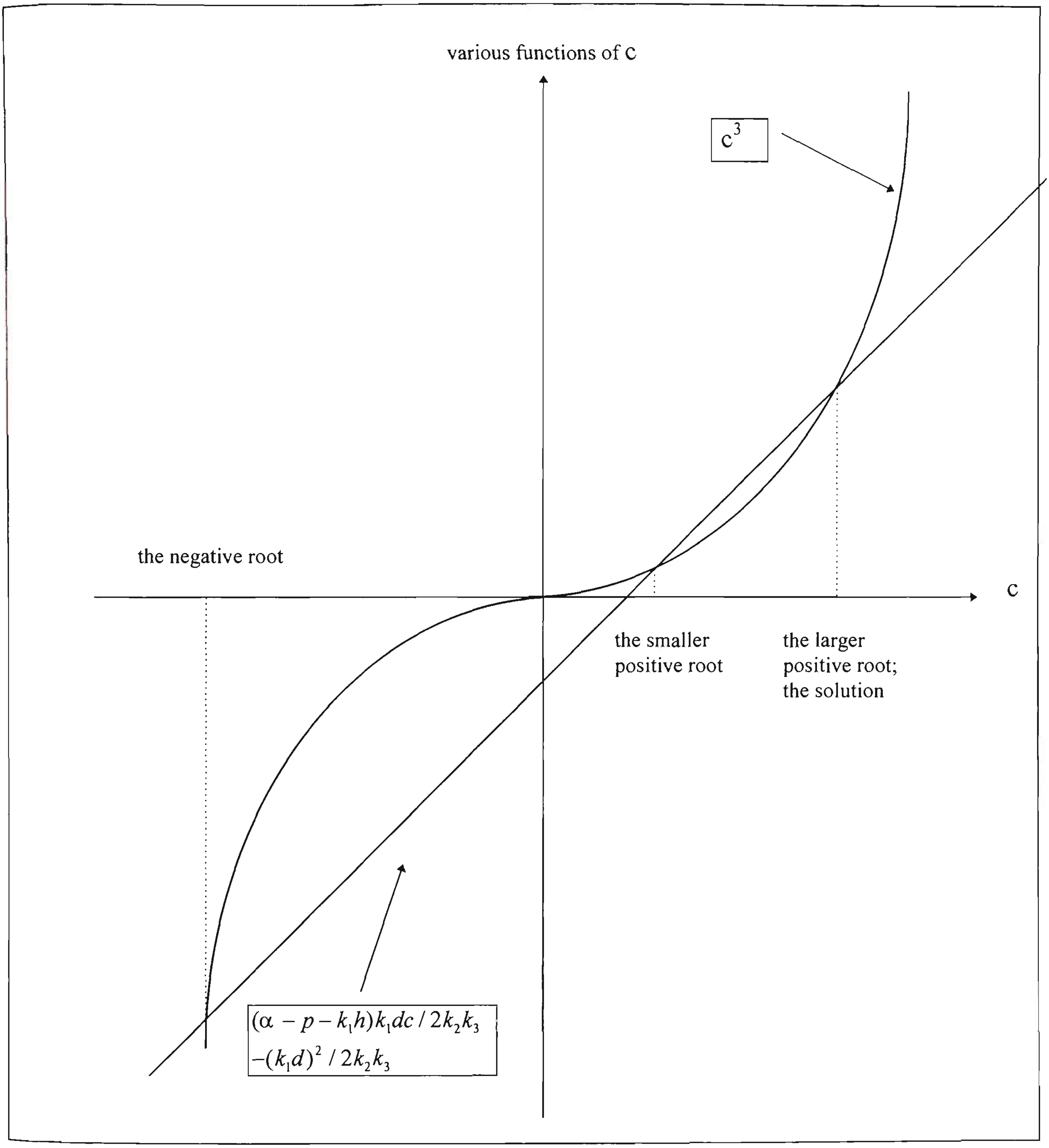



**Figure 7.5: The Three Different Roots of the Cubic First Order Equation**

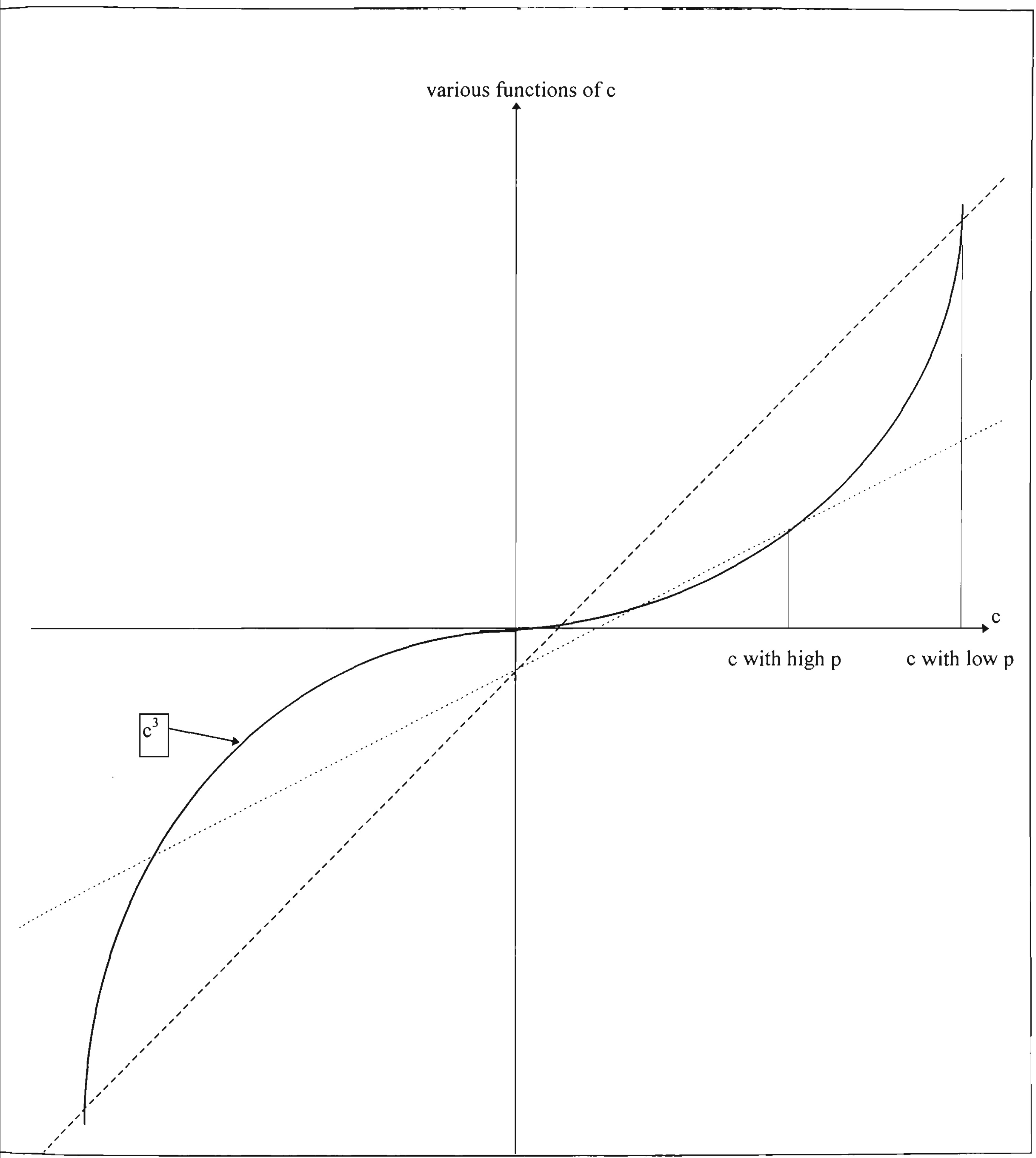



**Figure 7.6 The Effect of a Change in P**

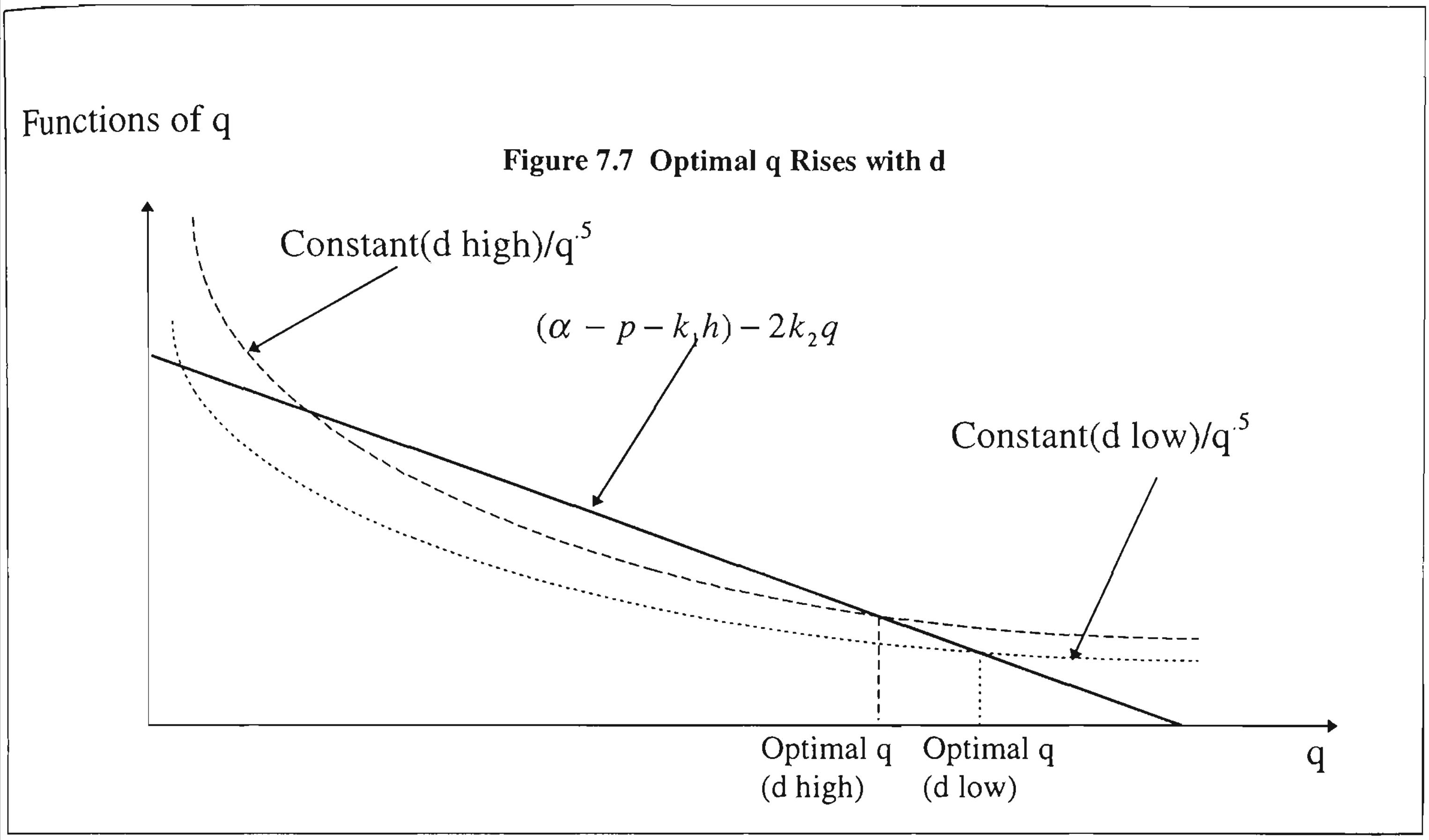



FIGURE 7.7: OPTIMAL q RISES WITH d

**TYPE 1 PREDICTED**

| | n | c | q |
|---|---|---|---|
| p | – | – | – |
| d | – | + | – |
| h | – | – | – |

**TYPE 2 PREDICTED**

| | n | c | q |
|---|---|---|---|
| p | 0 | 0 | 0 |
| d | – | + | 0 |
| h | + | – | 0 |

**OBSERVED**

| | n | c | q |
|---|---|---|---|
| p | – | – | – |
| d | – | + | – |
| h | + | – | – |

FIGURE 7.8: COMPARATIVE STATIC SIGNS

Clearly, a lower $h$ lowers $n$ (and raises $c$), while a higher $d$ also has the same effect. Apparently $p$ has no effect on either.

To complete the argument it is proposed that visiting ships constitute a mix of the two types described in the two models above. Assuming appropriate weights, the nine observed comparative statics signs are then easily explained (Figure 7.8). The fact that the existence of a reasonable number of type two ships is needed to do this, will play an important role in the price prescriptions given in the next section.

## 7.7 Were the Prices Optimal?

Returning to the estimates of the three equation system from section 7.5, the question is asked: given the facilities which determined $\alpha_t$, $\beta_t$, $\gamma_t$ were the prices 'correct' from the standpoint of optimal revenue generation? There are several clues in the results of sections 7.5 and 7.6 which make one suspect that this might not have been the case – higher prices might have been better. The price coefficients in the demand equations are relatively small and the coefficient of $h$ in the $n$ equation is positive. This type of behaviour is expected of decisionmakers who are transporting fixed amounts under contracts or of producers who are producing at capacity (and who are probably netting a marginal revenue much higher than the (total) prices they have to pay), so that raising of $p$ does not induce them to reduce their $q$. It appears that these types are well represented in the decisionmaker population and will lend price inelasticity to the total demand making higher prices profitable.

The above argument is somewhat heuristic. The fact is that even though $q$ is relatively inflexible, as $n$ and $c$ change, they will induce changes in $d$ (via the technology equation) and this will produce second round effects on $n$, $c$ and perhaps will then change $q$ significantly – as one may expect in a simultaneous system. In trying to answer the question as to whether the prices charged were indeed optimal, each t is solved for the following non-linear programming problem:

NLP1: $Max\ Profit_t = n_t\ c_t\ p_t$

subject to (5.6), (5.7), (5.8), (5.3) and $t$ set for the corresponding year.

Thus the only argument in the above maximisation problem is $p_t$ which is picked optimally and compared with the actual $p_t$ which was used in that particular year.

The problem was solved using the non-linear solver GINO and the results are tabulated in Table 7.5. They show that for each of the years considered, the optimal price was much higher than the actual price and the optimal profit was anywhere between 200 to 300 % larger than the actual profits. The optimal values of $n$ were on an average less than half of the actual values. The optimal $c$ values, however, tended to be only a little less than actual values, on average by 10% or so. Naturally, with lower $n$ and lower $c$ one expects low (optimal) $T$ which is what was found. Optimal price is at a level much, much higher than current levels and is hardly affected by technological changes in the system.

**Table 7.5 Results from NLP1: Optimal Values of *p* and all Endogenous Variables (1987 - 1996)**

| Year | n | | c | | T | | Profit | | p | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Actual** | **Optimal** | **Actual** | **Optimal** | **Actual** | **Optimal** | **Actual** | **Optimal** | **Actual** | **Optimal** |
| '87 | 898 | 423.76 | 45 | 41.25 | 273.12 | 232.29 | 245873.8 | 561548.8 | 6.084 | 32.125 |
| '88 | 933 | 412.10 | 47 | 44.12 | 258.24 | 231.16 | 229094.9 | 584005.1 | 5.224 | 32.121 |
| '89 | 840 | 392.52 | 52 | 50.21 | 230.88 | 219.57 | 313780.0 | 632892.4 | 7.184 | 32.115 |
| '90 | 808 | 398.93 | 54 | 48.57 | 252.72 | 216.90 | 311001.3 | 622606.5 | 7.128 | 32.134 |
| '91 | 781 | 408.59 | 53 | 47.24 | 269.52 | 201.52 | 271274.6 | 620321.6 | 6.554 | 32.141 |
| '92 | 703 | 421.05 | 59 | 47.53 | 246.72 | 164.26 | 232889.6 | 643846.5 | 5.615 | 32.173 |
| '93 | 764 | 353.58 | 67 | 61.95 | 241.20 | 231.97 | 279939.5 | 703325.3 | 5.469 | 32.110 |
| '94 | 736 | 351.51 | 70 | 65.07 | 223.44 | 202.86 | 274801.2 | 734624.9 | 5.334 | 32.119 |
| '95 | 755 | 343.84 | 72 | 67.60 | 220.08 | 208.29 | 228047.9 | 746514.0 | 4.195 | 32.116 |
| '96 | 805 | 335.64 | 76 | 72.11 | 207.12 | 195.27 | 279254.9 | 777257.0 | 4.564 | 32.115 |

Several caveats of these GINO outputs must be pointed out. It must be considered that the real data was subject to random shocks both from the demand and the technology sides. But more importantly, concluding that the above figures provide global optima when the estimated functions are only locally valid, would be impractical. Consequently, perhaps a more relevant question is: what would be the implicit derivative of revenue with respect to prices (taking care to fulfil all the constraints simultaneously)? Or one could ask what were the elasticities of $q$ with respect to $p$? It is well known that a monopolist service provider should be operating at prices where elasticity is -1. Contrarily, if maximising the social welfare is the objective, it can be shown that either the prices should be dropped to 0 or be such that desired elasticity is +1.[11] Thus by comparing the actual elasticities to these benchmarks, one can assess where the port authorities stood in terms of their objectives.

To resolve this issue, one must solve for each year, another non-linear programming problem (NLP2) which makes two changes to NLP1. First, it appends the additional constraint: $p_t$ = actual price for year t, and second it changes the objective from $p_t\, q_t$ to simply $q_t$. Although the problem now has no free variable to maximise with respect to, its output gives a lot of information. Second, it gives a good idea of the model fit as one can now compare the actual values with the model-generated values. For facility of comparison, both sets of numbers are listed in Table 7.6.

One can see that the $c$ series has been remarkably well predicted but the $n$ series has differed quite a bit from the predictions. Turnaround time has been within 95% confidence intervals in all but one year (1992 when it was within 90%). As for profits, except for 1992 and 1996, the fit is reasonably good.

[11] In the latter case, at least a portion of the demand curve must be upward sloping. In a general queuing environment it is not implausible that such a demand curve can exist.

**Table 7.6 Results from NLP2: Actual Against Model-Predicted Values**

| *Year* | *n* | | *c* | | *T* | | *Profit* | |
|---|---|---|---|---|---|---|---|---|
| | **Actual** | **Model** | **Actual** | **Model** | **Actual** | **Model** | **Actual** | **Model** |
| 1987 | 898 | 872.3 | 45 | 45.07 | 273.12 | 268.61 | 245873.8 | 239223.1 |
| 1988 | 933 | 876.6 | 47 | 47.91 | 258.24 | 259.91 | 229094.9 | 219439.3 |
| 1989 | 840 | 798.8 | 52 | 53.62 | 230.88 | 235.27 | 313780.0 | 307674.1 |
| 1990 | 808 | 793.0 | 54 | 53.21 | 252.72 | 255.22 | 311001.3 | 300765.7 |
| 1991 | 781 | 802.5 | 53 | 53.32 | 269.52 | 262.94 | 271274.6 | 280399.7 |
| 1992 | 703 | 797.0 | 59 | 57.33 | 246.72 | 267.92 | 232889.6 | 256561.6 |
| 1993 | 764 | 765.6 | 67 | 65.59 | 241.20 | 237.21 | 279939.5 | 274614.9 |
| 1994 | 736 | 750.5 | 70 | 70.17 | 223.44 | 222.88 | 274801.2 | 280877.1 |
| 1995 | 755 | 764.4 | 72 | 72.54 | 220.08 | 222.33 | 228047.9 | 232611.2 |
| 1996 | 805 | 739.4 | 76 | 77.18 | 207.12 | 206.90 | 279254.9 | 260504.1 |

The other important information yielded by the solution to NLP2 is the dual price on the added constraint. This is the (total) price derivative of $q$, the aggregate demand (given that the system has settled in equilibrium). From these, the price elasticity are computed. These are listed below in Table 7.7.

**Table 7.7 Rate of Revenue Change and its Elasticity with Respect to Price**

| *Year* | $\Delta q/\Delta p$ | $p/q * \Delta q/\Delta p$ |
|---|---|---|
| 1987 | -1223.835 | -0.189257 |
| 1988 | -1307.593 | -0.162651 |
| 1989 | -1333.565 | -0.223559 |
| 1990 | -1313.338 | -0.221923 |
| 1991 | -1331.221 | -0.204107 |
| 1992 | -1420.648 | -0.174422 |
| 1993 | -1563.769 | -0.170035 |
| 1994 | -1639.505 | -0.165946 |
| 1995 | -1726.505 | -0.130466 |
| 1996 | -1777.118 | -0.141990 |

Given that the magnitude of actual elasticities is roughly 80% smaller than the optimal magnitudes, there is no escaping the fact that the services were generally underpriced during the years covered by this study. This conclusion, at first glance, may seem counter-intuitive. Given that demand is in a state of decline, should it not be boosted by a drop in prices? Also, given that the turnaround time is already large, would not an increase in prices drive away the remaining customers? The answer can be found in noting that the elasticity figures are quite small – not too different from 0. This shows that the port has in this period been forced to operate on the inelastic segment of the demand curve having already lost the more price and performance sensitive customers perhaps to competing ports. The remaining customers, perhaps because of rigid geographical preferences, suffer from a lack of mobility – and consequently seem willing to bear a further rise in prices. To some extent this helps those who have large opportunity cost of delay by weeding out those who do not (as these shipowners will not benefit from the thinning of traffic and will bear the full burden of rising prices).

## 7.8 Conclusions

The chapter develops an interesting methodology which combines the technique of simulation of port operations with the econometrics of simultaneous equations in order to estimate the demand for port services. It facilitates demand estimation by simulating the technological environment and by using estimates of the technology equation from simulated data. The results demonstrate that prices can be a crucial instrument in regulating queue performance at a port. It tries to unravel a story of what is happening at an ailing port by asking the question: what should be true of the behavior of decision makers which will generate estimates such as the ones found in the above exercise? The insight derived from the answers fits quite well with the prescriptions given by optimisation packages used in the exercise.

# Appendix 7.1

| # Ship | SH wait (hrs) | Inpilotage (hrs) | L/Unl time (hrs) | Idle time (hrs) | Tot.berth t (hrs) | Outpilotag (hrs) | Turnrnd T (hrs) |
|---|---|---|---|---|---|---|---|
| 7 | 11.76 | 22.00 | 169.20 | 3.36 | 172.56 | 17.00 | 223.32 |
| 10 | 2.64 | 22.44 | 102.48 | 6.96 | 109.44 | 27.50 | 162.02 |
| 18 | 0.24 | 18.00 | 169.92 | 95.76 | 265.68 | 12.83 | 296.75 |
| 19 | 34.32 | 24.00 | 148.56 | 6.48 | 155.04 | 17.16 | 230.52 |
| 21 | 2.64 | 25.25 | 45.84 | 17.52 | 63.36 | 12.75 | 104.00 |
| 27 | 3.60 | 13.50 | 95.04 | 7.92 | 102.96 | 18.32 | 138.38 |
| 32 | 2.16 | 12.50 | 7.20 | 31.92 | 39.12 | 9.50 | 63.28 |
| 33 | 1.68 | 12.08 | 156.24 | 39.12 | 195.36 | 18.75 | 227.87 |
| 37 | 6.48 | 23.59 | 22.08 | 17.28 | 39.36 | 9.75 | 79.18 |
| 37 | 6.48 | 23.59 | 22.08 | 17.28 | 39.36 | 9.75 | 79.18 |
| 45 | 43.92 | 26.00 | 36.48 | 30.72 | 67.20 | 10.00 | 147.12 |
| 54 | 9.12 | 24.25 | 87.84 | 177.84 | 265.68 | 20.25 | 319.30 |
| 54 | 9.12 | 24.25 | 87.84 | 177.84 | 265.68 | 20.25 | 319.30 |
| 57 | 47.04 | 9.45 | 140.88 | 52.08 | 192.96 | 18.66 | 268.11 |
| 57 | 47.04 | 9.45 | 140.88 | 52.08 | 192.96 | 18.66 | 268.11 |
| 64 | 8.00 | 23.75 | 80.00 | 4.30 | 84.30 | 17.00 | 133.05 |
| 65 | 6.48 | 24.42 | 126.72 | 40.80 | 167.52 | 19.75 | 218.17 |
| 67 | 5.76 | 23.92 | 108.08 | 13.92 | 122.00 | 19.75 | 171.43 |
| 68 | 0.48 | 14.00 | 95.04 | 23.76 | 118.80 | 19.50 | 152.78 |
| 69 | 15.36 | 14.81 | 56.88 | 21.36 | 78.24 | 11.50 | 119.91 |
| 69 | 15.36 | 14.81 | 56.88 | 21.36 | 78.24 | 11.50 | 119.91 |
| 72 | 5.76 | 13.25 | 41.52 | 23.76 | 65.28 | 10.00 | 94.29 |
| 72 | 5.76 | 13.25 | 41.52 | 23.76 | 65.28 | 10.00 | 94.29 |
| 72 | 5.76 | 13.25 | 41.52 | 23.76 | 65.28 | 10.00 | 94.29 |
| 77 | 0.00 | 32.75 | 892.08 | 188.16 | 1080.24 | 24.16 | 1137.15 |
| 86 | 1.92 | 24.66 | 114.48 | 43.20 | 157.68 | 12.32 | 196.58 |
| 93 | 0.48 | 13.45 | 48.72 | 30.48 | 79.20 | 18.00 | 111.13 |
| 102 | 0.72 | 24.00 | 18.96 | 19.68 | 38.64 | 17.50 | 80.86 |
| 102 | 0.72 | 24.00 | 18.96 | 19.68 | 38.64 | 17.50 | 80.86 |
| 109 | 0.24 | 24.00 | 84.72 | 17.76 | 102.48 | 19.75 | 146.47 |
| 111 | 0.96 | 24.00 | 131.76 | 45.60 | 177.36 | 21.16 | 223.48 |
| 116 | 1.20 | 24.00 | 119.52 | 7.92 | 127.44 | 20.34 | 172.98 |
| 119 | 1.20 | 24.00 | 60.72 | 43.68 | 104.40 | 33.00 | 162.60 |
| 129 | 9.12 | 25.50 | 100.32 | 19.68 | 120.00 | 22.50 | 177.12 |
| 133 | 2.88 | 15.00 | 98.16 | 43.92 | 142.08 | 21.32 | 181.28 |
| 148 | 37.68 | 12.00 | 26.40 | 40.56 | 66.96 | 41.66 | 158.30 |
| 149 | 0.72 | 20.08 | 52.08 | 27.12 | 79.20 | 20.00 | 120.00 |
| 153 | 4.80 | 23.00 | 83.28 | 23.76 | 107.04 | 16.66 | 151.50 |
| 153 | 4.80 | 23.00 | 83.28 | 23.76 | 107.04 | 16.66 | 151.50 |
| 154 | 144.96 | 25.00 | 59.04 | 18.72 | 77.76 | 40.26 | 287.98 |
| 162 | 63.84 | 30.17 | 37.92 | 22.32 | 60.24 | 57.32 | 211.57 |
| 163 | 0.24 | 10.75 | 85.44 | 33.60 | 119.04 | 76.50 | 206.53 |

| # Ship | SH wait | Inpilotage | L/Unl time | Idle time | Tot.berth t | Outpilotag | Turnrnd t |
|---|---|---|---|---|---|---|---|
| | (hrs) | (hrs) | (hrs) | (hrs) | (hrs) | (hrs) | (hrs) |
| 168 | 1.44 | 10.50 | 55.44 | 15.60 | 71.04 | 76.66 | 159.64 |
| 170 | 0.24 | 11.43 | 172.08 | 156.24 | 328.32 | 12.25 | 352.24 |
| 177 | 76.56 | 41.50 | 275.28 | 62.40 | 337.68 | 40.00 | 495.74 |
| 181 | 87.36 | 25.00 | 71.04 | 64.08 | 135.12 | 13.08 | 260.56 |
| 185 | 10.80 | 26.50 | 47.28 | 8.64 | 55.92 | 18.50 | 111.72 |
| 194 | 23.04 | 10.00 | 14.88 | 23.52 | 38.40 | 12.00 | 83.44 |
| 198 | 12.00 | 10.75 | 16.80 | 30.24 | 47.04 | 21.25 | 91.04 |
| 199 | 46.08 | 25.25 | 12.48 | 14.16 | 26.64 | 22.75 | 120.72 |
| 212 | 0.24 | 14.00 | 187.44 | 80.40 | 267.84 | 19.00 | 301.08 |
| 217 | 71.52 | 22.24 | 95.52 | 60.72 | 156.24 | 28.84 | 278.84 |
| 217 | 71.52 | 22.24 | 95.52 | 60.72 | 156.24 | 28.84 | 278.84 |
| 218 | 0.72 | 16.59 | 112.08 | 93.12 | 205.20 | 25.16 | 247.67 |
| 219 | 11.04 | 12.32 | 195.36 | 124.08 | 319.44 | 15.66 | 358.46 |
| 228 | 0.24 | 11.25 | 38.88 | 41.52 | 80.40 | 27.16 | 119.05 |
| 232 | 1.92 | 22.00 | 56.88 | 21.84 | 78.72 | 16.08 | 118.72 |
| 233 | 5.76 | 16.00 | 96.72 | 19.20 | 115.92 | 20.00 | 157.68 |
| 238 | 7.68 | 13.84 | 33.60 | 30.96 | 64.56 | 11.42 | 97.50 |
| 239 | 0.24 | 20.84 | 44.16 | 20.64 | 64.80 | 23.42 | 109.30 |
| 241 | 2.40 | 11.50 | 139.68 | 103.92 | 243.60 | 32.84 | 290.34 |
| 247 | 0.24 | 14.16 | 39.36 | 38.16 | 77.52 | 22.08 | 114.00 |
| 248 | 0.24 | 16.25 | 64.08 | 91.68 | 155.76 | 56.50 | 228.75 |
| 254 | 7.92 | 22.25 | 127.20 | 121.92 | 249.12 | 34.25 | 313.54 |
| 255 | 7.92 | 21.84 | 249.12 | 99.36 | 348.48 | 21.25 | 399.49 |
| 255 | 7.92 | 21.84 | 249.12 | 99.36 | 348.48 | 21.25 | 399.49 |
| 258 | 21.12 | 11.50 | 32.16 | 31.20 | 63.36 | 26.00 | 121.98 |
| 259 | 6.24 | 25.67 | 36.96 | 51.36 | 88.32 | 22.25 | 142.48 |
| 260 | 0.24 | 11.75 | 224.40 | 103.20 | 327.60 | 35.16 | 374.75 |
| 260 | 0.24 | 11.75 | 224.40 | 103.20 | 327.60 | 35.16 | 374.75 |
| 283 | 1.25 | 22.16 | 128.74 | 57.60 | 186.34 | 28.25 | 238.00 |
| 289 | 0.32 | 20.00 | 113.60 | 64.08 | 177.68 | 28.66 | 226.66 |
| 293 | 0.50 | 11.75 | 194.41 | 75.84 | 270.25 | 16.00 | 298.50 |
| 295 | 2.00 | 20.50 | 89.20 | 64.80 | 154.00 | 14.16 | 190.66 |
| 299 | 40.84 | 14.42 | 84.98 | 11.52 | 96.50 | 29.42 | 181.18 |
| 300 | 36.41 | 12.50 | 182.51 | 72.24 | 254.75 | 30.16 | 333.82 |
| 304 | 33.18 | 12.00 | 143.83 | 49.92 | 193.75 | 23.07 | 262.00 |
| 308 | 0.25 | 13.00 | 19.99 | 17.76 | 37.75 | 14.00 | 65.00 |
| 310 | 13.00 | 19.25 | 44.86 | 15.12 | 59.98 | 29.32 | 121.55 |
| 312 | 11.58 | 11.08 | 45.60 | 14.40 | 60.00 | 8.50 | 91.16 |
| 315 | 0.42 | 18.00 | 184.76 | 132.24 | 317.00 | 17.75 | 353.17 |
| 321 | 6.25 | 20.50 | 78.84 | 206.16 | 285.00 | 30.66 | 342.41 |
| 321 | 6.25 | 20.50 | 78.84 | 206.16 | 285.00 | 30.66 | 342.41 |
| 322 | 4.66 | 11.84 | 161.86 | 38.64 | 200.50 | 22.50 | 239.50 |
| 325 | 87.50 | 12.32 | 38.66 | 17.52 | 56.18 | 14.50 | 170.50 |
| 326 | 0.00 | 27.50 | 40.00 | 12.00 | 52.00 | 15.32 | 94.82 |
| 328 | 0.84 | 34.66 | 111.86 | 44.64 | 156.50 | 23.25 | 215.25 |
| 328 | 0.84 | 34.66 | 111.86 | 44.64 | 156.50 | 23.25 | 215.25 |

| # Ship | SH wait (hrs) | Inpilotage (hrs) | L/Unl time (hrs) | Idle time (hrs) | Tot.berth t (hrs) | Outpilotag (hrs) | Turnrnd t (hrs) |
|---|---|---|---|---|---|---|---|
| 339 | 0.25 | 10.75 | 59.52 | 24.48 | 84.00 | 17.00 | 112.00 |
| 341 | 0.50 | 21.25 | 53.99 | 29.76 | 83.75 | 16.25 | 121.75 |
| 344 | 0.50 | 17.00 | 60.10 | 26.40 | 86.50 | 15.50 | 119.50 |
| 352 | 106.80 | 25.75 | 248.64 | 85.92 | 334.56 | 28.32 | 495.43 |
| 353 | 22.08 | 25.16 | 108.96 | 158.40 | 267.36 | 23.84 | 338.44 |
| 358 | 0.48 | 13.00 | 56.16 | 1.68 | 57.84 | 16.75 | 88.07 |
| 360 | 10.56 | 13.33 | 168.00 | 75.84 | 243.84 | 18.75 | 286.48 |
| 364 | 0.48 | 11.40 | 72.96 | 21.60 | 94.56 | 39.75 | 146.19 |
| 367 | 4.32 | 13.08 | 22.80 | 9.84 | 32.64 | 28.00 | 78.04 |
| 375 | 3.36 | 47.50 | 12.96 | 27.12 | 40.08 | 10.42 | 101.36 |
| 379 | 0.48 | 15.42 | 156.00 | 68.64 | 224.64 | 26.50 | 267.04 |
| 389 | 6.00 | 15.32 | 89.04 | 57.60 | 146.64 | 33.50 | 201.46 |
| 395 | 0.48 | 27.50 | 77.04 | 169.44 | 246.48 | 42.50 | 316.96 |
| 407 | 0.24 | 14.50 | 56.16 | 24.00 | 80.16 | 18.16 | 113.06 |
| **mean** | **14.30** | **19.15** | **100.99** | **51.94** | **152.93** | **22.94** | **209.33** |

# Appendix 7.2

**SIMAN fit for Idle Time**

=====================================================================

Data File: C:\bani\data\IDLE.TXT

Histogram Range: 1 to 207

No. of Data Points = 102
No. of Intervals = 10

Min Data Value = 1.68
Max Data Value = 206

Sample Mean = 51.9
Sample Std Dev = 48.1

Distribution Function: Lognormal

=====================================================================

"SIMAN USAGE: 1 + LOGN(54.8, 71.8)"
Sq Error = 0.002642

Chi Square Test:
 No. of intervals = 4
 Degrees of freedom = 1
 Test Statistic = 1.4
 Corresponding p-value = 0.242
Kolmogorov-Smirnov Test:
 Test Statistic = 0.0812
 Corresponding p-value > 0.15

=====================================================================

| Int. No. | No. of Data Pts. | x | Probability Density Data | Probability Density Function | Cumulative Distribution Data | Cumulative Distribution Function |
|---|---|---|---|---|---|---|
| 0 | 31 | 2.160e+001 | 0.304 | 0.317 | 0.304 | 0.317 |
| 1 | 28 | 4.220e+001 | 0.275 | 0.269 | 0.578 | 0.585 |
| 2 | 15 | 6.280e+001 | 0.147 | 0.147 | 0.725 | 0.733 |
| 3 | 8 | 8.340e+001 | 0.078 | 0.086 | 0.804 | 0.818 |
| 4 | 9 | 1.040e+002 | 0.088 | 0.053 | 0.892 | 0.871 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 2 | 1.246e+002 | 0.020 | 0.034 | 0.912 | 0.906 |
| 6 | 1 | 1.452e+002 | 0.010 | 0.023 | 0.922 | 0.929 |
| 7 | 2 | 1.658e+002 | 0.020 | 0.016 | 0.941 | 0.945 |
| 8 | 3 | 1.864e+002 | 0.029 | 0.012 | 0.971 | 0.957 |
| 9 | 3 | 2.070e+002 | 0.029 | 0.009 | 1.000 | 0.966 |

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BEST FIT SUMMARY

Data File: C:\bani\data\IDLE.TXT

| Function | Sq Error |
|---|---|
| Lognormal | 0.002642 |
| Weibull | 0.005445 |
| Gamma | 0.005494 |
| Exponential | 0.006171 |
| Erlang | 0.006171 |
| Beta | 0.01741 |
| Triangular | 0.04911 |
| Normal | 0.06027 |
| Uniform | 0.1059 |

**SIMAN fit for Loading Unloading or Cargo Handling Time**

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Data File: C:\bani\data\LOADUNL.TXT

Histogram Range: 7 to 893

No. of Data Points = 102
No. of Intervals = 10

Min Data Value = 7.2
Max Data Value = 892

Sample Mean = 101
Sample Std Dev = 100

Distribution Function: Gamma

=========================================================
=

"SIMAN USAGE: 7 + GAMM(68.4, 1.37)"
Sq Error = 0.001284

Chi Square Test:
No. of intervals = 3
Degrees of freedom = 0
Test Statistic = 1.17
Corresponding p-value < 0.005
Kolmogorov-Smirnov Test:
Test Statistic = 0.06426
Corresponding p-value > 0.15

================================================================
=

| Int. No. | No. of Data Pts. | x | Probability Density Data | Probability Density Function | Cumulative Distribution Data | Cumulative Distribution Function |
|---|---|---|---|---|---|---|
| 0 | 62 | 9.560e+001 | 0.608 | 0.582 | 0.608 | 0.582 |
| 1 | 29 | 1.842e+002 | 0.284 | 0.277 | 0.892 | 0.859 |
| 2 | 9 | 2.728e+002 | 0.088 | 0.093 | 0.980 | 0.952 |
| 3 | 1 | 3.614e+002 | 0.010 | 0.029 | 0.990 | 0.981 |
| 4 | 0 | 4.500e+002 | 0.000 | 0.009 | 0.990 | 0.990 |
| 5 | 0 | 5.386e+002 | 0.000 | 0.003 | 0.990 | 0.993 |
| 6 | 0 | 6.272e+002 | 0.000 | 0.001 | 0.990 | 0.994 |
| 7 | 0 | 7.158e+002 | 0.000 | 0.000 | 0.990 | 0.994 |
| 8 | 0 | 8.044e+002 | 0.000 | 0.000 | 0.990 | 0.994 |
| 9 | 1 | 8.930e+002 | 0.010 | 0.000 | 1.000 | 0.994 |

================================================================
====

BEST FIT SUMMARY

Data File: C:\bani\data\LOADUNL.TXT

| Function | Sq Error |
|---|---|
| Gamma | 0.001284 |
| Weibull | 0.001413 |
| Erlang | 0.003207 |
| Exponential | 0.003207 |
| Lognormal | 0.007501 |
| Beta | 0.008668 |
| Normal | 0.0985 |
| Triangular | 0.2757 |
| Uniform | 0.3583 |

**SIMAN fit for arrival draught of Ships**

=======================================================================

Data File: a:\IDRAFT96.TXT

Histogram Range: 3 to 7.51

No. of Data Points = 58
No. of Intervals = 7

Min Data Value = 3
Max Data Value = 7.1

Sample Mean = 5.46
Sample Std Dev = 0.8458

Distribution Function: Normal

=================================================================

"SIMAN USAGE: NORM(5.46, 0.8385)"
Sq Error = 0.002046

Chi Square Test:
No. of intervals = 4
Degrees of freedom = 1
Test Statistic = 0.6705
Corresponding p-value = 0.4379
Kolmogorov-Smirnov Test:
Test Statistic = 0.1047
Corresponding p-value > 0.15

=================================================================

| Int. No. | No. of Data Pts. | x | Probability Density Data | Probability Density Function | Cumulative Distribution Data | Cumulative Distribution Function |
|---|---|---|---|---|---|---|
| 0 | 1 | 3.643e+000 | 0.017 | 0.013 | 0.017 | 0.015 |
| 1 | 4 | 4.288e+000 | 0.069 | 0.066 | 0.086 | 0.081 |
| 2 | 10 | 4.932e+000 | 0.172 | 0.183 | 0.259 | 0.264 |
| 3 | 17 | 5.577e+000 | 0.293 | 0.291 | 0.552 | 0.555 |
| 4 | 15 | 6.221e+000 | 0.259 | 0.263 | 0.810 | 0.818 |
| 5 | 10 | 6.866e+000 | 0.172 | 0.135 | 0.983 | 0.953 |
| 6 | 1 | 7.510e+000 | 0.017 | 0.040 | 1.000 | 0.993 |

==========================================================
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BEST FIT SUMMARY

Data File: a:\IDRAFT96.TXT

| Function | Sq Error |
| --- | --- |
| Normal | 0.002046 |
| Beta | 0.002078 |
| Triangular | 0.0074 |
| Weibull | 0.009001 |
| Gamma | 0.04226 |
| Erlang | 0.04292 |
| Uniform | 0.07474 |
| Lognormal | 0.1104 |
| Exponential | 0.1385 |

==========================================================
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**SIMAN fit for Departure draught of Ships**

==========================================================
==================

Data File: a:\ODRFT96.TXT

Histogram Range: 3 to 7.5

No. of Data Points = 58
No. of Intervals = 7

Min Data Value = 3.1
Max Data Value = 7.1

Sample Mean = 5.42
Sample Std Dev = 0.7911

Distribution Function: Normal

==========================================================
=

SIMAN USAGE: NORM(5.42, 0.7843)
Sq Error = 0.001439

Chi Square Test:
No. of intervals = 4
Degrees of freedom = 1
Test Statistic = 0.3509
Corresponding p-value = 0.5737
Kolmogorov-Smirnov Test:
Test Statistic = 0.1083
Corresponding p-value > 0.15

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=

| Int. No. | No. of Data Pts. | x | Probability Density Data | Probability Density Function | Cumulative Distribution Data | Cumulative Distribution Function |
|---|---|---|---|---|---|---|
| 0 | 1 | 3.643e+000 | 0.017 | 0.011 | 0.017 | 0.012 |
| 1 | 2 | 4.286e+000 | 0.034 | 0.063 | 0.052 | 0.075 |
| 2 | 12 | 4.929e+000 | 0.207 | 0.192 | 0.259 | 0.267 |
| 3 | 18 | 5.571e+000 | 0.310 | 0.311 | 0.569 | 0.579 |
| 4 | 15 | 6.214e+000 | 0.259 | 0.267 | 0.828 | 0.846 |
| 5 | 8 | 6.857e+000 | 0.138 | 0.121 | 0.966 | 0.967 |
| 6 | 2 | 7.500e+000 | 0.034 | 0.029 | 1.000 | 0.996 |

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====

BEST FIT SUMMARY

Data File: a:\ODRFT96.TXT

| Function | Sq Error |
|---|---|
| Normal | 0.001439 |
| Weibull | 0.002179 |
| Beta | 0.003003 |
| Triangular | 0.01269 |
| Erlang | 0.01289 |
| Gamma | 0.01297 |
| Lognormal | 0.03442 |
| Uniform | 0.08485 |
| Exponential | 0.1524 |

# Appendix 7.3

**[The Network Model]**

```
GEN,MADHUBANI,CALCUTTA PORT,19/7/90
   LIMITS,7,26,2000;
   NETWORK;
      RESOURCE/BRTH(33),1;
      RESOURCE/RPILOT(26),2,7;
      RESOURCE/HPILOT(6),3,6;
      RESOURCE/RTUG(8),3,6;
      RESOURCE/DPILOT(31),4,5;
      RESOURCE/DTUG(12),4,5;
;
;     SHIP ARRIVAL SEGMENT
;     --------------------
      CREATE,EXPON(10.43,3);
      ACT,,,ARV1;
ARV1  ASSIGN,ATRIB(5)=1+RLOGN(73.13,71.8,3),ATRIB(6)=7+GAMA(68.51,1.36),
      ATRIB(1)=RNORM(5.46,0.8385,3),ATRIB(2)=RNORM(5.42,0.7843,3);
      ACT,,XX(1).NE.0.,POR1;
      ACT,,XX(1).EQ.0.,ERST;

;     INITIALIZATION SEGMENT
;     --------------------
ERST  ASSIGN,XX(1)=1;     INITIALIZATION OVER
      ASSIGN,XX(2)=0;     NUMBER OF RPILOT AT SANDHEADS
      ASSIGN,XX(3)=26;    NUMBER OF RPILOT AT HARBOUR
      ACT,,,POR1;


;
;
;     PORT OPERATION SEGMENT
;     -------------------------
POR1  ASSIGN,ATRIB(9)=TNOW;
      AWAIT(1),BRTH/1;   WAIT FOR AN AVAILABLE BERTH
      ACT,,,T01;
T01   COLCT,INT(9),T01 WT FOR BERTH;
      ACT,,,PORT;
PORT ASSIGN,ATRIB(11)=TNOW;
      AWAIT(2),ALLOC(1);   WAIT FOR AN AVAILABLE RPILOT
      ACT,,ATRIB(12).EQ.0,COL1;
      ACT,,ATRIB(12).EQ.1,DUM1;
DUM1ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,3);
      ACT,ATRIB(13),,COL1;
COL1     ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,3);
      ACT,,,T11;
T11      COLCT,INT(11),T11  WT FOR RPILOT;
      ACT,,,IRIVER;
IRIVER ASSIGN,ATRIB(14)=TNOW;
      EVENT(1);
      ACT,ATRIB(15),,COL2; DELAY FOR TIDE  AND DRAFT
COL2 ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
      ACT,,,T21;
```

```
T21    COLCT,INT(14),T21  WT FOR RIVER;
       ACT,,,INPLOT;
INPLOTASSIGN,ATRIB(16)=TNOW;
       ACT/1,ATRIB(13);     RIVER INPILOTAGE TIME
       FREE,RPILOT/1;       RELEASE THE RPILOT
       ASSIGN,XX(3)=XX(3)+1;
       ACT,,,T31;
T31    COLCT,INT(16),T31 RIVER INPILOTAGE TIME;
       ACT,,,STAY;
STAY  AWAIT(3),ALLOC(2); WAIT FOR AVAILABLE HPILOT AND TUGS
TRBE  ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       ACT,UNFRM(2.,4.,3); TRAVEL TO LOCKS
       FREE,HPILOT/1; RELEASE THE HPILOT
       FREE,RTUG/2; RELEASE THE RTUGS
       ACT,,,COL3;
COL3  ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       AWAIT(4),ALLOC(3); WAIT FOR AVAILABLE DPILOT AND DTUGS
URBE ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       ACT,UNFRM(1.,2.,3);
       FREE,DPILOT/1; RELEASE THE DPILOT
       FREE,DTUG/2;  RELEASE THE DTUGS
       ACT,,,BERTH;
BERTH ASSIGN,ATRIB(17)=TNOW;
       ACT,ATRIB(6),,S1;
S1     COLCT,INT(17),S1 CARGO HANDLING TIME;
       ACT,,,BER2;
BER2 ASSIGN,ATRIB(23)=TNOW;
       ACT,ATRIB(5),,I1;
I1     COLCT,INT(23),I1 IDLE TIME;
       ACT,,,BER3;
BER3  ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
       AWAIT(5),ALLOC(4); WAIT FOR AVAILABLE DPILOT AND DTUGS
COL5  ASSIGN,ATRIB(8)=0;  DUMMY ASSIGNMENT
       ACT,,,RELB;
RELB  FREE,BRTH/1;          RELEASE A BERTH
       ACT,,,T41;
T41    COLCT,INT(17),T41 TIME AT BERTH;
       ACT,,,OUPLOT;
OUPLOT ASSIGN,ATRIB(25)=TNOW;
       ACT,UNFRM(1.,2.,3),,DPREL; TRAVEL TO LOCK
DPREL FREE,DPILOT/1; RELEASE THE DPILOT
       FREE,DTUG/2; RELEASE THE DTUGS
       ACT,,,WAIT;
WAIT AWAIT(6),ALLOC(5); WAIT FOR AVAILABLE HPILOT AND RTUGS
COL6  ASSIGN,ATRIB(8)=0;  DUMMY ASSIGNMENT
       ACT,UNFRM(2.,4.,3),,HPREL; TRAVEL TO GARDEN REACH
HPREL FREE,HPILOT/1; RELEASE THE HPILOT
       FREE,RTUG/2; RELEASE THE RTUGS
       ACT,,,H1;
H1    COLCT,INT(25),H1 HARBOUR OUTPILOTAGE TIME;
       ACT,,,GRDH;
GRDH ASSIGN,ATRIB(19)=TNOW;
       AWAIT(7),ALLOC(6); WAIT FOR AVAILABLE RPILOT
       ACT,,ATRIB(24).EQ.0,DUM2;
       ACT,,ATRIB(24).EQ.1,DUM3;
DUM3 ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,3);
       ACT,ATRIB(13),,DUM2;
DUM2 ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,3);
       ACT,,,T51;
```

```
T51    COLCT,INT(19),T51  WT FOR RPILOT;
       ACT,,,ORIVER;
ORIVER  ASSIGN,ATRIB(20)=TNOW;
       EVENT(2);
       ACT,ATRIB(21),,T61;  DELAY FOR TIDE AND DRAFT
T61    COLCT,INT(20),T61  WT FOR RIVER;
       ACT,,,TROUT;
TROUT ASSIGN,ATRIB(22)=TNOW;
       ASSIGN, ATRIB(13)=UNFRM(7.5,10.5,3); TIME TO REACH SH
       ACT/2,ATRIB(13);  RIVER OUTPILOTAGE TIME
       FREE,RPILOT/1;    RELEASE A RPILOT
       ASSIGN,XX(2)=XX(2)+1;
       ACT,,,OPT1;
OPT1  COLCT,INT(22),O1 RIVER OUTPILOTAGE TIME;
       ACT,,,DPT1;
DPT1  COLCT,INT(9),T1 IN PORT TIME;
       TERM;
       ENDNETWORK;
INIT,0,17520;
;MONTR,TRACE,0,200;
FIN;
```

**[The Subroutines]**

```
     INTEGER DAY,MONTH,YEAR,JDAY
     DIMENSION NODAY(12)
     INTEGER NODAY
     COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA,        76
    1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100),           77
    2SSL(100),TNEXT, TNOW, XX(100)                              78
     COMMON QSET(5000)                                     79
     DATA NODAY/30,31,30,31,31,30,31,30,31,31,28,31/
     NNSET=100000                                     81
     NCRDR=5                                        82
     NPRNT=6                                        83
     NTAPE=7                                        84
C    WRITE(*,*)'    PL. ENTER DAY, MONTH, YEAR:'
C    READ(*,*) DAY,MONTH,YEAR
C    WRITE(*,*) '  PL. ENTER ,SLW1,GLW1,GLW2:'
C    READ(*,*)  SLW1,GLW1,GLW2
     IF(MOD(YEAR,4) .EQ.0) THEN
     NODAY(11)=29
     ENDIF
     JDAY=0
     I=MONTH-4
     IF(I.LT.0) I=I+12
     IF (I.GT.0) THEN
     DO 20 K=1,I
 20  JDAY=JDAY+NODAY(K)
     ENDIF
     JDAY=JDAY+DAY
C    WRITE(*,*) 'CALENDER DATE',DAY,MONTH,YEAR, '  PROJECT DAY:',JDAY
     TNOW=JDAY*24
     TDAY=MOD(TNOW,24.)
     CALL SLAM                                     85
     STOP                                        86
     END                                         87
```

```
      SUBROUTINE ALLOC(I,IFLAG)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      IFLAG=0
      GO TO(1,2,3,4,5,6),I
C*****
C     ALLOCATION RULE1-ALLOCATION OF RPILOT FOR BERTHING
C     CHECK THE POSITION OF RESOURCE RPILOT
C     RPILOT MAY BE 1) AT SANDHEADS
C                   2) AT HARBOUR
C                   3) IN THE RIVER HEADING FOR SANDHEADS
C                   4) IN THE RIVER HEADING FOR HARBOUR
C*****
 1      IF (XX(2) .GT. 0) THEN
         CALL SEIZE(2,1)
         XX(2)=XX(2)-1
C          WRITE(*,*)'SEIZING XX(2):',XX(2)
C          WRITE(*,*)'RPILOT SEIZED-1'
         IFLAG=1
         ATRIB(12)=0
         RETURN
        ELSE IF(NNACT(2).GT.0) THEN
            RETURN
          ELSE IF(XX(3).GT.0.AND.NNQ(7).EQ.O) THEN
             CALL SEIZE(2,1)
             XX(3)=XX(3)-1
C              WRITE(*,*)'SEIZING XX(3):',XX(3)
             IFLAG=1
             ATRIB(12)=1
             RETURN
            ELSE
              RETURN
         END IF
C*****
C     ALLOCATION RULE2-ALLOCATION OF HPILOT AND RTUGS FOR BERTHING
C     ALLOCATE IF A),HPILOT AND RTUG WAS LAST DEBERTHING,XX(4)=0,OR
C                 B),HPILOT AND RTUG WAS LAST BERTHING BUT NO SHIP
C                   WAS READY TO DEBERTH
C*****
C3    WRITE(*,*)'ENTERED ALLOC(2)'
 2    IF (XX(4).EQ.0) GOTO 400
      IF(NNQ(6) .EQ.0) GO TO 400
      RETURN
C*****
C     BERTHING WILL OCCUR IF BOTH HPILOT AND RTUGS ARE AVAILABLE
C*****
 400  IF(NNRSC(3) .LE.0.OR.NNRSC(4) .LE.0) THEN
       XX(4)=0
       RETURN
      ENDIF
      CALL SEIZE(3,1)
      CALL SEIZE(4,2)
      IFLAG=1
      XX(4)=1
      RETURN
C*****ALLOCATION RULE3- ALLOCATION OF DPILOT AND DTUGS FOR BERTHING
C*****ALLOCATE IF A) DPILOT AND DTUG WAS LAST DEBERTHING, XX(5)=0 OR
C*****          B) DPILOT AND DTUG WAS LAST BERTHING BUT NO SHIP WAS
C*****             READY TO DEBERTH
```

```
C*****
C4   WRITE(*,*)'ENTERED ALLOC(3)'
 3   IF (XX(5).EQ.0) GOTO 600
     IF (NNQ(5).EQ.0) GOTO 600
     RETURN
C******
C    BERTHING WILL OCCUR IF BOTH DPILOT AND DTUGS ARE AVAILABLE
C******
600  IF (NNRSC(5).LE.0.OR.NNRSC(6).LE.0) THEN
       XX(5) = 0
       RETURN
     ENDIF
     CALL SEIZE(5,1)
     CALL SEIZE(6,2)
     IFLAG = 1
     XX(5) = 1
     RETURN
C******
C    ALLOCATION RULE-4 : ALLOCATION OF DPILOTS AND DTUGS FOR DEBERTHING
C    ALLOCATE IF A) DPILOT AND DTUG WAS LAST BERTHING I.E. XX(5)=1 OR
C              B) DPILOT AND DTUGS WERE LAST DEBERTHING BUT NO SHIP
C                 WAS READY TO BERTH
C*******
C5   WRITE(*,*)'ENTERED ALLOC(4)'
4    IF (XX(5).EQ.1) GOTO 700
     IF (NNQ(4).EQ.0) GOTO 700
     RETURN
C******
C    DEBERTHING WILL OCCUR IF BOTH DPILOT AND DTUGS ARE AVAILABLE
C******
700  IF (NNRSC(5).LE.0.OR.NNRSC(6).LE.0) THEN
       XX(5) = 1
       RETURN
     ENDIF
     CALL SEIZE(5,1)
     CALL SEIZE(6,2)
     IFLAG = 1
     XX(5) = 0
     RETURN

C*****ALLOCATION RULE5-ALLOCATION OF HPILOT AND RTUGS FOR DEBERTHING
C    ALLOCATE IF A),HPILOT AND RTUG WAS LAST BERTHING XX(4)=1,OR
C              B),HPILOT AND RTUGS WERE LAST DEBERTHING BUT NO
C                 SHIP WAS READY TO BERTH
C*****
C3   WRITE(*,*)'ENTERED ALLOC(5)'
 5   IF(XX(4).EQ.1) GO TO 500
     IF (NNQ(3).EQ.0) GO TO 500
     RETURN
C*****
C    DEBERTHING WILL OCCUR IF BOTH HPILOT AND TUGS ARE AVAILABLE
C*****
500  IF(NNRSC(3) .LE.0.OR.NNRSC(4) .LE.0) THEN
      XX(4)=1
      RETURN
     ENDIF
     CALL SEIZE(3,1)
     CALL SEIZE(4,2)
     IFLAG=1
```

```
      XX(4)=0
      RETURN

C*****
C     ALLOCATION RULE6-ALLOCATION OF RPILOT FOR DEPARTING
C     CHECK THE POSITION OF THE RESOURCE RPILOT
C     RPILOT MAY BE 1) AT HARBOUR
C                   2) AT SANDHEADS
C                   3) IN THE RIVER HEADING FOR HARBOUR
C                   4) IN THE RIVER HEADING FOR SANDHEADS
C*****
 6    IF (XX(3) .GT .0) THEN
       CALL SEIZE(2,1)
       XX(3)=XX(3)-1
C       WRITE(*,*)'****SEIZING XX(3):',XX(3)
       IFLAG=1
       ATRIB(24)=0
       RETURN
      ELSE IF(NNACT(1).GT.0) THEN
        RETURN
       ELSE IF(XX(2).GT.0.AND.NNQ(2).EQ.0.) THEN
         CALL SEIZE(2,1)
         XX(2)=XX(2)-1
C         WRITE(*,*)'******SEIZING XX(2):',XX(2)
         IFLAG=1
         ATRIB(24)=1
         RETURN
        ELSE
          RETURN
      END IF
      END
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      DIMENSION ARDRFT(365),DRDRFT(365),SLONE(365),GLONE(365),GLTWO(365)
      GO TO (1,2),I

      DATA (ARDRFT(K),K=1,269)
     *         /6.9,7.1,7.3,7.3,7.3,7.1,6.9,6.6,6.2,5.7,5.7,6.0,6.5,
     * 7.0,7.4,7.7,7.8,7.7,7.5,7.2,6.8,6.5,6.1,5.5,5.5,5.7,6.1,6.5,6.8,
     * 7.1,7.6,7.8,7.8,7.7,7.6,7.3,7.1,6.6,6.2,6.3,6.6,7.0,7.4,7.7,7.9,
     * 7.9,7.9,7.7,7.5,7.2,7.0,6.8,6.2,6.2,6.3,6.5,6.7,7.1,7.4,7.6,7.9,
     * 8.1,8.1,8.0,7.8,7.6,7.4,6.8,6.9,7.0,7.2,7.5,7.6,7.8,7.9,7.9,7.9,
     * 7.7,7.6,7.4,7.3,7.1,6.9,6.7,6.9,7.0,7.2,7.4,7.8,7.9,8.2,8.4,8.3,
     * 8.2,8.0,7.8,7.6,7.5,7.4,7.4,7.5,7.7,7.7,7.9,8.0,8.0,8.0,8.0,7.9,
     * 7.8,7.7,7.5,7.2,7.2,7.2,7.2,7.6,7.9,8.3,8.4,8.4,8.4,8.5,8.5,8.1,
     * 7.7,7.1,7.4,7.3,7.3,7.5,7.8,8.0,8.2,8.2,8.3,8.3,8.2,8.1,7.9,7.7,
     * 7.3,6.8,7.0,7.1,7.5,8.0,8.4,8.7,8.7,8.7,8.7,8.5,8.1,7.6,7.1,6.8,
     * 7.0,7.2,7.4,7.7,8.0,8.2,8.3,8.3,8.3,8.2,8.1,7.9,7.6,7.3,6.7,6.6,
     * 7.2,7.5,8.0,8.5,8.5,8.5,8.5,8.5,8.4,8.0,7.4,6.8,6.2,6.6,6.9,7.2,
     * 7.4,7.6,7.8,7.9,8.0,8.0,7.9,7.8,7.6,7.4,7.2,6.3,6.5,7.2,7.4,7.7,
     * 8.0,8.3,8.3,8.3,8.2,7.8,7.5,7.2,6.6,5.6,6.0,6.5,6.7,6.8,7.0,7.2,
     * 7.3,7.4,7.5,7.5,7.3,7.2,7.0,6.5,5.5,6.0,6.6,6.9,7.1,7.3,7.4,7.5,
     * 7.5,7.4,7.2,7.0,6.7,6.2,5.4,5.6,6.2,6.4,6.4,6.5,6.7,6.8,7.0,7.0,
     * 7.1,7.1,7.1,7.0,6.5,5.6,5.8,6.5,6.7,6.7,6.7,6.8,6.8,6.9,7.0,7.0/
       DATA (ARDRFT(K),K=270,365) /
     * 6.9,6.8,6.4,6.0,5.7,5.6,5.8,5.9,5.8,5.8,6.0,6.3,6.6,6.9,7.0,7.1,
     * 7.1,6.7,5.9,5.5,5.7,6.0,6.0,5.9,6.0,6.2,6.4,6.6,6.7,6.8,6.8,6.8,
     * 6.6,6.2,5.9,5.4,5.4,5.6,5.6,5.9,6.2,6.7,6.7,7.0,7.2,7.1,7.0,6.6,
```

```
* 6.0,5.3,5.3,5.3,5.3,5.6,5.9,6.4,6.6,6.8,7.0,7.0,7.0,6.9,6.7,6.4,
* 6.0,5.7,5.5,5.6,5.9,6.3,7.1,7.1,7.3,7.5,7.4,7.3,7.1,6.7,6.1,5.5,
* 5.5,5.6,5.9,6.2,6.7,7.1,7.2,7.4,7.4,7.4,7.3,7.1,6.9,6.6,6.1,5.5/

 DATA (SLONE(K),K=1,178)
*       /4.0,4.5,4.8,5.2,5.7,6.1,6.5,7.1,7.8,8.9,11.1,0.5,1.7,
* 2.7,3.4,4.1,4.6,5.1,5.6,6.1,6.5,7.0,7.5,8.5,10.2,0.3,1.3,2.0,
* 2.7,3.2,3.7,4.2,4.7,5.2,5.7,6.3,6.9,7.7,8.9,10.9,12.4,1.0,2.0,
* 2.8,3.4,4.0,4.5,5.1,5.6,6.1,6.6,7.2,8.0,9.2,10.8,12.3,0.7,1.6,
* 2.4,3.0,3.7,4.3,4.9,5.5,6.2,6.9,7.8,8.9,10.4,11.8,0.2,1.3,2.2,
* 3.0,3.6,4.2,4.8,5.3,5.8,6.4,6.9,7.5,8.3,9.4,10.7,12.1,0.5,1.6,
* 2.5,3.3,4.1,4.8,5.4,6.1,6.8,7.6,8.5,9.6,10.9,12.4,0.5,1.7,2.6,
* 3.4,4.0,4.6,5.1,5.6,6.1,6.5,7.1,7.6,8.4,9.4,10.9,12.6,1.0,2.1,
* 3.1,3.9,4.6,5.4,6.0,6.7,7.2,8.0,8.8,10.1,11.9,0.2,1.5,2.6,3.4,
* 4.0,4.5,4.9,5.3,5.7,6.1,6.5,7.0,7.8,8.5,9.9,12.3,0.7,1.9,2.9,
* 3.7,4.4,5.1,5.7,6.4,6.9,7.5,8.2,9.2,11.9,0.0,1.5,2.4,3.2,3.7,
* 4.2,4.5,4.9,5.3,5.8,6.2,6.7,7.2,8.1,9.7,12.1,0.5,1.7,2.7,3.5/
 DATA (SLONE(K),K=179,365) /
* 4.2,4.8,5.4,6.0,6.5,7.1,7.7,8.7,11.6,12.9,1.2,2.1,2.7,3.3,3.7,
* 4.1,4.5,5.0,5.5,6.1,6.5,7.2,8.1,9.7,11.6,0.3,1.5,2.4,3.2,3.8,
* 4.5,5.1,5.7,6.3,6.9,7.5,8.4,10.2,11.9,0.3,1.3,2.1,2.7,3.2,3.7,
* 4.2,4.8,5.4,6.0,6.6,7.4,8.4,9.7,11.1,12.3,1.1,2.1,2.9,3.6,4.3,
* 4.9,5.6,6.2,6.9,7.5,8.2,9.0,10.1,11.4,0.1,1.2,2.0,2.7,3.4,4.0,
* 4.7,5.4,6.1,6.9,7.6,8.4,9.3,10.4,11.5,0.5,1.7,2.7,3.6,4.3,5.0,
* 5.6,6.2,6.8,7.3,7.7,8.3,8.9,9.7,10.8,12.2,1.3,2.3,3.2,4.0,4.7,
* 5.5,6.2,6.9,7.5,8.2,8.9,9.6,10.7,12.0,1.5,2.7,3.7,4.4,5.0,5.5,
* 6.0,6.5,6.9,7.3,7.7,8.1,8.6,9.4,10.0,10.5,11.2,12.1,0.3,1.2,
* 5.9,6.5,7.1,7.7,8.3,8.9,9.7,11.3,1.3,2.7,3.6,4.3,4.8,5.3,5.6,
* 5.9,6.3,12.3,7.1,7.4,7.8,8.4,9.6,12.0,1.6,2.7,3.5,4.2,4.8,5.5,
* 6.1,6.6,7.2,7.7,8.2,9.0,10.7,1.3,1.1,2.3,3.1,3.7,4.2,4.7,5.0,
* 5.2,5.6,6.1,6.4,6.9,7.2,7.9,9.2/
 DATA (DRDRFT(K),K=1,252)
*        /6.9,7.1,7.2,7.2,7.2,7.1,6.9,6.7,6.4,6.1,5.3,5.9,
* 6.5,7.0,7.4,7.6,7.7,7.6,7.5,7.2,6.8,6.5,6.1,5.9,5.8,5.7,6.2,
* 6.5,6.8,7.1,7.6,7.7,7.7,7.6,7.5,7.3,7.2,6.9,6.7,5.6,6.4,7.1,
* 7.4,7.6,7.7,7.8,7.8,7.6,7.4,7.3,7.0,6.7,6.5,6.4,5.6,6.4,6.8,
* 7.2,7.4,7.5,7.8,8.0,8.0,7.9,7.7,7.5,7.4,7.2,7.1,6.8,7.2,7.5,
* 7.6,7.7,7.8,7.8,7.8,7.6,7.6,7.4,7.3,7.2,7.0,6.9,6.8,6.7,7.2,
* 7.4,7.7,7.8,8.2,8.4,8.3,8.2,8.0,7.8,7.6,7.5,7.2,7.3,7.5,7.7,
* 7.8,7.8,7.9,8.0,8.0,7.9,7.8,7.8,7.7,7.5,7.3,7.1,6.7,7.1,7.6,
* 7.8,8.3,8.4,8.4,8.4,8.7,8.5,8.1,7.7,7.3,6.9,6.6,7.3,7.5,7.7,
* 7.9,8.1,8.2,8.3,8.3,8.2,8.0,7.8,7.7,7.3,7.0,6.8,6.8,7.6,8.0,
* 8.5,8.7,8.7,8.7,8.6,8.5,8.1,7.7,7.2,6.7,6.4,7.2,7.5,7.7,8.0,
* 8.2,8.3,8.3,8.2,8.2,8.1,7.9,7.6,7.3,7.0,6.8,6.7,7.4,8.0,8.5,
* 8.5,8.5,8.5,8.5,8.4,7.9,7.4,6.9,6.6,6.3,6.9,7.1,7.4,7.6,7.8,
* 7.9,8.0,8.0,7.9,7.8,7.6,7.4,7.0,6.8,6.2,6.4,7.4,7.7,8.0,8.3,
* 8.4,8.3,8.2,7.8,7.5,7.1,6.8,6.2,5.6,6.1,6.6,6.8,6.9,7.1,7.2,
* 7.3,7.5,7.4,7.2,7.1,6.9,6.6,6.5,5.7,6.2,6.9,7.0,7.2,7.3,7.5,
* 7.5,7.3,7.1,6.9,6.6,6.6,6.4,6.2,5.5,6.0,6.3,6.5,6.5,6.7,6.8/
 DATA (DRDRFT(K),K=253,365)/
* 6.9,7.0,7.0,7.0,6.9,6.8,6.7,6.0,5.7,6.4,6.6,6.6,6.7,6.7,6.8,
* 6.8,6.8,6.8,6.7,6.6,6.5,6.4,6.3,5.8,5.3,5.8,5.9,6.0,6.3,6.6,
* 6.8,7.0,7.1,7.1,7.0,6.9,6.5,5.9,5.5,5.9,5.9,6.1,6.2,6.4,6.6,
* 6.7,6.8,6.8,6.8,6.7,6.6,6.4,6.4,5.8,5.2,5.5,5.7,6.2,6.6,6.6,
* 6.8,7.0,6.9,6.8,6.7,6.4,6.0,5.3,5.1,5.3,5.6,5.9,6.4,6.6,6.7,
* 6.8,6.8,6.8,6.7,6.7,6.4,6.2,6.1,5.6,5.3,5.8,6.3,6.9,6.9,7.2,
* 7.3,7.2,7.1,6.9,6.6,6.2,5.8,5.2,5.4,5.8,6.2,6.6,6.9,7.1,7.2,
* 7.2,7.2,7.1,7.0,6.8,6.6,6.3,6.1/
```

```
 DATA (GLONE(K),K=1,191)
*       /10.0,10.4,10.8,11.2,11.7,0.0,0.5,1.0,1.4,2.2,3.4,5.8,
* 7.3,8.3,9.3,10.1,10.7,11.2,11.7,0.1,0.5,0.8,1.1,1.7,3.3,5.3,6.4,
* 7.3,8.2,8.9,9.5,10.1,10.5,11.1,11.7,0.2,0.7,1.3,2.3,3.7,5.2,6.4,
* 7.5,8.5,9.2,9.9,10.4,11.0,11.5,0.0,0.5,0.9,1.5,2.3,3.5,4.8,5.8,
* 6.8,7.7,8.6,9.3,10.1,10.7,11.5,0.0,0.7,1.4,2.2,3.3,4.4,5.5,6.7,
* 7.7,8.6,9.3,10.0,10.5,11.1,11.5,0.3,0.7,1.2,1.7,2.4,3.2,4.3,5.6,
* 6.8,8.0,9.0,9.8,10.7,11.4,0.0,0.7,1.3,2.0,2.7,3.5,4.6,5.9,7.1,
* 8.1,9.0,9.7,10.4,10.8,11.4,0.0,0.5,0.8,1.2,1.5,2.0,2.8,4.4,6.2,
* 7.5,8.7,9.7,10.6,11.3,12.0,0.5,1.1,1.6,2.0,2.6,3.6,5.2,6.7,7.9,
* 8.9,9.7,10.2,10.7,11.0,11.5,0.0,0.4,0.7,0.8,1.2,2.0,3.5,5.8,7.4,
* 8.6,9.6,10.4,11.1,11.7,0.1,0.7,1.1,1.4,1.7,2.7,5.0,6.5,7.6,8.6,
* 9.4,10.0,10.3,10.7,11.2,11.7,12.2,0.2,0.4,0.7,1.5,3.4,5.7,7.2,
* 8.4,9.4,10.2,10.8,11.4,12.0,0.2,0.6,0.9,1.2,2.0,4.6,6.1,7.1,8.1/
 DATA (GLONE(K),K=192,365) /
*8.8,9.5,10.0,10.4,10.8,11.4,11.8,12.3,0.3,0.7,1.7,3.5,5.6,7.0,8.1,
*9.1,9.8,10.5,11.1,11.7,12.2,0.2,0.6,1.0,1.6,3.2,5.2,6.3,7.3,8.1,
*8.8,
*9.5,10.1,10.7,11.2,11.8,12.4,0.4,1.1,2.0,3.6,5.3,6.6,7.7,8.7,9.6,
*10.2,10.8,11.5,12.1,12.6,0.5,1.0,1.5,2.3,3.7,5.2,6.4,7.4,8.3,9.1,
*10.0,10.7,11.3,12.0,0.0,0.7,1.4,2.3,3.4,4.7,6.1,7.3,8.4,9.4,10.2,
*11.0,11.5,12.2,12.6,0.4,1.0,1.4,2.0,2.6,3.7,5.1,6.6,7.7,8.8,9.9,
*10.7,11.5,12.2,0.2,1.0,1.6,2.2,3.0,4.0,5.3,7.0,8.2,9.3,10.3,11.1,
*11.7,12.1,12.4,0.2,0.7,1.2,1.6,2.0,2.5,3.5,5.6,7.4,8.7,9.8,10.7,
*11.5,12.0,0.2,0.2,0.9,1.4,2.3,3.0,3.9,5.3,6.9,8.3,9.3,10.3,11.1,
*11.7,12.0,12.3,0.3,0.8,1.2,1.4,1.8,2.6,4.7,6.8,8.2,9.3,10.3,11.0,
*11.6,12.2,0.5,1.2,1.6,2.0,2.5,3.8,6.3,7.6,8.6,9.5,10.1,10.7,11.0,
*11.3,11.7,12.1,0.3,0.7,1.1,1.4,2.2/

 DATA (GLTWO(K),K=1,153)
*    /22.1,22.5,23.0,23.5,11.7,12.1,12.5,12.9,13.3,14.3,16.5,18.5,
*19.8,21.0,21.8,22.5,23.1,23.6,11.7,12.1,12.5,12.7,13.0,13.7,15.2,
*17.6,18.7,19.8,20.6,21.4,21.9,22.5,23.0,23.6,11.7,12.2,12.7,13.4,
*14.5,16.4,18.0,19.3,20.4,21.2,22.0,22.5,23.1,23.5,11.5,12.0,12.3,
*12.8,13.4,14.4,16.0,17.5,18.6,19.6,20.5,21.3,22.1,22.8,23.4,11.4,
*12.1,12.8,13.6,14.6,16.0,17.3,18.6,19.7,20.6,21.4,22.1,22.7,23.3,
*23.8,11.6,12.1,12.6,13.2,13.8,14.7,16.0,17.4,18.7,19.8,20.8,21.7,
*22.7,23.3,11.3,12.1,12.8,13.6,14.4,15.3,16.5,17.8,19.1,20.2,21.2,
*22.0,22.7,23.2,23.7,11.3,11.9,12.4,12.9,13.3,13.9,14.7,16.1,17.9,
*19.3,20.6,21.6,22.5,23.2,23.9,12.0,12.7,13.3,13.9,14.6,15.6,17.2,
*18.8,20.0,21.0,21.8,22.5,22.9,23.3,23.7,11.5,12.1,12.5,12.9,13.2,
*13.6,15.2,17.5,19.1,20.2,21.4,22.2,22.9,23.6,11.8,12.4/
 DATA (GLTWO(K),K=154,365) /
*12.9,13.4,13.8,14.6,17.1,18.5,19.6,20.5,21.3,22.0,22.4,22.8,23.1,
*23.5,23.9,12.2,12.5,12.9,13.5,14.9,17.3,18.8,19.9,20.9,21.8,22.5,
*23.1,23.7,12.0,12.5,12.9,13.3,14.0,16.7,17.9,18.8,19.8,20.6,21.2,
*21.8,22.2,22.6,23.1,23.5,23.9,12.3,12.8,13.6,15.0,16.9,18.2,19.4,
*20.4,21.2,21.9,22.6,23.1,23.7,12.2,12.6,13.1,13.7,15.3,16.8,17.8,
*18.7,19.6,20.4,21.1,21.6,22.2,22.7,23.3,23.8,12.4,13.0,13.8,15.0,
*16.4,17.7,18.8,19.8,20.7,21.5,22.2,22.8,23.4,24.0,12.6,13.1,13.6,
*14.2,15.2,16.4,17.5,18.5,19.5,20.4,21.2,22.0,22.7,23.4,12.0,12.6,
*13.2,14.0,14.8,15.8,16.9,18.1,19.3,20.4,21.3,22.1,22.7,23.3,23.9,
*12.6,13.1,13.4,13.8,14.2,14.9,15.9,17.2,18.7,19.9,21.0,22.0,22.7,
*23.5,12.2,12.7,13.3,13.9,14.5,15.1,16.0,17.3,18.9,20.2,21.2,22.2,
*22.8,23.3,23.7,12.4,12.8,13.1,13.4,13.7,14.0,14.5,15.7,17.9,
*19.5,20.9,21.9,22.7,23.5,12.1,12.6,13.2,13.7,14.1,14.5,15.1,16.5,
*18.6,20.1,21.2,22.1,22.7,23.1,23.5,23.9,12.3,12.7,13.0,13.1,13.2,
*13.5,14.7,17.2,19.2,20.5,21.7,22.5,23.2,23.9,12.2,12.7,13.2,13.5,
*13.8,14.6,15.9,18.2,19.7,20.7,21.6,22.2,22.7,23.0,23.3,23.9,12.2,
```

```
   *12.3,12.7,12.8,13.2,14.3/

C*****



1     JDAY=TNOW/24
      TDAY=MOD(TNOW,24.)
      IF(JDAY.GT.365) JDAY=JDAY-365
       ARVDRF=ARDRFT(JDAY)-27.0
      IF ((ATRIB(1).GT.ARVDRF).OR.(TDAY.GT.SLONE(JDAY)+1))THEN
        IDAY=JDAY
 10       IDAY=IDAY+1
        IF(ATRIB(1).GT.(ARDRFT(IDAY)-27.0)) GO TO 10
        ATRIB(15)=24-MOD(TDAY,24.)+(IDAY-JDAY-1)*24+SLONE(IDAY)+1
        IF (ATRIB(15).GE.24) ATRIB(7)=3
        RETURN
        ENDIF


 2    JDAY=TNOW/24
      TDAY=MOD(TNOW,24.)
      IF(JDAY.GT.365)   JDAY=JDAY-365
       DRVDRF=DRDRFT(JDAY)+0.18
      IF((ATRIB(2).GT.DRVDRF).OR.(TDAY.GT.GLTWO(JDAY)-3))THEN
        IDAY=JDAY
 20      IDAY=IDAY+1
        IF (ATRIB(2).GT.(DRDRFT(IDAY)+0.18)) GO TO 20
         ATRIB(21)=24-MOD(TDAY,24.)+(IDAY-JDAY-1)*24+GLONE(IDAY)+1
         RETURN
        ELSE IF(TDAY.LE.GLONE(JDAY)-3) THEN
          ATRIB(21)=GLONE(JDAY)-3-TDAY
          RETURN
         ELSE
          ATRIB(21)=GLTWO(JDAY)-3-TDAY
          RETURN
        ENDIF



        END
```

# Appendix 7.4

**[ The Output of the Generalised Model for 1995-96 ]**

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* IN THE SOFTWARE
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      GEN,MADHUBANI,CALCUTTA PORT,19/7/90
      LIMITS,7,26,2000;
      NETWORK;
          RESOURCE/BRTH(33),1;
          RESOURCE/RPILOT(33),2,7;
          RESOURCE/HPILOT(11),3,6;
          RESOURCE/RTUG(10),3,6;
          RESOURCE/DPILOT(44),4,5;
          RESOURCE/DTUG(10),4,5;
 ;
 ;        SHIP ARRIVAL SEGMENT
 ;        ---------------------
          CREATE,EXPON(10.88,2);
          ACT,,,ARV1;
 ARV1       ASSIGN,ATRIB(5)=1+RLOGN(73.13,71.8,2),ATRIB(6)=7+GAMA(106.47,0.56,2)
          ASSIGN,ATRIB(1)=RNORM(5.46,0.8385,2),ATRIB(2)=RNORM(5.42,0.7843,2);
          ACT,,XX(1).NE.0.,POR1;
          ACT,,XX(1).EQ.0.,ERST;

 ;        INITIALIZATION SEGMENT
 ;        ---------------------
 ERST       ASSIGN,XX(1)=1;      INITIALIZATION OVER
          ASSIGN,XX(2)=0;      NUMBER OF RPILOT AT SANDHEADS
          ASSIGN,XX(3)=33;      NUMBER OF RPILOT AT HARBOUR
          ACT,,,POR1;

 ;
 ;
 ;        PORT OPERATION SEGMENT
 ;        --------------------------
 POR1       ASSIGN,ATRIB(9)=TNOW;
          AWAIT(1),BRTH/1;   WAIT FOR AN AVAILABLE BERTH
          ACT,,,T01;
 T01        COLCT,INT(9),T01 WT FOR BERTH;
          ACT,,,PORT;
 PORT       ASSIGN,ATRIB(11)=TNOW;
          AWAIT(2),ALLOC(1);   WAIT FOR AN AVAILABLE RPILOT
          ACT,,ATRIB(12).EQ.0,COL1;
          ACT,,ATRIB(12).EQ.1,DUM1;
 DUM1       ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,2);
          ACT,ATRIB(13),,COL1;
 COL1       ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,2);
          ACT,,,T11;
 T11        COLCT,INT(11),T11  WT FOR RPILOT;
```

```
        ACT,,,IRIVER;
IRIVER    ASSIGN,ATRIB(14)=TNOW;
        EVENT(1);
        ACT,ATRIB(15),,COL2; DELAY FOR TIDE  AND DRAFT
COL2      ASSIGN,ATRIB(8)=0;  DUMMY STATEMENT
        ACT,,,T21;
T21       COLCT,INT(14),T21  WT FOR RIVER;
        ACT,,,INPLOT;
INPLOT    ASSIGN,ATRIB(16)=TNOW;
        ACT/1,ATRIB(13);      RIVER INPILOTAGE TIME
        FREE,RPILOT/1;       RELEASE THE RPILOT
        ASSIGN,XX(3)=XX(3)+1;
        ACT,,,T31;
T31       COLCT,INT(16),T31 RIVER INPILOTAGE TIME;
        ACT,,,STAY;
STAY      AWAIT(3),ALLOC(2); WAIT FOR AVAILABLE HPILOT AND TUGS
TRBE      ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,UNFRM(2.,4.,2); TRAVEL TO LOCKS
        FREE,HPILOT/1; RELEASE THE HPILOT
        FREE,RTUG/2; RELEASE THE RTUGS
        ACT,,,COL3;
COL3      ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        AWAIT(4),ALLOC(3); WAIT FOR AVAILABLE DPILOT AND DTUGS
URBE      ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        ACT,UNFRM(1.,2.,2);
        FREE,DPILOT/1; RELEASE THE DPILOT
        FREE,DTUG/2;  RELEASE THE DTUGS
        ACT,,,BERTH;
BERTH     ASSIGN,ATRIB(17)=TNOW;
        ACT,ATRIB(6),,S1;
S1        COLCT,INT(17),S1 CARGO HANDLING TIME;
        ACT,,,BER2;
BER2      ASSIGN,ATRIB(23)=TNOW;
        ACT,ATRIB(5),,I1;
I1        COLCT,INT(23),I1 IDLE TIME;
        ACT,,,BER3;
BER3      ASSIGN,ATRIB(8)=0; DUMMY ASSIGNMENT
        AWAIT(5),ALLOC(4); WAIT FOR AVAILABLE DPILOT AND DTUGS
COL5      ASSIGN,ATRIB(8)=0;  DUMMY ASSIGNMENT
        ACT,,,RELB;
RELB      FREE,BRTH/1;          RELEASE A BERTH
        ACT,,,T41;
T41       COLCT,INT(17),T41 TIME AT BERTH;
        ACT,,,OUPLOT;
OUPLOT    ASSIGN,ATRIB(25)=TNOW;
        ACT,UNFRM(1.,2.,2),,DPREL; TRAVEL TO LOCK
DPREL     FREE,DPILOT/1; RELEASE THE DPILOT
        FREE,DTUG/2; RELEASE THE DTUGS
        ACT,,,WAIT;
WAIT      AWAIT(6),ALLOC(5); WAIT FOR AVAILABLE HPILOT AND RTUGS
COL6      ASSIGN,ATRIB(8)=0;  DUMMY ASSIGNMENT
        ACT,UNFRM(2.,4.,2),,HPREL; TRAVEL TO GARDEN REACH
HPREL     FREE,HPILOT/1; RELEASE THE HPILOT
        FREE,RTUG/2; RELEASE THE RTUGS
        ACT,,,H1;
H1        COLCT,INT(25),H1 HARBOUR OUTPILOTAGE TIME;
        ACT,,,GRDH;
GRDH      ASSIGN,ATRIB(19)=TNOW;
        AWAIT(7),ALLOC(6); WAIT FOR AVAILABLE RPILOT
```

```
        ACT,,ATRIB(24).EQ.0,DUM2;
        ACT,,ATRIB(24).EQ.1,DUM3;
DUM3     ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,2);
        ACT,ATRIB(13),,DUM2;
DUM2     ASSIGN,ATRIB(13)=UNFRM(7.5,10.5,2);                    T
        ACT,,,T51;
T51      COLCT,INT(19),T51  WT FOR RPILOT;
        ACT,,,ORIVER;
ORIVER   ASSIGN,ATRIB(20)=TNOW;
        EVENT(2);
        ACT,ATRIB(21),,T61;  DELAY FOR TIDE AND DRAFT
T61      COLCT,INT(20),T61  WT FOR RIVER;
        ACT,,,TROUT;
TROUT    ASSIGN,ATRIB(22)=TNOW;
        ASSIGN, ATRIB(13)=UNFRM(7.5,10.5,2); TIME TO REACH SH
        ACT/2,ATRIB(13);  RIVER OUTPILOTAGE TIME
        FREE,RPILOT/1;   RELEASE A RPILOT
        ASSIGN,XX(2)=XX(2)+1;
        ACT,,,OPT1;
OPT1     COLCT,INT(22),O1 RIVER OUTPILOTAGE TIME;
        ACT,,,DPT1;
DPT1     COLCT,INT(9),T1 IN PORT TIME;
        TERM;
        ENDNETWORK;
INIT,0,17520;
;MONTR,TRACE,0,200;
FIN;
1
```

S L A M   I I   E C H O   R E P O R T

SIMULATION PROJECT CALCUTTA PORT          BY MADHUBANI

DATE 19/ 7/1990          RUN NUMBER   1 OF   1

SLAM II VERSION AUG 92

GENERAL OPTIONS

PRINT INPUT STATEMENTS (ILIST): YES
PRINT ECHO REPORT (IECHO): YES
EXECUTE SIMULATIONS (IXQT): YES
WARN OF DESTROYED ENTITIES: YES
PRINT INTERMEDIATE RESULTS HEADING (IPIRH): YES
PRINT SUMMARY REPORT (ISMRY): YES

LIMITS ON FILES

MAXIMUM NUMBER OF USER FILES (MFILS): 7
MAXIMUM NUMBER OF USER ATTRIBUTES (MATR): 26
MAXIMUM NUMBER OF CONCURRENT ENTRIES (MNTRY): 2000

FILE SUMMARY

FILE        INITIAL      RANKING

| NUMBER | ENTRIES | CRITERION |
|---|---|---|
| 1 | 0 | FIFO |
| 2 | 0 | FIFO |
| 3 | 0 | FIFO |
| 4 | 0 | FIFO |
| 5 | 0 | FIFO |
| 6 | 0 | FIFO |
| 7 | 0 | FIFO |

STATISTICS BASED ON OBSERVATIONS

| COLCT NUMBER | COLLECTION MODE | IDENTIFIER | HISTOGRAM SPECIFICATIONS NCEL | HLOW | HWID |
|---|---|---|---|---|---|
| 1 | NETWORK | T01 WT FOR BERTH | | | |
| 2 | NETWORK | T11 WT FOR RPIL | | | |
| 3 | NETWORK | T21 WT FOR RIVE | | | |
| 4 | NETWORK | T31 RIVER INPILO | | | |
| 5 | NETWORK | S1 CARGO HANDLIN | | | |
| 6 | NETWORK | I1 IDLE TIME | | | |
| 7 | NETWORK | T41 TIME AT BERT | | | |
| 8 | NETWORK | H1 HARBOUR OUTPI | | | |
| 9 | NETWORK | T51 WT FOR RPIL | | | |
| 10 | NETWORK | T61 WT FOR RIVE | | | |
| 11 | NETWORK | O1 RIVER OUTPILO | | | |
| 12 | NETWORK | T1 IN PORT TIME | | | |

RANDOM NUMBER STREAMS

| STREAM NUMBER | SEED VALUE | REINITIALIZATION OF STREAM |
|---|---|---|
| 1 | 428956419 | NO |
| 2 | 1954324947 | NO |
| 3 | 1145661099 | NO |
| 4 | 1835732737 | NO |
| 5 | 794161987 | NO |
| 6 | 1329531353 | NO |
| 7 | 200496737 | NO |
| 8 | 633816299 | NO |
| 9 | 1410143363 | NO |
| 10 | 1282538739 | NO |

INITIALIZATION OPTIONS

BEGINNING TIME OF SIMULATION (TTBEG): .0000E+00
ENDING TIME OF SIMULATION (TTFIN): .1752E+05
STATISTICAL ARRAYS CLEARED (JJCLR): YES
VARIABLES INITIALIZED (JJVAR): YES
FILES INITIALIZED (JJFIL): YES

NSET/QSET STORAGE ALLOCATION

DIMENSION OF NSET/QSET (NNSET): 100000

WORDS ALLOCATED TO FILING SYSTEM: 60000
WORDS ALLOCATED TO VARIABLES: 2685
WORDS AVAILABLE FOR PLOTS/TABLES: 37315

INPUT ERRORS DETECTED: 0

EXECUTION WILL BE ATTEMPTED
1 **INTERMEDIATE RESULTS**

1

SLAM II SUMMARY REPORT

SIMULATION PROJECT CALCUTTA PORT BY MADHUBANI

DATE 19/ 7/1990 RUN NUMBER 1 OF 1

CURRENT TIME .1752E+05
STATISTICAL ARRAYS CLEARED AT TIME .0000E+00

**STATISTICS FOR VARIABLES BASED ON OBSERVATION**

| | MEAN VALUE | STANDARD DEVIATION | COEFF. OF VARIATION | MINIMUM VALUE | MAXIMUM VALUE | NUMBER OF OBSERVATIONS |
|---|---|---|---|---|---|---|
| T01 WT FOR BERTH | .0000E+00 | .0000E+00 | .9999E+04 | .0000E+00 | .0000E+00 | 1592 |
| T11 WT FOR RPIL | .2395E+00 | .1481E+01 | .6185E+01 | .0000E+00 | .1808E+02 | 1592 |
| T21 WT FOR RIVE | .2335E+02 | .1236E+03 | .5296E+01 | .0000E+00 | .4052E+04 | 1586 |
| T31 RIVER INPILO | .9027E+01 | .8719E+00 | .9658E-01 | .7501E+01 | .1050E+02 | 1586 |
| S1 CARGO HANDLIN | .6423E+02 | .7735E+02 | .1204E+01 | .7000E+01 | .7195E+03 | 1577 |
| I1 IDLE TIME | .7588E+02 | .7796E+02 | .1027E+01 | .4494E+01 | .1344E+04 | 1568 |
| T41 TIME AT BERT | .1401E+03 | .1086E+03 | .7751E+00 | .1468E+02 | .1535E+04 | 1568 |
| H1 HARBOUR OUTPI | .4502E+01 | .6413E+00 | .1425E+00 | .3071E+01 | .6987E+01 | 1568 |
| T51 WT FOR RPIL | .0000E+00 | .0000E+00 | .9999E+04 | .0000E+00 | .0000E+00 | 1568 |
| T61 WT FOR RIVE | .1761E+02 | .9903E+02 | .5623E+01 | .1318E-01 | .2414E+04 | 1562 |
| O1 RIVER OUTPILO | .8996E+01 | .8726E+00 | .9699E-01 | .7500E+01 | .1050E+02 | 1562 |
| T1 IN PORT TIME | .2085E+03 | .1930E+03 | .9257E+00 | .4258E+02 | .4196E+04 | 1562 |

**FILE STATISTICS**

| FILE NUMBER | LABEL/TYPE | AVERAGE LENGTH | STANDARD DEVIATION | MAXIMUM LENGTH | CURRENT LENGTH | AVERAGE WAITING TIME |
|---|---|---|---|---|---|---|
| 1 | AWAIT | .0000 | .0000 | 1 | 0 | .0000 |
| 2 | AWAIT | .0037 | .0680 | 3 | 0 | .0411 |
| 3 | AWAIT | .0009 | .0321 | 2 | 0 | .0095 |
| 4 | AWAIT | .0000 | .0015 | 1 | 0 | .0000 |
| 5 | AWAIT | .0000 | .0000 | 1 | 0 | .0000 |
| 6 | AWAIT | .0002 | .0156 | 1 | 0 | .0027 |
| 7 | AWAIT | .0000 | .0000 | 1 | 0 | .0000 |
| 8 | CALENDAR | 20.2207 | 5.7588 | 36 | 31 | 3.8691 |

**REGULAR ACTIVITY STATISTICS**

| ACTIVITY INDEX/LABEL | AVERAGE UTILIZATION | STANDARD DEVIATION | MAXIMUM UTIL | CURRENT UTIL | ENTITY COUNT |
|---|---|---|---|---|---|
| 1 RIVER INPILO | .8172 | 1.2697 | 8 | 0 | 1586 |
| 2 RIVER OUTPIL | .8021 | 1.0216 | 7 | 0 | 1562 |

**RESOURCE STATISTICS**

| RESOURCE NUMBER | RESOURCE LABEL | CURRENT CAPACITY | AVERAGE UTILIZATION | STANDARD DEVIATION | MAXIMUM UTILIZATION | CURRENT UTILIZATION |
|---|---|---|---|---|---|---|
| 1 | BRTH | 33 | 16.2026 | 4.7911 | 31 | 24 |
| 2 | RPILOT | 33 | 5.6915 | 3.8092 | 20 | 12 |
| 3 | HPILOT | 11 | .5412 | .8586 | 5 | 0 |
| 4 | RTUG | 10 | 1.0823 | 1.7172 | 10 | 0 |
| 5 | DPILOT | 44 | .2702 | .5754 | 5 | 0 |
| 6 | DTUG | 10 | .5403 | 1.1508 | 10 | 0 |

| RESOURCE NUMBER | RESOURCE LABEL | CURRENT AVAILABLE | AVERAGE AVAILABLE | MINIMUM AVAILABLE | MAXIMUM AVAILABLE |
|---|---|---|---|---|---|
| 1 | BRTH | 9 | 16.7975 | 2 | 33 |
| 2 | RPILOT | 21 | 27.3085 | 13 | 33 |
| 3 | HPILOT | 11 | 10.4588 | 6 | 11 |
| 4 | RTUG | 10 | 8.9177 | 0 | 10 |
| 5 | DPILOT | 44 | 43.7299 | 39 | 44 |
| 6 | DTUG | 10 | 9.4597 | 0 | 10 |

## Appendix 7.5

S: Seed

IT: Index for Interarrival Time

TR: Traffic

TTIME: Turnaround Time

| S | IT | TR | TTIME |
|---|---|---|---|
| 3 | 1 | 71 | .1958E+03 |
| 3 | 1 | 72 | .2016E+03 |
| 3 | 1 | 73 | .2007E+03 |
| 3 | 1 | 74 | .2027E+03 |
| 3 | 1 | 75 | .1971E+03 |
| 3 | 1 | 76 | .2014E+03 |
| 3 | 1 | 77 | .2090E+03 |
| 3 | 1 | 78 | .2032E+03 |
| 3 | 1 | 79 | .2067E+03 |
| 3 | 1 | 80 | .2090E+03 |
| 3 | 1 | 81 | .2084E+03 |
| 3 | 2 | 71 | .1974E+03 |
| 3 | 2 | 72 | .1993E+03 |
| 3 | 2 | 73 | .2054E+03 |
| 3 | 2 | 74 | .2024E+03 |
| 3 | 2 | 75 | .2051E+03 |
| 3 | 2 | 76 | .2094E+03 |
| 3 | 2 | 77 | .2099E+03 |
| 3 | 2 | 78 | .2058E+03 |
| 3 | 2 | 79 | .2085E+03 |
| 3 | 2 | 80 | .2090E+03 |
| 3 | 2 | 81 | .2051E+03 |
| 3 | 3 | 71 | .2047E+03 |
| 3 | 3 | 72 | .2042E+03 |
| 3 | 3 | 73 | .2025E+03 |
| 3 | 3 | 74 | .2066E+03 |
| 3 | 3 | 75 | .2072E+03 |
| 3 | 3 | 76 | .2049E+03 |
| 3 | 3 | 77 | .2096E+03 |
| 3 | 3 | 78 | .2046E+03 |
| 3 | 3 | 79 | .2125E+03 |
| 3 | 3 | 80 | .2135E+03 |
| 3 | 3 | 81 | .2130E+03 |
| 3 | 4 | 71 | .2056E+03 |
| 3 | 4 | 72 | .2037E+03 |
| 3 | 4 | 73 | .2057E+03 |
| 3 | 4 | 74 | .2068E+03 |
| 3 | 4 | 75 | .2076E+03 |
| 3 | 4 | 76 | .2083E+03 |
| 3 | 4 | 77 | .2102E+03 |
| 3 | 4 | 78 | .2119E+03 |
| 3 | 4 | 79 | .2096E+03 |
| 3 | 4 | 80 | .2120E+03 |
| 3 | 4 | 81 | .2097E+03 |

| | | | |
|---|---|---|---|
| 3 | 5 | 71 | .2028E+03 |
| 3 | 5 | 72 | .2057E+03 |
| 3 | 5 | 73 | .2054E+03 |
| 3 | 5 | 74 | .2052E+03 |
| 3 | 5 | 75 | .2075E+03 |
| 3 | 5 | 76 | .2091E+03 |
| 3 | 5 | 77 | .2088E+03 |
| 3 | 5 | 78 | .2068E+03 |
| 3 | 5 | 79 | .2118E+03 |
| 3 | 5 | 80 | .2121E+03 |
| 3 | 5 | 81 | .2113E+03 |
| 3 | 6 | 71 | .2031E+03 |
| 3 | 6 | 72 | .2048E+03 |
| 3 | 6 | 73 | .2049E+03 |
| 3 | 6 | 74 | .2064E+03 |
| 3 | 6 | 75 | .2077E+03 |
| 3 | 6 | 76 | .2079E+03 |
| 3 | 6 | 77 | .2097E+03 |
| 3 | 6 | 78 | .2105E+03 |
| 3 | 6 | 79 | .2083E+03 |
| 3 | 6 | 80 | .2100E+03 |
| 3 | 6 | 81 | .2080E+03 |
| 3 | 7 | 71 | .2039E+03 |
| 3 | 7 | 72 | .2068E+03 |
| 3 | 7 | 73 | .2025E+03 |
| 3 | 7 | 74 | .2075E+03 |
| 3 | 7 | 75 | .2056E+03 |
| 3 | 7 | 76 | .2088E+03 |
| 3 | 7 | 77 | .2069E+03 |
| 3 | 7 | 78 | .2062E+03 |
| 3 | 7 | 79 | .2096E+03 |
| 3 | 7 | 80 | .2098E+03 |
| 3 | 7 | 81 | .2109E+03 |
| 3 | 8 | 71 | .2038E+03 |
| 3 | 8 | 72 | .2055E+03 |
| 3 | 8 | 73 | .2030E+03 |
| 3 | 8 | 74 | .2038E+03 |
| 3 | 8 | 75 | .2043E+03 |
| 3 | 8 | 76 | .2075E+03 |
| 3 | 8 | 77 | .2073E+03 |
| 3 | 8 | 78 | .2067E+03 |
| 3 | 8 | 79 | .2061E+03 |
| 3 | 8 | 80 | .2086E+03 |
| 3 | 8 | 81 | .2105E+03 |
| 3 | 9 | 71 | .1994E+03 |
| 3 | 9 | 72 | .1994E+03 |
| 3 | 9 | 73 | .2051E+03 |
| 3 | 9 | 74 | .2025E+03 |
| 3 | 9 | 75 | .2037E+03 |
| 3 | 9 | 76 | .2043E+03 |
| 3 | 9 | 77 | .2034E+03 |
| 3 | 9 | 78 | .2050E+03 |
| 3 | 9 | 79 | .2072E+03 |
| 3 | 9 | 80 | .2081E+03 |
| 3 | 9 | 81 | .2109E+03 |
| 3 | 10 | 71 | .2006E+03 |
| 3 | 10 | 72 | .2021E+03 |
| 3 | 10 | 73 | .2018E+03 |
| 3 | 10 | 74 | .2019E+03 |

| | | | |
|---|---|---|---|
| 3 | 10 | 75 | .2031E+03 |
| 3 | 10 | 76 | .2022E+03 |
| 3 | 10 | 77 | .2054E+03 |
| 3 | 10 | 78 | .2073E+03 |
| 3 | 10 | 79 | .2061E+03 |
| 3 | 10 | 80 | .2086E+03 |
| 3 | 10 | 81 | .2086E+03 |
| 3 | 11 | 71 | .1999E+03 |
| 3 | 11 | 72 | .2004E+03 |
| 3 | 11 | 73 | .1993E+03 |
| 3 | 11 | 74 | .2012E+03 |
| 3 | 11 | 75 | .2038E+03 |
| 3 | 11 | 76 | .2029E+03 |
| 3 | 11 | 77 | .2025E+03 |
| 3 | 11 | 78 | .2030E+03 |
| 3 | 11 | 79 | .2067E+03 |
| 3 | 11 | 80 | .2068E+03 |
| 3 | 11 | 81 | .2065E+03 |
| 3 | 12 | 71 | .1983E+03 |
| 3 | 12 | 72 | .1996E+03 |
| 3 | 12 | 73 | .2018E+03 |
| 3 | 12 | 74 | .2031E+03 |
| 3 | 12 | 75 | .2039E+03 |
| 3 | 12 | 76 | .2055E+03 |
| 3 | 12 | 77 | .2027E+03 |
| 3 | 12 | 78 | .2029E+03 |
| 3 | 12 | 79 | .2054E+03 |
| 3 | 12 | 80 | .2054E+03 |
| 3 | 12 | 81 | .2075E+03 |
| 3 | 13 | 71 | .1975E+03 |
| 3 | 13 | 72 | .1968E+03 |
| 3 | 13 | 73 | .1991E+03 |
| 3 | 13 | 74 | .1998E+03 |
| 3 | 13 | 75 | .2022E+03 |
| 3 | 13 | 76 | .2012E+03 |
| 3 | 13 | 77 | .2045E+03 |
| 3 | 13 | 78 | .2066E+03 |
| 3 | 13 | 79 | .2079E+03 |
| 3 | 13 | 80 | .2042E+03 |
| 3 | 13 | 81 | .2069E+03 |
| 3 | 14 | 71 | .1997E+03 |
| 3 | 14 | 72 | .2010E+03 |
| 3 | 14 | 73 | .1983E+03 |
| 3 | 14 | 74 | .1993E+03 |
| 3 | 14 | 75 | .1994E+03 |
| 3 | 14 | 76 | .2028E+03 |
| 3 | 14 | 77 | .2037E+03 |
| 3 | 14 | 78 | .2051E+03 |
| 3 | 14 | 79 | .2059E+03 |
| 3 | 14 | 80 | .2055E+03 |
| 3 | 14 | 81 | .2087E+03 |
| 3 | 15 | 71 | .1983E+03 |
| 3 | 15 | 72 | .1976E+03 |
| 3 | 15 | 73 | .2007E+03 |
| 3 | 15 | 74 | .2014E+03 |
| 3 | 15 | 75 | .2027E+03 |
| 3 | 15 | 76 | .1993E+03 |
| 3 | 15 | 77 | .2019E+03 |
| 3 | 15 | 78 | .2064E+03 |

| | | | |
|---|---|---|---|
| 3 | 15 | 79 | .2045E+03 |
| 3 | 15 | 80 | .2084E+03 |
| 3 | 15 | 81 | .2080E+03 |
| 4 | 1 | 71 | .1992E+03 |
| 4 | 1 | 72 | .2021E+03 |
| 4 | 1 | 73 | .1958E+03 |
| 4 | 1 | 74 | .1990E+03 |
| 4 | 1 | 75 | .2012E+03 |
| 4 | 1 | 76 | .2058E+03 |
| 4 | 1 | 77 | .2050E+03 |
| 4 | 1 | 78 | .2036E+03 |
| 4 | 1 | 79 | .2018E+03 |
| 4 | 1 | 80 | .2086E+03 |
| 4 | 1 | 81 | .2027E+03 |
| 4 | 2 | 71 | .1982E+03 |
| 4 | 2 | 72 | .1999E+03 |
| 4 | 2 | 73 | .2055E+03 |
| 4 | 2 | 74 | .2040E+03 |
| 4 | 2 | 75 | .2014E+03 |
| 4 | 2 | 76 | .1995E+03 |
| 4 | 2 | 77 | .1990E+03 |
| 4 | 2 | 78 | .2059E+03 |
| 4 | 2 | 79 | .2049E+03 |
| 4 | 2 | 80 | .2026E+03 |
| 4 | 2 | 81 | .2082E+03 |
| 4 | 3 | 71 | .2042E+03 |
| 4 | 3 | 72 | .1965E+03 |
| 4 | 3 | 73 | .2074E+03 |
| 4 | 3 | 74 | .2038E+03 |
| 4 | 3 | 75 | .2026E+03 |
| 4 | 3 | 76 | .2076E+03 |
| 4 | 3 | 77 | .2063E+03 |
| 4 | 3 | 78 | .2105E+03 |
| 4 | 3 | 79 | .2092E+03 |
| 4 | 3 | 80 | .2123E+03 |
| 4 | 3 | 81 | .2118E+03 |
| 4 | 4 | 71 | .2042E+03 |
| 4 | 4 | 72 | .2039E+03 |
| 4 | 4 | 73 | .2070E+03 |
| 4 | 4 | 74 | .2041E+03 |
| 4 | 4 | 75 | .2061E+03 |
| 4 | 4 | 76 | .2061E+03 |
| 4 | 4 | 77 | .2086E+03 |
| 4 | 4 | 78 | .2112E+03 |
| 4 | 4 | 79 | .2123E+03 |
| 4 | 4 | 80 | .2119E+03 |
| 4 | 4 | 81 | .2078E+03 |
| 4 | 5 | 71 | .2030E+03 |
| 4 | 5 | 72 | .2053E+03 |
| 4 | 5 | 73 | .2020E+03 |
| 4 | 5 | 74 | .2056E+03 |
| 4 | 5 | 75 | .2071E+03 |
| 4 | 5 | 76 | .2070E+03 |
| 4 | 5 | 77 | .2068E+03 |
| 4 | 5 | 78 | .2054E+03 |
| 4 | 5 | 79 | .2102E+03 |
| 4 | 5 | 80 | .2095E+03 |
| 4 | 5 | 81 | .2084E+03 |
| 4 | 6 | 71 | .2035E+03 |

| | | | |
|---|---|---|---|
| 4 | 6 | 72 | .2019E+03 |
| 4 | 6 | 73 | .2053E+03 |
| 4 | 6 | 74 | .2027E+03 |
| 4 | 6 | 75 | .2064E+03 |
| 4 | 6 | 76 | .2058E+03 |
| 4 | 6 | 77 | .2089E+03 |
| 4 | 6 | 78 | .2089E+03 |
| 4 | 6 | 79 | .2088E+03 |
| 4 | 6 | 80 | .2094E+03 |
| 4 | 6 | 81 | .2135E+03 |
| 4 | 7 | 71 | .2028E+03 |
| 4 | 7 | 72 | .2030E+03 |
| 4 | 7 | 73 | .2034E+03 |
| 4 | 7 | 74 | .2081E+03 |
| 4 | 7 | 75 | .2060E+03 |
| 4 | 7 | 76 | .2065E+03 |
| 4 | 7 | 77 | .2061E+03 |
| 4 | 7 | 78 | .2090E+03 |
| 4 | 7 | 79 | .2097E+03 |
| 4 | 7 | 80 | .2111E+03 |
| 4 | 7 | 81 | .2112E+03 |
| 4 | 8 | 71 | .2013E+03 |
| 4 | 8 | 72 | .2009E+03 |
| 4 | 8 | 73 | .2032E+03 |
| 4 | 8 | 74 | .2022E+03 |
| 4 | 8 | 75 | .2060E+03 |
| 4 | 8 | 76 | .2053E+03 |
| 4 | 8 | 77 | .2043E+03 |
| 4 | 8 | 78 | .2044E+03 |
| 4 | 8 | 79 | .2102E+03 |
| 4 | 8 | 80 | .2088E+03 |
| 4 | 8 | 81 | .2100E+03 |
| 4 | 9 | 71 | .2017E+03 |
| 4 | 9 | 72 | .1973E+03 |
| 4 | 9 | 73 | .2028E+03 |
| 4 | 9 | 74 | .2033E+03 |
| 4 | 9 | 75 | .2042E+03 |
| 4 | 9 | 76 | .2055E+03 |
| 4 | 9 | 77 | .2072E+03 |
| 4 | 9 | 78 | .2059E+03 |
| 4 | 9 | 79 | .2086E+03 |
| 4 | 9 | 80 | .2069E+03 |
| 4 | 9 | 81 | .2076E+03 |
| 4 | 10 | 71 | .1992E+03 |
| 4 | 10 | 72 | .1981E+03 |
| 4 | 10 | 73 | .1991E+03 |
| 4 | 10 | 74 | .2016E+03 |
| 4 | 10 | 75 | .2034E+03 |
| 4 | 10 | 76 | .2032E+03 |
| 4 | 10 | 77 | .2040E+03 |
| 4 | 10 | 78 | .2041E+03 |
| 4 | 10 | 79 | .2085E+03 |
| 4 | 10 | 80 | .2068E+03 |
| 4 | 10 | 81 | .2105E+03 |
| 4 | 11 | 71 | .1979E+03 |
| 4 | 11 | 72 | .1999E+03 |
| 4 | 11 | 73 | .1991E+03 |
| 4 | 11 | 74 | .2012E+03 |
| 4 | 11 | 75 | .2032E+03 |

| | | | |
|---|---|---|---|
| 4 | 11 | 76 | .2044E+03 |
| 4 | 11 | 77 | .2040E+03 |
| 4 | 11 | 78 | .2050E+03 |
| 4 | 11 | 79 | .2061E+03 |
| 4 | 11 | 80 | .2089E+03 |
| 4 | 11 | 81 | .2085E+03 |
| 4 | 12 | 71 | .1987E+03 |
| 4 | 12 | 72 | .2012E+03 |
| 4 | 12 | 73 | .1992E+03 |
| 4 | 12 | 74 | .2015E+03 |
| 4 | 12 | 75 | .2012E+03 |
| 4 | 12 | 76 | .1999E+03 |
| 4 | 12 | 77 | .2045E+03 |
| 4 | 12 | 78 | .2066E+03 |
| 4 | 12 | 79 | .2069E+03 |
| 4 | 12 | 80 | .2085E+03 |
| 4 | 12 | 81 | .2055E+03 |
| 4 | 13 | 71 | .1985E+03 |
| 4 | 13 | 72 | .2020E+03 |
| 4 | 13 | 73 | .2014E+03 |
| 4 | 13 | 74 | .2017E+03 |
| 4 | 13 | 75 | .2021E+03 |
| 4 | 13 | 76 | .2038E+03 |
| 4 | 13 | 77 | .2037E+03 |
| 4 | 13 | 78 | .2020E+03 |
| 4 | 13 | 79 | .2045E+03 |
| 4 | 13 | 80 | .2077E+03 |
| 4 | 13 | 81 | .2087E+03 |
| 4 | 14 | 71 | .1980E+03 |
| 4 | 14 | 72 | .1998E+03 |
| 4 | 14 | 73 | .1999E+03 |
| 4 | 14 | 74 | .1990E+03 |
| 4 | 14 | 75 | .2028E+03 |
| 4 | 14 | 76 | .2044E+03 |
| 4 | 14 | 77 | .2010E+03 |
| 4 | 14 | 78 | .2069E+03 |
| 4 | 14 | 79 | .2073E+03 |
| 4 | 14 | 80 | .2069E+03 |
| 4 | 14 | 81 | .2042E+03 |
| 4 | 15 | 71 | .1995E+03 |
| 4 | 15 | 72 | .1979E+03 |
| 4 | 15 | 73 | .2025E+03 |
| 4 | 15 | 74 | .1991E+03 |
| 4 | 15 | 75 | .2021E+03 |
| 4 | 15 | 76 | .2012E+03 |
| 4 | 15 | 77 | .2029E+03 |
| 4 | 15 | 78 | .2022E+03 |
| 4 | 15 | 79 | .2017E+03 |
| 4 | 15 | 80 | .2085E+03 |
| 4 | 15 | 81 | .2060E+03 |
| 5 | 1 | 71 | .1995E+03 |
| 5 | 1 | 72 | .2002E+03 |
| 5 | 1 | 73 | .2009E+03 |
| 5 | 1 | 74 | .1998E+03 |
| 5 | 1 | 75 | .2004E+03 |
| 5 | 1 | 76 | .1994E+03 |
| 5 | 1 | 77 | .1985E+03 |
| 5 | 1 | 78 | .2033E+03 |
| 5 | 1 | 79 | .2059E+03 |

| | | | |
|---|---|---|---|
| 5 | 1 | 80 | .2036E+03 |
| 5 | 1 | 81 | .2059E+03 |
| 5 | 2 | 71 | .2012E+03 |
| 5 | 2 | 72 | .1975E+03 |
| 5 | 2 | 73 | .2070E+03 |
| 5 | 2 | 74 | .1998E+03 |
| 5 | 2 | 75 | .2021E+03 |
| 5 | 2 | 76 | .2010E+03 |
| 5 | 2 | 77 | .2120E+03 |
| 5 | 2 | 78 | .2015E+03 |
| 5 | 2 | 79 | .2031E+03 |
| 5 | 2 | 80 | .2111E+03 |
| 5 | 2 | 81 | .2113E+03 |
| 5 | 3 | 71 | .2038E+03 |
| 5 | 3 | 72 | .2088E+03 |
| 5 | 3 | 73 | .2048E+03 |
| 5 | 3 | 74 | .2068E+03 |
| 5 | 3 | 75 | .2081E+03 |
| 5 | 3 | 76 | .2070E+03 |
| 5 | 3 | 77 | .2109E+03 |
| 5 | 3 | 78 | .2118E+03 |
| 5 | 3 | 79 | .2120E+03 |
| 5 | 3 | 80 | .2084E+03 |
| 5 | 3 | 81 | .2126E+03 |
| 5 | 4 | 71 | .2035E+03 |
| 5 | 4 | 72 | .2047E+03 |
| 5 | 4 | 73 | .2059E+03 |
| 5 | 4 | 74 | .2040E+03 |
| 5 | 4 | 75 | .2066E+03 |
| 5 | 4 | 76 | .2052E+03 |
| 5 | 4 | 77 | .2072E+03 |
| 5 | 4 | 78 | .2079E+03 |
| 5 | 4 | 79 | .2124E+03 |
| 5 | 4 | 80 | .2147E+03 |
| 5 | 4 | 81 | .2109E+03 |
| 5 | 5 | 71 | .2038E+03 |
| 5 | 5 | 72 | .2038E+03 |
| 5 | 5 | 73 | .2055E+03 |
| 5 | 5 | 74 | .2081E+03 |
| 5 | 5 | 75 | .2073E+03 |
| 5 | 5 | 76 | .2085E+03 |
| 5 | 5 | 77 | .2065E+03 |
| 5 | 5 | 78 | .2095E+03 |
| 5 | 5 | 79 | .2121E+03 |
| 5 | 5 | 80 | .2108E+03 |
| 5 | 5 | 81 | .2118E+03 |
| 5 | 6 | 71 | .2037E+03 |
| 5 | 6 | 72 | .2014E+03 |
| 5 | 6 | 73 | .2045E+03 |
| 5 | 6 | 74 | .2061E+03 |
| 5 | 6 | 75 | .2070E+03 |
| 5 | 6 | 76 | .2069E+03 |
| 5 | 6 | 77 | .2078E+03 |
| 5 | 6 | 78 | .2100E+03 |
| 5 | 6 | 79 | .2085E+03 |
| 5 | 6 | 80 | .2098E+03 |
| 5 | 6 | 81 | .2131E+03 |
| 5 | 7 | 71 | .2038E+03 |
| 5 | 7 | 72 | .2020E+03 |

| | | | |
|---|---|---|---|
| 5 | 7 | 73 | .2042E+03 |
| 5 | 7 | 74 | .2061E+03 |
| 5 | 7 | 75 | .2055E+03 |
| 5 | 7 | 76 | .2075E+03 |
| 5 | 7 | 77 | .2101E+03 |
| 5 | 7 | 78 | .2087E+03 |
| 5 | 7 | 79 | .2082E+03 |
| 5 | 7 | 80 | .2077E+03 |
| 5 | 7 | 81 | .2120E+03 |
| 5 | 8 | 71 | .2030E+03 |
| 5 | 8 | 72 | .2054E+03 |
| 5 | 8 | 73 | .2035E+03 |
| 5 | 8 | 74 | .2035E+03 |
| 5 | 8 | 75 | .2023E+03 |
| 5 | 8 | 76 | .2044E+03 |
| 5 | 8 | 77 | .2052E+03 |
| 5 | 8 | 78 | .2068E+03 |
| 5 | 8 | 79 | .2076E+03 |
| 5 | 8 | 80 | .2093E+03 |
| 5 | 8 | 81 | .2100E+03 |
| 5 | 9 | 71 | .2000E+03 |
| 5 | 9 | 72 | .1987E+03 |
| 5 | 9 | 73 | .2012E+03 |
| 5 | 9 | 74 | .2048E+03 |
| 5 | 9 | 75 | .2030E+03 |
| 5 | 9 | 76 | .2056E+03 |
| 5 | 9 | 77 | .2043E+03 |
| 5 | 9 | 78 | .2086E+03 |
| 5 | 9 | 79 | .2084E+03 |
| 5 | 9 | 80 | .2078E+03 |
| 5 | 9 | 81 | .2084E+03 |
| 5 | 10 | 71 | .1969E+03 |
| 5 | 10 | 72 | .1994E+03 |
| 5 | 10 | 73 | .2010E+03 |
| 5 | 10 | 74 | .1990E+03 |
| 5 | 10 | 75 | .2021E+03 |
| 5 | 10 | 76 | .2020E+03 |
| 5 | 10 | 77 | .2058E+03 |
| 5 | 10 | 78 | .2059E+03 |
| 5 | 10 | 79 | .2038E+03 |
| 5 | 10 | 80 | .2082E+03 |
| 5 | 10 | 81 | .2082E+03 |
| 5 | 11 | 71 | .1987E+03 |
| 5 | 11 | 72 | .1996E+03 |
| 5 | 11 | 73 | .2005E+03 |
| 5 | 11 | 74 | .1992E+03 |
| 5 | 11 | 75 | .2022E+03 |
| 5 | 11 | 76 | .2035E+03 |
| 5 | 11 | 77 | .2053E+03 |
| 5 | 11 | 78 | .2065E+03 |
| 5 | 11 | 79 | .2055E+03 |
| 5 | 11 | 80 | .2057E+03 |
| 5 | 11 | 81 | .2108E+03 |
| 5 | 12 | 71 | .1988E+03 |
| 5 | 12 | 72 | .2016E+03 |
| 5 | 12 | 73 | .1987E+03 |
| 5 | 12 | 74 | .2009E+03 |
| 5 | 12 | 75 | .2057E+03 |
| 5 | 12 | 76 | .2028E+03 |

| | | | |
|---|---|---|---|
| 5 | 12 | 77 | .2057E+03 |
| 5 | 12 | 78 | .2047E+03 |
| 5 | 12 | 79 | .2058E+03 |
| 5 | 12 | 80 | .2092E+03 |
| 5 | 12 | 81 | .2071E+03 |
| 5 | 13 | 71 | .2008E+03 |
| 5 | 13 | 72 | .1999E+03 |
| 5 | 13 | 73 | .2025E+03 |
| 5 | 13 | 74 | .2008E+03 |
| 5 | 13 | 75 | .2040E+03 |
| 5 | 13 | 76 | .2025E+03 |
| 5 | 13 | 77 | .2031E+03 |
| 5 | 13 | 78 | .2035E+03 |
| 5 | 13 | 79 | .2089E+03 |
| 5 | 13 | 80 | .2056E+03 |
| 5 | 13 | 81 | .2091E+03 |
| 5 | 14 | 71 | .1997E+03 |
| 5 | 14 | 72 | .1969E+03 |
| 5 | 14 | 73 | .2012E+03 |
| 5 | 14 | 74 | .2002E+03 |
| 5 | 14 | 75 | .2025E+03 |
| 5 | 14 | 76 | .2060E+03 |
| 5 | 14 | 77 | .2033E+03 |
| 5 | 14 | 78 | .2074E+03 |
| 5 | 14 | 79 | .2014E+03 |
| 5 | 14 | 80 | .2045E+03 |
| 5 | 14 | 81 | .2075E+03 |
| 5 | 15 | 71 | .1961E+03 |
| 5 | 15 | 72 | .2017E+03 |
| 5 | 15 | 73 | .1964E+03 |
| 5 | 15 | 74 | .2029E+03 |
| 5 | 15 | 75 | .2001E+03 |
| 5 | 15 | 76 | .2031E+03 |
| 5 | 15 | 77 | .2017E+03 |
| 5 | 15 | 78 | .2014E+03 |
| 5 | 15 | 79 | .2042E+03 |
| 5 | 15 | 80 | .2043E+03 |
| 5 | 15 | 81 | .2057E+03 |
| 6 | 1 | 71 | .2017E+03 |
| 6 | 1 | 72 | .1971E+03 |
| 6 | 1 | 73 | .2036E+03 |
| 6 | 1 | 74 | .1988E+03 |
| 6 | 1 | 75 | .2041E+03 |
| 6 | 1 | 76 | .2007E+03 |
| 6 | 1 | 77 | .2007E+03 |
| 6 | 1 | 78 | .2073E+03 |
| 6 | 1 | 79 | .2081E+03 |
| 6 | 1 | 80 | .2037E+03 |
| 6 | 1 | 81 | .2053E+03 |
| 6 | 2 | 71 | .2071E+03 |
| 6 | 2 | 72 | .1997E+03 |
| 6 | 2 | 73 | .2057E+03 |
| 6 | 2 | 74 | .2057E+03 |
| 6 | 2 | 75 | .2012E+03 |
| 6 | 2 | 76 | .2062E+03 |
| 6 | 2 | 77 | .2047E+03 |
| 6 | 2 | 78 | .2108E+03 |
| 6 | 2 | 79 | .2082E+03 |
| 6 | 2 | 80 | .2037E+03 |

| | | | |
|---|---|---|---|
| 6 | 2 | 81 | .2147E+03 |
| 6 | 3 | 71 | .2074E+03 |
| 6 | 3 | 72 | .1993E+03 |
| 6 | 3 | 73 | .1993E+03 |
| 6 | 3 | 74 | .2108E+03 |
| 6 | 3 | 75 | .2060E+03 |
| 6 | 3 | 76 | .2089E+03 |
| 6 | 3 | 77 | .2093E+03 |
| 6 | 3 | 78 | .2071E+03 |
| 6 | 3 | 79 | .2132E+03 |
| 6 | 3 | 80 | .2023E+03 |
| 6 | 3 | 81 | .2119E+03 |
| 6 | 4 | 71 | .2050E+03 |
| 6 | 4 | 72 | .2057E+03 |
| 6 | 4 | 73 | .2046E+03 |
| 6 | 4 | 74 | .2066E+03 |
| 6 | 4 | 75 | .2037E+03 |
| 6 | 4 | 76 | .2087E+03 |
| 6 | 4 | 77 | .2087E+03 |
| 6 | 4 | 78 | .2111E+03 |
| 6 | 4 | 79 | .2111E+03 |
| 6 | 4 | 80 | .2098E+03 |
| 6 | 4 | 81 | .2115E+03 |
| 6 | 5 | 71 | .1990E+03 |
| 6 | 5 | 72 | .2049E+03 |
| 6 | 5 | 73 | .2053E+03 |
| 6 | 5 | 74 | .2079E+03 |
| 6 | 5 | 75 | .2060E+03 |
| 6 | 5 | 76 | .2070E+03 |
| 6 | 5 | 77 | .2060E+03 |
| 6 | 5 | 78 | .2082E+03 |
| 6 | 5 | 79 | .2097E+03 |
| 6 | 5 | 80 | .2113E+03 |
| 6 | 5 | 81 | .2119E+03 |
| 6 | 6 | 71 | .2027E+03 |
| 6 | 6 | 72 | .2041E+03 |
| 6 | 6 | 73 | .2024E+03 |
| 6 | 6 | 74 | .2053E+03 |
| 6 | 6 | 75 | .2076E+03 |
| 6 | 6 | 76 | .2075E+03 |
| 6 | 6 | 77 | .2089E+03 |
| 6 | 6 | 78 | .2116E+03 |
| 6 | 6 | 79 | .2088E+03 |
| 6 | 6 | 80 | .2121E+03 |
| 6 | 6 | 81 | .2097E+03 |
| 6 | 7 | 71 | .2021E+03 |
| 6 | 7 | 72 | .2035E+03 |
| 6 | 7 | 73 | .2007E+03 |
| 6 | 7 | 74 | .2060E+03 |
| 6 | 7 | 75 | .2057E+03 |
| 6 | 7 | 76 | .2059E+03 |
| 6 | 7 | 77 | .2077E+03 |
| 6 | 7 | 78 | .2085E+03 |
| 6 | 7 | 79 | .2099E+03 |
| 6 | 7 | 80 | .2115E+03 |
| 6 | 7 | 81 | .2114E+03 |
| 6 | 8 | 71 | .1991E+03 |
| 6 | 8 | 72 | .2029E+03 |
| 6 | 8 | 73 | .2011E+03 |

| | | | |
|---|---|---|---|
| 6 | 8 | 74 | .2039E+03 |
| 6 | 8 | 75 | .2076E+03 |
| 6 | 8 | 76 | .2072E+03 |
| 6 | 8 | 77 | .2075E+03 |
| 6 | 8 | 78 | .2066E+03 |
| 6 | 8 | 79 | .2062E+03 |
| 6 | 8 | 80 | .2083E+03 |
| 6 | 8 | 81 | .2102E+03 |
| 6 | 9 | 71 | .2008E+03 |
| 6 | 9 | 72 | .2036E+03 |
| 6 | 9 | 73 | .2036E+03 |
| 6 | 9 | 74 | .2027E+03 |
| 6 | 9 | 75 | .2046E+03 |
| 6 | 9 | 76 | .2055E+03 |
| 6 | 9 | 77 | .2047E+03 |
| 6 | 9 | 78 | .2071E+03 |
| 6 | 9 | 79 | .2062E+03 |
| 6 | 9 | 80 | .2115E+03 |
| 6 | 9 | 81 | .2089E+03 |
| 6 | 10 | 71 | .2005E+03 |
| 6 | 10 | 72 | .2004E+03 |
| 6 | 10 | 73 | .1983E+03 |
| 6 | 10 | 74 | .2021E+03 |
| 6 | 10 | 75 | .2016E+03 |
| 6 | 10 | 76 | .2064E+03 |
| 6 | 10 | 77 | .2042E+03 |
| 6 | 10 | 78 | .2067E+03 |
| 6 | 10 | 79 | .2062E+03 |
| 6 | 10 | 80 | .2118E+03 |
| 6 | 10 | 81 | .2119E+03 |
| 6 | 11 | 71 | .2007E+03 |
| 6 | 11 | 72 | .1998E+03 |
| 6 | 11 | 73 | .2018E+03 |
| 6 | 11 | 74 | .2015E+03 |
| 6 | 11 | 75 | .2008E+03 |
| 6 | 11 | 76 | .2069E+03 |
| 6 | 11 | 77 | .2059E+03 |
| 6 | 11 | 78 | .2054E+03 |
| 6 | 11 | 79 | .2063E+03 |
| 6 | 11 | 80 | .2039E+03 |
| 6 | 11 | 81 | .2076E+03 |
| 6 | 12 | 71 | .1987E+03 |
| 6 | 12 | 72 | .2021E+03 |
| 6 | 12 | 73 | .2018E+03 |
| 6 | 12 | 74 | .2005E+03 |
| 6 | 12 | 75 | .2033E+03 |
| 6 | 12 | 76 | .2018E+03 |
| 6 | 12 | 77 | .2036E+03 |
| 6 | 12 | 78 | .2048E+03 |
| 6 | 12 | 79 | .2068E+03 |
| 6 | 12 | 80 | .2081E+03 |
| 6 | 12 | 81 | .2091E+03 |
| 6 | 13 | 71 | .1971E+03 |
| 6 | 13 | 72 | .1997E+03 |
| 6 | 13 | 73 | .2004E+03 |
| 6 | 13 | 74 | .2015E+03 |
| 6 | 13 | 75 | .2039E+03 |
| 6 | 13 | 76 | .2062E+03 |
| 6 | 13 | 77 | .2049E+03 |

| | | | |
|---|---|---|---|
| 6 | 13 | 78 | .2072E+03 |
| 6 | 13 | 79 | .2071E+03 |
| 6 | 13 | 80 | .2077E+03 |
| 6 | 13 | 81 | .2094E+03 |
| 6 | 14 | 71 | .2001E+03 |
| 6 | 14 | 72 | .1974E+03 |
| 6 | 14 | 73 | .2004E+03 |
| 6 | 14 | 74 | .2029E+03 |
| 6 | 14 | 75 | .2008E+03 |
| 6 | 14 | 76 | .2024E+03 |
| 6 | 14 | 77 | .2041E+03 |
| 6 | 14 | 78 | .2059E+03 |
| 6 | 14 | 79 | .2028E+03 |
| 6 | 14 | 80 | .2055E+03 |
| 6 | 14 | 81 | .2081E+03 |
| 6 | 15 | 71 | .1987E+03 |
| 6 | 15 | 72 | .1998E+03 |
| 6 | 15 | 73 | .1984E+03 |
| 6 | 15 | 74 | .1998E+03 |
| 6 | 15 | 75 | .2030E+03 |
| 6 | 15 | 76 | .2027E+03 |
| 6 | 15 | 77 | .2022E+03 |
| 6 | 15 | 78 | .2021E+03 |
| 6 | 15 | 79 | .2037E+03 |
| 6 | 15 | 80 | .2056E+03 |
| 6 | 15 | 81 | .2056E+03 |
| 7 | 1 | 71 | .1946E+03 |
| 7 | 1 | 72 | .1959E+03 |
| 7 | 1 | 73 | .2022E+03 |
| 7 | 1 | 74 | .2003E+03 |
| 7 | 1 | 75 | .2013E+03 |
| 7 | 1 | 76 | .2006E+03 |
| 7 | 1 | 77 | .2077E+03 |
| 7 | 1 | 78 | .2018E+03 |
| 7 | 1 | 79 | .2029E+03 |
| 7 | 1 | 80 | .2102E+03 |
| 7 | 1 | 81 | .2087E+03 |
| 7 | 2 | 71 | .1954E+03 |
| 7 | 2 | 72 | .2043E+03 |
| 7 | 2 | 73 | .2017E+03 |
| 7 | 2 | 74 | .2006E+03 |
| 7 | 2 | 75 | .2004E+03 |
| 7 | 2 | 76 | .2102E+03 |
| 7 | 2 | 77 | .2011E+03 |
| 7 | 2 | 78 | .2001E+03 |
| 7 | 2 | 79 | .2053E+03 |
| 7 | 2 | 80 | .2087E+03 |
| 7 | 2 | 81 | .2105E+03 |
| 7 | 3 | 71 | .2028E+03 |
| 7 | 3 | 72 | .2065E+03 |
| 7 | 3 | 73 | .2013E+03 |
| 7 | 3 | 74 | .2077E+03 |
| 7 | 3 | 75 | .2084E+03 |
| 7 | 3 | 76 | .2015E+03 |
| 7 | 3 | 77 | .2090E+03 |
| 7 | 3 | 78 | .2137E+03 |
| 7 | 3 | 79 | .2116E+03 |
| 7 | 3 | 80 | .2120E+03 |
| 7 | 3 | 81 | .2108E+03 |

| | | | |
|---|---|---|---|
| 7 | 4 | 71 | .2030E+03 |
| 7 | 4 | 72 | .2046E+03 |
| 7 | 4 | 73 | .2059E+03 |
| 7 | 4 | 74 | .2055E+03 |
| 7 | 4 | 75 | .2053E+03 |
| 7 | 4 | 76 | .2075E+03 |
| 7 | 4 | 77 | .2078E+03 |
| 7 | 4 | 78 | .2091E+03 |
| 7 | 4 | 79 | .2098E+03 |
| 7 | 4 | 80 | .2099E+03 |
| 7 | 4 | 81 | .2127E+03 |
| 7 | 5 | 71 | .2028E+03 |
| 7 | 5 | 72 | .2044E+03 |
| 7 | 5 | 73 | .2035E+03 |
| 7 | 5 | 74 | .2028E+03 |
| 7 | 5 | 75 | .2070E+03 |
| 7 | 5 | 76 | .2094E+03 |
| 7 | 5 | 77 | .2071E+03 |
| 7 | 5 | 78 | .2095E+03 |
| 7 | 5 | 79 | .2121E+03 |
| 7 | 5 | 80 | .2130E+03 |
| 7 | 5 | 81 | .2123E+03 |
| 7 | 6 | 71 | .2011E+03 |
| 7 | 6 | 72 | .2062E+03 |
| 7 | 6 | 73 | .2052E+03 |
| 7 | 6 | 74 | .2052E+03 |
| 7 | 6 | 75 | .2061E+03 |
| 7 | 6 | 76 | .2088E+03 |
| 7 | 6 | 77 | .2064E+03 |
| 7 | 6 | 78 | .2096E+03 |
| 7 | 6 | 79 | .2109E+03 |
| 7 | 6 | 80 | .2117E+03 |
| 7 | 6 | 81 | .2103E+03 |
| 7 | 7 | 71 | .2015E+03 |
| 7 | 7 | 72 | .2039E+03 |
| 7 | 7 | 73 | .2049E+03 |
| 7 | 7 | 74 | .2062E+03 |
| 7 | 7 | 75 | .2064E+03 |
| 7 | 7 | 76 | .2070E+03 |
| 7 | 7 | 77 | .2083E+03 |
| 7 | 7 | 78 | .2090E+03 |
| 7 | 7 | 79 | .2092E+03 |
| 7 | 7 | 80 | .2122E+03 |
| 7 | 7 | 81 | .2116E+03 |
| 7 | 8 | 71 | .1976E+03 |
| 7 | 8 | 72 | .2005E+03 |
| 7 | 8 | 73 | .2041E+03 |
| 7 | 8 | 74 | .2044E+03 |
| 7 | 8 | 75 | .2061E+03 |
| 7 | 8 | 76 | .2011E+03 |
| 7 | 8 | 77 | .2083E+03 |
| 7 | 8 | 78 | .2101E+03 |
| 7 | 8 | 79 | .2101E+03 |
| 7 | 8 | 80 | .2104E+03 |
| 7 | 8 | 81 | .2108E+03 |
| 7 | 9 | 71 | .2020E+03 |
| 7 | 9 | 72 | .2011E+03 |
| 7 | 9 | 73 | .2032E+03 |
| 7 | 9 | 74 | .2009E+03 |

| | | | |
|---|---|---|---|
| 7 | 9 | 75 | .2055E+03 |
| 7 | 9 | 76 | .2041E+03 |
| 7 | 9 | 77 | .2058E+03 |
| 7 | 9 | 78 | .2056E+03 |
| 7 | 9 | 79 | .2079E+03 |
| 7 | 9 | 80 | .2129E+03 |
| 7 | 9 | 81 | .2096E+03 |
| 7 | 10 | 71 | .1991E+03 |
| 7 | 10 | 72 | .1997E+03 |
| 7 | 10 | 73 | .2013E+03 |
| 7 | 10 | 74 | .2027E+03 |
| 7 | 10 | 75 | .2032E+03 |
| 7 | 10 | 76 | .2046E+03 |
| 7 | 10 | 77 | .2046E+03 |
| 7 | 10 | 78 | .2052E+03 |
| 7 | 10 | 79 | .2055E+03 |
| 7 | 10 | 80 | .2072E+03 |
| 7 | 10 | 81 | .2072E+03 |
| 7 | 11 | 71 | .2005E+03 |
| 7 | 11 | 72 | .1981E+03 |
| 7 | 11 | 73 | .2012E+03 |
| 7 | 11 | 74 | .2013E+03 |
| 7 | 11 | 75 | .2007E+03 |
| 7 | 11 | 76 | .2038E+03 |
| 7 | 11 | 77 | .2066E+03 |
| 7 | 11 | 78 | .2068E+03 |
| 7 | 11 | 79 | .2051E+03 |
| 7 | 11 | 80 | .2094E+03 |
| 7 | 11 | 81 | .2067E+03 |
| 7 | 12 | 71 | .1974E+03 |
| 7 | 12 | 72 | .1990E+03 |
| 7 | 12 | 73 | .1999E+03 |
| 7 | 12 | 74 | .2024E+03 |
| 7 | 12 | 75 | .2043E+03 |
| 7 | 12 | 76 | .2032E+03 |
| 7 | 12 | 77 | .2050E+03 |
| 7 | 12 | 78 | .2064E+03 |
| 7 | 12 | 79 | .2066E+03 |
| 7 | 12 | 80 | .2049E+03 |
| 7 | 12 | 81 | .2085E+03 |
| 7 | 13 | 71 | .1986E+03 |
| 7 | 13 | 72 | .1991E+03 |
| 7 | 13 | 73 | .2001E+03 |
| 7 | 13 | 74 | .2005E+03 |
| 7 | 13 | 75 | .2009E+03 |
| 7 | 13 | 76 | .2035E+03 |
| 7 | 13 | 77 | .2065E+03 |
| 7 | 13 | 78 | .2063E+03 |
| 7 | 13 | 79 | .2062E+03 |
| 7 | 13 | 80 | .2082E+03 |
| 7 | 13 | 81 | .2081E+03 |
| 7 | 14 | 71 | .1986E+03 |
| 7 | 14 | 72 | .2000E+03 |
| 7 | 14 | 73 | .1990E+03 |
| 7 | 14 | 74 | .1993E+03 |
| 7 | 14 | 75 | .1988E+03 |
| 7 | 14 | 76 | .2020E+03 |
| 7 | 14 | 77 | .2048E+03 |
| 7 | 14 | 78 | .2058E+03 |

| | | | |
|---|---|---|---|
| 7 | 14 | 79 | .2063E+03 |
| 7 | 14 | 80 | .2078E+03 |
| 7 | 14 | 81 | .2089E+03 |
| 7 | 15 | 71 | .1965E+03 |
| 7 | 15 | 72 | .1988E+03 |
| 7 | 15 | 73 | .1976E+03 |
| 7 | 15 | 74 | .2001E+03 |
| 7 | 15 | 75 | .2019E+03 |
| 7 | 15 | 76 | .2035E+03 |
| 7 | 15 | 77 | .2034E+03 |
| 7 | 15 | 78 | .2043E+03 |
| 7 | 15 | 79 | .2078E+03 |
| 7 | 15 | 80 | .2057E+03 |
| 7 | 15 | 81 | .2055E+03 |

□

## Appendix 7.6

**[The LIMDEP input file for estimating turnaround time as a function of number of ships and traffic]**

```
Read ; file = a:\nn87.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed87, ia87indx, c87, tt87$

Create; ia87 = 8.75 + .25 * ia87indx $

Read ; file = a:\nn88.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed88, ia88indx, c88, tt88$

Create; ia88 = 8.75 + .25 * ia88indx $

Read ; file = a:\nn89.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed89, ia89indx, c89, tt89$

Create; ia89 = 8.75 + .25 * ia89indx $

Read ; file = a:\nn90.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed90, ia90indx, c90, tt90$

Create; ia90 = 8.75 + .25 * ia90indx $

Read ; file = a:\nn91.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed91, ia91indx, c91, tt91$
```

```
Create; ia91 = 8.75 + .25 * ia91indx $

Read ; file = a:\nn92.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed92, ia92indx, c92, tt92$

Create; ia92 = 8.75 + .25 * ia92indx $

Read ; file = a:\nn93.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed93, ia93indx, c93, tt93$

Create; ia93 = 8.75 + .25 * ia93indx $

Read ; file = a:\nn94.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed94, ia94indx, c94, tt94$

Create; ia94 = 8.75 + .25 * ia94indx $

Read ; file = a:\nn95.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed95, ia95indx, c95, tt95$

Create; ia95 = 8.75 + .25 * ia95indx $

Read ; file = a:\nn96.txt
    ; nvar = 4
    ; nobs = 450
    ; names = seed96, ia96indx, c96, tt96$

Create; ia96 = 8.75 + .25 * ia96indx $
```

```
Create; num87 = 8760 / ia87
     ; num88 =  8760 / ia88
     ; num89 = 8760 / ia89
     ; num90 = 8760 / ia90
     ; num91 = 8760 / ia91
     ; num92 = 8760 / ia92
     ; num93 = 8760 / ia93
     ; num94 = 8760 / ia94
     ; num95 = 8760 / ia95
     ; num96 = 8760 / ia96  $

Sure ; lhs = log(tt87), log(tt88), log(tt89), log(tt90), log(tt91),
          log(tt92), log(tt93), log(tt94), log(tt95), log(tt96)
    ; eq1 = one, log(num87), log(c87)
    ; eq2 = one, log(num88), log(c88)
    ; eq3 = one, log(num89), log(c89)
    ; eq4 = one, log(num90), log(c90)
    ; eq5 = one, log(num91), log(c91)
    ; eq6 = one, log(num92), log(c92)
    ; eq7 = one, log(num93), log(c93)
    ; eq8 = one, log(num94), log(c94)
    ; eq9 = one, log(num95), log(c95)
    ; eq10= one, log(num96), log(c96)
$
```

FIGURE XX : ESTIMATING TURNAROUND TIME AS A FUNCTION OF NUMBER AND TRAFFIC; THE LIMDEP INPUT FILE

## Appendix 7.7

**[Final Estimation in Nonlinear 3SLS using LIMDEP]**

```
/* This program is the final estimation exercise ; it estimates the
demand functions (num and c(traffic)) making use of the estimates of t
(turnaround time) from the program ttsure.lim. p is nominal price, defl
is the deflator; alph, bet, gam are obtained from the output of ttsure.lim
and h is the inverse of handling rate (time required per unit cargo
handled.                              */

Read; nvar = 10
   ; names = yr, t, num, c, p, defl, alph, bet , gam , h
   ; nobs = 10 $


87 273.12 898 45  9.723 1.598 2.8291 0.1434 0.4711 2.54400
88 258.24 933 47  9.080 1.738 3.1357 0.1049 0.4608 2.34380
89 230.88 840 52 13.498 1.879 3.4931 0.0590 0.4130 1.93385
90 252.72 808 54 14.498 2.034 2.4820 0.1701 0.5018 2.01778
91 269.52 781 53 14.785 2.256 1.6663 0.3079 0.4807 2.03774
92 246.72 703 59 14.537 2.589 -.6649 0.5989 0.5708 1.85085
93 241.20 764 67 15.362 2.809 3.9516 0.0015 0.3711 1.39343
94 223.44 736 70 16.423 3.079 3.3826 0.0899 0.3432 1.17257
95 220.08 755 72 14.339 3.418 3.6444 0.0524 0.3323 1.09000
96 207.12 805 76 16.528 3.621 3.6523 0.0462 0.3140 0.88421

create; rp = p / defl
    ; ln = log(num)
    ; lc = log(c)
    ; lt = log(t) $

NLSUR; lhs = ln, lc, lt
   ; fn1 =  y1 * yr + c1 + c2 * log(t - h*c) + c3 * rp + c4 * h
   ; fn2 =  y2 * yr + c5 + c6 * log(t - h*c) + c7 * rp + c8 * h
   ; fn3 = alph + bet * ln + gam * lc
   ; labels = c1, c2, c3, c4, c5, c6, c7, c8, y1, y2
```

```
; inst = one, rp, alph, bet, gam, h, yr
; start = 10, -10, -10, -10, 10, 10, -10, -10, -10, -10
; maxit = 500                          ? iterations limit
; AR1                       ? allows for autocorrelated errors
$
```

# CHAPTER 8

# CONCLUSION



## 8.1 Concluding Remarks

In view of the growing criticism against the performance of the Calcutta-Haldia port complex and its impact on the demand for port services, this study pinpointed certain bottlenecks in the ship-handling aspect of port operations with the help of a simulation model that was developed during the course of the study. The intricacies of ship-handling in a riverine port like Calcutta has been carefully reproduced in the simulation model. The rest of the thesis is devoted to developing a stylised technique of estimating the demand for the port's services by combining traditional econometric tools with computer simulation. Finally, the study makes some observations regarding the optimality of prices charged with the objective of profit maximisation.

The thesis historically traces the performance of the port complex vis-a-vis that of other competing Indian ports. It was observed that there was a marked decline in the volume of traffic handled through the port since the mid sixties which had adversely affected its revenue generation. Delays in port operations resulted in a high turnaround time of ships which hampered its competitiveness. On comparing the average turnaround time of the port of Calcutta and Haldia to that of some other major ports, it was found that the turnaround time at Calcutta where there was a chronic shortage of traffic was almost as high as that of Bombay, which happens to be the nation's busiest port. A need was felt, therefore, to precisely estimate the turnaround time at Calcutta and identify its components to seek an answer to this riddle. This was attempted with the help of a properly verified and validated simulation model. The model was run under a number of alternative scenarios to discern the effect of various parametric changes on the turnaround time of calling ships.

In the present era of microeconomic reforms, the aspect of profitably running state-owned enterprises has generated a lot of debate. The Calcutta-Haldia port complex has thus been a subject of scrutiny given its performance over the past few decades. This thesis dealt with ways to improve the performance and profit-making potential of the port complex through estimation of the demand for port services at Calcutta. The main thrust was to show an intelligent way to tackle the aspect of demand estimation and comment on optimal pricing strategy by making use of the tool of simulation to estimate the port's performance and combining its output with standard econometric tools for greater accuracy.

The simulation model enabled us to predict in precise quantitative terms, the areas where further investments would reap maximum benefits in terms of enhanced turnaround time. A look at the results from the various simulation runs, indicates that with the existing volume of traffic, the number of berths assigned for containerships are quite sufficient. So are the number of river pilots handling the container vessels. It is indeed, the waiting for proper riverine conditions that occupies most of the ships' waiting time. This reveals the critical need for improving the navigability of the river if the turnaround time at Calcutta port is to be reduced. Thus, under the existing facilities and volume of traffic, the simulation exercise indicated that it is the improvement of river draught that should be of prime concern to the port authorities. Once this is achieved and the number of ships calling at the port increase, time shortages may be felt in other port resources such as, berths and pilots. The impact of these changes can then be studied with the help of this model.

The various experiments tried on the model point to the fact that if in future, with improvements in the river draught conditions, a greater volume of ships call at the port, there will be a need to increase the resource berth. If with greater volume of traffic, the port has to accommodate deeper draughted vessels, then once again attention will have to be paid towards further improvement of river draught. In case of the port of Calcutta, where the stigma of inefficiency has tarnished its earlier reputation, this kind of a simulation technique may serve as a useful tool in the hands of the port authorities in judging the existing lacunae and taking suitable steps to correct the situation. The model provides quantitative assessment of the nature of the problem and is an important tool in pinpointing the specific areas where improvement is required. The simulated results obtained after considering the alternative policy measures need to be carefully analysed. The model can be used to study other riverine ports as well, with suitable parametric adjustments.

A similar modeling exercise, this time concentrating on tanker vessels visiting Haldia, yielded several useful findings about that port. Experiments on the model indicated that the number of berths were in short supply at Haldia and an increase in the number of tanker berths could be instrumental in reducing turnaround time for ships. This was, however, not true of the number of river pilots which proved quite sufficient for the existing volume of traffic. A rise in the number of river pilots could at best marginally improve the turnaround time of tankers. A similar situation was noticed for river tugs as well, which proved quite sufficient to handle the existing volume of ship traffic. A number of other experiments were also carried out in order to understand system reaction to varying conditions. One such experiment involved greater arrival rate of ships. As an obvious consequence, a shortage was felt in the existing pool of port facilities. The average wait for berth and river pilots increased dramatically. Thus, although for the existing volume of traffic, the port facilities were just about sufficient, major resource bottlenecks could be expected with a rise in traffic flow, all other things remaining the same.

Another interesting experiment was carried out relating to a greater arrival percentage of heavier ships. Predictably, it was found that this caused a larger number of ships to neap, i.e. get detained due to draught restrictions. This delay caused pressure on other port resources such as the river pilot and generally resulted in a higher average turnaround time of ships. An experiment which combined greater arrival of all ships in general and higher arrival percentage of heavier ships in particular, naturally confirmed and magnified these effects. The model was also run using river draught data of 1991-92 which was slightly improved from the 1987-88 figures due to dredging and other river training programmes. As a consequence, the average wait for river declined to a certain extent for all ship types. However, due to the stochastic nature of the variables involved in the simulation run, these time savings were sometimes overshadowed by increases in some other component of turnaround time. Thus, a decline in average turnaround time could not be observed in the case of all ship types. It must also be borne in mind that the draught improvements were only marginal. In another experiment using the new draught figures and a greater arrival of ships, it was found that the situation of the neaped category of ships showed a decline in average estimated turnaround time compared to those in the similar experiment using earlier draught data. The same was true when a similar experiment was conducted with greater arrival percentage of heavier ships.

In conclusion, it could be stated that appreciable improvements needed to be made in the river draught situation at Haldia in order to live up to the promise of handling deeper draughted larger vessels. Although the existing port facilities were more or less sufficient to handle the current volume of traffic, it would be the resources river pilot and berth which would turn out to be insufficient should the traffic volume increase in future.

However, such experiments on a simulation model aimed at reconfiguring the facilities of a complex queuing system such as this port complex, does not take into account the effect of such reconfigurations on future arrival patterns. The thesis argues that attention should be given to the feedback effect of such changes on future ship arrivals while predicting the demand for port services. It suggests a simple methodology which combines discrete event simulation with the econometrics of simultaneous equations estimation for this purpose. This procedure is less likely to suffer from identification problems than the latter method on its own. This is used to estimate the demand for the services of the riverine port of Calcutta using data for the past decade. Empirically obtained coefficients are reconciled with predictions from models of shipowner behaviour built using microeconomic theory. Finally, the estimates are used as parameters for a non linear programming problem designed to derive price elasticities at the levied prices. The analysis indicates that an increase in profits and a reduction in turnaround time could both be achieved by raising prices.

The thesis demonstrates that prices can be a crucial instrument in regulating queue performance. It develops a methodology which facilitates demand estimation by simulating the technological environment and by using estimates of the technology equation from simulated data and answers the question: How should prices be modified in order to enhance the profit-making potential of the port ?

Given that the magnitude of actual elasticities are roughly 80% smaller than the optimal magnitudes, it was concluded that the services were generally underpriced during the years used for this study if profits were to be maximised. This conclusion, at first glance, may seem counter-intuitive. Given that demand is in a state of decline, should it not be boosted by a drop in prices? Also, given that the turnaround time is already large would not an increase in prices drive away the remaining customers? The answer can be found in the elasticity figures which are quite small – not too different from 0. This means that the port has in this period been forced to operate on the inelastic segment of the demand curve having already lost the more price and performance sensitive customers perhaps to competing ports. The remaining customers, perhaps because of rigid geographical preferences, suffer from a lack of mobility – and consequently seem willing to bear a further rise in prices. The insight derived from this analysis is consistent with the prescriptions given by optimisation packages, demonstrating thereby that quite simple macroeconomic models combined with microeconomic insight can be extremely useful to derive first-pass analyses of complex engineering-economic systems such as the Calcutta Haldia port complex.

## 8.2 Scope for Further Research

The work reported here can be extended in future in at least three directions. First, regarding the simulation model, one can improve its predictive behaviour by adding further detail to ship classification, collecting data on idle time and cargo handling time for ships in each class, thus disaggregating the model. A comparative simulated study of the performance of Calcutta with that of another competing port may give useful insight into the problem. In the model that has been considered, only the ship-port interface has been taken into account. The inland transportation network, the storage and routing of cargo, and the impact of the hinterland's economy lie beyond the scope of the model. These may be important investigations leading to more meaningful answers. A cost-benefit study of the improvement measures suggested and their impact on the revenue generating capacity of the port would be a useful exercise. Moreover, the price measures can be disaggregated further. As different ship classes carry different types of cargo and as prices and handling rates are cargo specific, such an analysis will enable the authorities with more concrete suggestions as to which prices are relatively better candidates for a raise. Finally, the demand equations can be expanded by incorporating other variables such as prices and performances of other ports in the neighbouring geographical regions and the level of economic activity in the hinterland.

# BIBLIOGRAPHY

Adkins, G. and Pooch, U.W. (1977). 'Computer Simulation: A Tutorial.' *Computer,* 10(4): 12-17.

Adler, A.H. (1987). *Economic Appraisal of Transport Projects: A Manual with Case Studies.* Baltimore: The Johns Hopkins University Press.

Asian Development Bank (1988). *Ports and Shipping Sector Study - India.* Inception Report. New Delhi. December.

Atkinson, J.B. (1996) 'A Note on a Queueing Optimization Problem.' *Journal of Operational Research Society*, 47(3): 463-467.

Balmer, D.W. and Ray, J.P. (1986). 'CASM - The Right Environment for Simulation.' *Journal of the Operational Research Society,* 37(5): 443-452.

Bombay Port Trust (1950 - 1994). *Administrative Report.* Various issues. Bombay.

Branch, A.E. (1986). *Elements of Port Operation and Management.* London: Chapman.

Bratley, P., Bennet, L.F. and Linus, E.S. (1987). *A Guide to Simulation* (2nd edn). New York: Springer-Verlag.

Breiman, L. (1973). *Statistics: With a View Toward Application.* Boston: Houghton Mifflin.

Calcutta Port Trust (1950-1996). *Administrative Report.* Various issues. Calcutta.

Cellier, F.E. (ed.) (1982). *Progress in Modelling and Simulation.* London: Academic Press.

Central Inland Water Transport Corporation Ltd (CIWTC). (1990). *Feasibility Study: Ship Repair Complex at Haldia.* Occasional Paper. Calcutta: CIWTC.

Chakrabarty, S. (1976). *A Functional Aspect of Optimum Utilisation.* Occasional Paper. Calcutta: Calcutta Port Trust.

Chappell, D. (1990). 'Provision of Optimal Cargo-Handling Facilities at Berth.' *Maritime Policy and Management,* 17(2): 99-106.

Chaudhuri, S. (1988).'An Alternative to Calcutta Port.' Unpublished paper. Indian Institute of Port Management.

Crook, G.C. (1980). 'Queueing Theory Data for Port Planning.' *Journal of Dock and Harbour Authority,* 60(713): 405-411.

De Vany A. and Saving, T.R. (1980). 'Competition and Highway Pricing for Stochastic Traffic.' *The Journal of Business,* 53(1): 45-60.

______ . (1977). 'Product Quality, Uncertainty, and Regulation: The Trucking Industry.' *American Economic Review,* 67(4): 583-594.

Economic Social Commission For Asia and the Pacific (1993). *Maritime Policy Planning Model POSIM.* ST/ESCAP/1345. New York: United Nations.

Edelson, N.M. and Hildenbrand, K. (1975). 'Congestion Tolls for Poisson Queueing Processes.' *Econometrica,* 43: 81-92.

Edmon, E.D. (1975). Operating Capacity of Container Berths for Scheduled Services by Queue Theory, *Docks and Harbour Authority,* November.

El Sheikh, A.A.R., Paul, R.J., Harding, A.S. and Balmer, D.W. (1987). 'A Microcomputer-Based Simulation Study of a Port.' *Journal of Operational Research Society,* 38(8): 673-681.

Fisher, F.M. (1965). *The Identification Problem in Econometrics.* New York: McGraw-Hill.

Fishman, G.S. and Kiviat, P.J. (1968). 'The Statistics of Discrete Event Simulation.' *Simulation,* 10: 185-195.

Frankel, E.G. (1974). *Port Design and Analysis Methodology.* Department of Ocean Engineering, Massachusetts Institute of Technology. Cambridge, Mass: MIT Press.

______ . (1987). *Port Planning and Development.* New York: John Wiley.

Fuller, S., Puimsomboon, P., Paggi, M. and Phillips, D. (1983). 'Modeling an Intermodal Transfer System: The Case of Export Grain Terminals.' *The Logistics and Transportation Review*, 19(3): 195-210.

Gordon, G. (1978). *System Simulation* (2nd edn), Englewood Cliffs, N.J.: Prentice Hall.

Graybeal, W.J. and Pooch, U.W. (1980). *Simulation Principles and Methods.* Cambridge: Winthorp Publishers.

Greenberg, E. and Webster, C.E. (1983). *Advanced Econometrics: Bridge to the Current Literature.* New York: Wiley.

Greene, W.H. (1995). *LIMDEP Version 7.0 User's Manual.* Econometric Software Inc.

Griffiths, J.D. (1976). 'Unloading Facilities at an Iron-Ore Terminal.' *Maritime Studies and Management,* 3(4): 237-242.

Guimares, R.C. and Kingsman, B.G. (1989).'Simulation-Optimisation: The Method and its Application in the Analysis of Grain Terminal Operations.' *European Journal of Operational Research,* 41: 44-53.

Hansen, J.B. (1972). 'Optimising Ports Through Computer Simulation: Sensitivity Analysis of Pertinent Parameters.' *Operational Research Quarterly,* 23(4): 519-530.

Hassin, R. (1995). 'Decentralized Regulation of a Queue.' *Management Science,* 41(1): 163-173.

______ . (1986). 'Consumer Information in Markets with Random Product Quality: The Case of Queues and Baulking.' *Econometrica,* (54): 1185-1195.

Haviv, M. (1991). 'Stable Strategies for Processor Sharing Systems.' *European Journal of Operations Research,* (52): 103-106.

Hayuth, Y., Pollatschek, M.A. and Roll, Y. (1994). 'Building a Port Simulator.' *Simulation,* Sept.: 179-189.

Hoggatt, A.C. and Balderston, F.E. (1963). *Symposium on Simulation Models: Methodology and Applications to the Behavioral Sciences.* Cincinnati, Ohio: South-Western Publishing Company.

Hwang, C.C. (1978). *Analysis of Container Port Through System Simulation*, PhD Thesis, North Carolina State University.

International Bank for Reconstruction and Development (1974). *PORTSIM User's Manual.* December, Washington.

Instrument Society of America (1987). *Modeling and Simulation,* 18 (1,2).

Japan International Cooperation Agency (JICA). (1989). *The Comprehensive Study on the Development of Calcutta and Haldia Dock Systems of the Calcutta Port Trust in India.* Report submitted to Calcutta Port Trust, July.

Johnston. J, (1984). *Econometric Methods*, 3rd edn. New York: McGraw Hill.

Lal, D. (1977). 'Distributional Weights, Shadow Wages and the Accounting Rate of Interest: Estimates for India.' *Indian Economic Review,* 12(2): 99-131.

Law, A.M. (1993). 'A Forum on Crucial Issues in Simulation Modeling.' *Industrial Engineering,* 25(5): 32-36.

Law, A.M. and Kelton, W.D. (1991). *Simulation Modeling and Analysis.* New York: Mcgraw Hill.

Lawless, J.F. (1982). *Statistical Models and Methods for Lifetime Data.* New York: Wiley Series in Probability and Mathematical Statistics.

Layard, R. (ed.) (1972). *Cost Benefit Analysis*. Middlesex: Penguin Books.

Little, I.M.D. and Mirrlees, J.A. (1968). *Manual of Industrial Project Analysis in Developing Countries*, Vol. II. Paris: OECD.

Madras Port Trust (1950 - 1994). *Administrative Report*. Various issues, Madras.

MASER (1985). *Report on Port User's Opinion Survey*. Calcutta.

Mistry, R. (1980). *Piloting the River Hooghly*. Hydraulic Study Department Occasional Paper. Calcutta: Calcutta Port Trust.

Mukherjee, N. (1968). *The Port of Calcutta: A Short History*. Calcutta: The Commissioners for the Port of Calcutta.

Naor, P. (1969). 'The Regulation of Queue Size by Levying Tolls.' *Econometrica*, (31): 15-24.

National Institute of Port Management (NIPM) (1992). *Port Management and Operations Course, 1992: Case Study, Calcutta Port Trust*. Madras.

Naylor, T. H. (1971). *Computer Simulation Experiments with Models of Economic Systems*. New York: John Wiley and Sons.

Naylor, T.H. and Finger, J.M. (1967). 'Verification of Computer Simulation Models.' *Management Science*, 14: 92-101.

Neelamkavil, F. (1987). *Computer Simulation and Modelling*. Chichester: John Wiley and Sons.

Nehrling, B.C. (1970). *Container Ship Loading and Unloading Simulation*. Working Paper, April, Dept. of Naval Architecture and Marine Engineering, Michigan. University of Michigan.

O'Reilly, J.J. (1990). *SLAM II Quick Reference Manual.* Indianapolis: Pritsker Corporation.

Otimong, S. (1983). *Quantitative Approach to Model Port Shipping Operations with Respect to Dar-Es-Salam Port.* M.Sc. Thesis, Cardiff: University of Wales.

Park, C.S. and Noh, Y.D. (1987). 'An Interactive Port Capacity Expansion Simulation Model.' *Engineering and Production Economics*, (11): 109-124.

Parsons, R. and Hill, L. (1971). *Analysis and Simulation of a Seaport.* May, 1971, Interim Report, Sea Grant Office. Cambridge, Mass: MIT Press.

Pegden, C.D. (1986). *Introduction to SIMAN.* State College, Pennsylvania: System Modelling Corporation.

Peterson, M.D., Bertsimas, D. J. and Odoni, A. R. (1995). ' Models and Algorithms for Transient Queueing Congestions at Airports.' *Management Science*, 41(8): 1279-1295.

Pierre, L. and Creton, J.M. (1973). *An Approach to the Optimal Design of a Container Terminal.* Master Thesis, Cambridge, Mass: MIT Press.

Plumlee, C.H. (1966). 'Optimum Size Seaports.' *Journal of the Waterways and Harbors Division of ASCE,* August.

Pope, J.A., Rakes, T.R., Rees, L.P. and Crouch, I.W.M. (1995). 'A Network Simulation of High Congestion Road Traffic Flows in Cities with Marine Container Terminals.' *Journal of Operational Research Society,* 46: 1090-1101.

Pritsker, A. and Alan, B. (1986). *Introduction to Simulation and SLAM II.* New York: John Wiley and Sons.

Pritsker, A., Alan, B and Sigal, C.E. (1983). *Management Decision Making : A Network Simulation Approach* . Englewood Cliffs, New Jersey: Prentice-Hall.

Raman, H. and Ramakumar, G. (1988). 'Simulation Model for Analysis of Waiting Time of Ships and Berth Occupancy in Ports.' *Journal of the Institution of Engineers ( India ),* 68(May): 35-40.

Ray, A. (1993). *Maritime India: Ports and Shipping.* Calcutta: Pearl Publishers.

Render, B. and Stair, M.Jr. (1994). *Quantitative Analysis for Management* (5th edn). Boston: Allyn and Bacon.

Roberts, N., Andersen, D., Deal, R., Garet, M. and Shaffer, W. (1983). *Introduction to Computer Simulation.* Reading, Massachusetts: Addison-Wesley Publishing Company.

Sau, S. (1980). *Economics of Haldia Port Complex.* PhD Thesis, Department of Economics, Faculty of Arts Calcutta University, Calcutta.

Schmidt, J.W. and Taylor, R.E. (1970). *Simulation and Analysis of Industrial Systems.* Homewood, Illinois: Richard D. Irwin.

School of Engineering and Applied Sciences (1969). *Simulation Analysis of the Port of Los Angeles, California.* Los Angeles: University of California.

Shannon, R.E. (1975). *Systems Simulation: The Art and Science.* Englewood Cliffs, N.J.: Prentice-Hall.

Sheikh, A.R., Paul, R.J., Harding, A.S. and Balmer, D.W. (1987). 'A Microcomputer Based Simulation Study of a Port.' *Journal of the Operational Research Society,* 38(8): 673-681.

Solomon, S.L. (1983). *Simulation of Waiting-Line Systems.* Englewood Cliffs, New Jersey: Prentice-Hall.

Stewart. W, and Donno, L. (1981). 'Simulation Modeling Improves Operations, Planning and Productivity of Fast Food Restaurants.' *Interfaces*, 11(6): 35-47.

Sugden, R. and Williams, A. (1978). *The Principles of Practical Cost-Benefit Analysis.* Oxford: Oxford University Press.

Sugrue, P.K. and Baker, E.K. (1984) 'Experience With Microcomputer Models Developed for a Caribbean Tanker Company.' *The Logistics and Transportation Review*, 20(4): 427-441.

Tugcu, S. (1993). 'A Simulation Study on the Determination of the Best Investment Plan for Istanbul Seaport.' *Journal of Operational Research Society*, 34(6): 479-487.

UNCTAD (1969). *Development of Ports - Improvement of Port Operations and Connected Facility*. TD/B/c4/42/Rev. 1. New York: United Nations.

____. (1973). *Berth Throughput - Systematic Methods for Improving General Cargo Operations*. TD/B/04/109. New York: United Nations.

Uspensky, J.V. (1948). *Theory of Equations*, McGraw-Hill, New York.

Van Ackere, A. and Ninios, P.(1993). 'Simulation and Queueing Theory Applied to a Single-Server Queue with Advertising and Baulking.' *Journal of Operational Research Society*, 44(3): 407-414.

Van Hee K.M., Huitinik, B. and Leegwater, D.K.(1988). 'PORTPLAN, Decision Support System for Port Terminals.' *European Journal of Operational Research*, 34: 249-261.

Vishakhapatnam Port Trust (1950-1994). *Administrative Report*. Various issues, Vishakhapatnam.

Waikar, A. and Pattanaik, M. (1992). 'Knowledge - Based Approach to Simulation Model Validation.' *Computers and Industrial Engineering*, 23(1-4): 245-248.

Working, E.J. (1927). 'What Do Statistical Demand Curves Show?' *Quarterly Journal of Economics*. February.

World Bank (1974). *PORTSIM User's Manual*, Washington DC: The World Bank.

____. (1982). *Staff Appraisal Report: Bangladesh, Chittagong Port Project*. Report No. 3666-BD. Washington DC: The World Bank.

____. (1983). *Staff Appraisal Report: Burma, Third Port Project.* Report No. 4339-BA. Washington DC: The World Bank.

____. (1984) *Staff Appraisal Report: India, Nhava Sheva Port Project.* Report No. 4826-IN. Washington DC: The World Bank.

____. (1995) *India Port Sector: Strategy Report.* Report No. 14059-IN. Washington DC: The World Bank.

____. (1995) *India Transport Sector: Long Term Issues.* Report No. 13192-IN. Washington DC: The World Bank.