Study of Port Activities and Ship Scheduling Problem at Haldia Dock Complex

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By

Ujjwal Kumar

(06IM3016)

Under the Guidance of

Prof. P.K. Ray

Department of Industrial Engineering & Management
Indian Institute of Technology, Kharagpur, India
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Declaration

I hereby declare that the entire work embodied in this dissertation has been carried out by me and no part of it has been submitted for any degree or diploma of any institution previously.

Name: Ujjwal Kumar

Place: IIT Kharagpur, India

Date: 2nd May, 2011

Certificate

This is to certify that the project report entitled: "**Study of Port Activities and Ship Scheduling Problem at Haldia Dock Complex**" submitted by Mr. Ujjwal Kumar in partial fulfilment of the requirements for the award of the degree of Master of Technology (M.Tech.) in Industrial Engineering and Management, Indian Institute of Technology, Kharagpur is a bonafide record of the work carried out at Department of Industrial Engineering and Management, Indian Institute of Technology Kharagpur, India from 20th July, 2010 to till date under my supervision and guidance.

Name: **Prof. P.K. Ray**
Designation: Professor, IEM, IIT Kharagpur
Date: 2nd May, 2011

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Abstract

The surface of the earth is roughly composed of 70% water and 30% land. This is one of the essential reasons for large quantities of goods to be transported successively both by land and by water in their journey from origin to destination each year. Goods transfer from land transportation, mainly railways and roads, to waterways or vice versa is unavoidable and of growing importance nowadays. The transportation through waterways is an important area of study. This dissertation deals with port activities and ship scheduling at Haldia Dock Complex.

One of the main concerns of the Haldia Dock Complex is the scheduling of ships. More ships can be operated in a lesser time with better scheduling of ships. This increases the capacity of a port. Moreover, as shipping requires a huge monetary investment (to the tune of multi-million rupees in most cases) and the daily operating costs of a ship may be in the order of millions of rupees. With better scheduling, the ships remain at the docks for a lesser time, and sail for a longer time, thereby increasing their value over time.

In the project work, a study has been made on the ship scheduling at the Haldia Dock Complex, Haldia, West Bengal. Our focus is to study the port activities at Haldia, identify the factors affecting ship scheduling at Haldia, and then develop a heuristic to minimize the total time required to operate all ships.

Keywords: *integer linear programming problem, berth allocation, search heuristic, port management*

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Chapter 1: Introduction

1.1 Introduction

There are more than 2000 ports around the world, ranging from single berth location handling a few hundred tons to multipurpose facilities handling up to 300 million tons a year. The world port traffic is made up of 36% of liquid bulk products (mainly oil, petroleum products and chemicals), of 24% of dry bulk goods (coal, iron ore, grain, bauxite, and phosphate), and of 40% of general cargo. Containers are large metal boxes made in standard dimensions and measured in multiples of twenty feet, called “twenty foot equivalent units” (TEUs). In 2003 the production of containers reached two million TEUs, with China being responsible for more than 90 percent of the output. Containers possess several advantages: they require less product packaging, they help reducing damage, and they yield higher productivity during the various handling phases. Moreover, containers allow for inter-modal transportation because transhipment between ships, trucks or trains is easily performed. The world container port throughput for 2002 reached 266.3 million TEUs, an increase of 22.5 million TEUs from the level of 243.8 million TEUs reached in 2001.

1.2 History of Haldia Dock Complex (HDC)

HDC is a part of the Kolkata Port Trust. A plan to complement the Kolkata Port was initiated in 1950s. During the 1950s, the search was on for a suitable location of a port down the river Hooghly near the estuary which would not have the problem of navigability and would provide adequate draft for big vessels. Of the different possible sites, Geonkhali, 60km southward from Calcutta, was a serious contender. It had 26ft draft all-round the year. It could allow vessels longer than 530ft which was the longest allowed in Calcutta. It was free from bore tides which afflicted Calcutta. But, it had a serious constraint, being situated north of Balari, it was a serious handicap for passage of big ships. And hence Haldia, nearer the sea, 104km from Calcutta, which did not suffer from these constraints was selected. It was on the western bank of the river which would provide easy railway and roadway connection, without intervention of the river, with the major portions of the port's hinterland which were also the major centres of mining of coal and ore, including iron and manganese. Indian ores had lucrative export markets. A modern port was required as outlet providing facilities for large ore carriers. Similarly, increasing oil import through large oil carriers necessitated a modern and deep drafted oil jetty. Haldia was tried as an anchorage for cargo operation in the fair season for 1959-60. The anchorage was found suitable for deep drafted vessels.

1.2.1 Haldia Project: Appraisal

The Haldia project report was prepared by the port's consultant, Rendell Palmer Tritton (RPT) of UK in 1959. Haldia had draft of 30ft for all the days, 32 ft for 238 days and 35ft for 39 days in a year. It was expected that with dredging and river training works, the draft would increase and by 1985, vessels upto 80,000 DWT would be able to come to Haldia. The navigational channel from Sandhead to Haldia was straight and hence unlike Calcutta, Haldia could take vessels of any length and beam. There were only two sand bars below Haldia – Auckland and Middleton.

The project envisaged a trident type dock system with two lock entrances and three arms radiating from the turning basin providing for 47 commercial berths. Two river side oil jetties and two dry docks were also conceived.

The outline of Haldia project was cleared by international experts. These included Posthuma, DG of Rotterdam Port, who advised the Government of India on port development of the country. The river regime was examined by Jansen, a Dutch hydraulic expert. The harbour engineering aspect was looked into by Larras, a French harbour engineer of international repute.

The International Bank of Reconstruction and Development (IBRD), Washington which was approached in 1960 for financial assistance for the Haldia project wanted further investigations and preparation of a complete Master Plan. Accordingly further studies were made by experts of London Port and Master Plan for the project was prepared by RPT. In 1963, World Bank was approached for a loan to cover the foreign exchange component for the proposal. Accordingly, a team was set up to assess traffic potential and examine financial viability of the project. The team headed by V.G. Bhatia, Director of Transport Research in The Ministry of Transport, submitted its report in 1965.

1.2.2 Haldia Project: Projections

The team felt that in 1970-71 when the project was likely to be operational, the total traffic at Haldia would be 14 MT and at Calcutta 6 MT making a total of 20 MT for the port as a whole. This would consist of 3.5 MT of crude and 0.3 MT of petroleum products, 1.5 MT of fertilizer raw material, 2 MT of food grains, 3 MT of iron ore, 3 MT of coal, 0.2 MT of salt and 0.5 MT of general cargo.

The traffic projection for 1975-76 was 21 MT at Haldia and 8 MT at Calcutta making a total of 29 MT for the port. The berth requirement for Haldia in 1975 – 76 was assessed at 16, including 8 GC berths to handle 1.5 MT of general cargo. The projection was 5 MT each for POL, coal and iron ore and 2 MT each for food grains and fertilizer raw materials, and 1 MT of salt.

The team recommended construction of 8 berths, POL, fertilizer raw material, food grains, coal and iron would require 5 berths – one for each commodity and three for general cargo.

The cost of the project was estimated at Rs. 40 crores with foreign exchange component of Rs. 14 crores. The total cost including renewals of facilities, etc., would come to Rs. 65 crores and the annual revenue return would be Rs. 37 crores.

The team felt that “new port facilities at Haldia should be considered as an integral part of the Calcutta Port along with the older facilities, such as Calcutta Jetties, Kidderpore Docks, K.G. Docks, Budge Budge Oil Jetties for the purpose of financial assessment of the port as a whole, though, of course, to the extent that is possible, all major operations should cover their costs.”

They also recommended that, “as the heavy burden of dredging and river maintenance is not a proper charge on the port, the idea of the Government taking over this expenditure, or a major part of it, should be examined.”

It was felt that industries, fishing harbour, free trade zone, etc., will develop at Haldia and it would develop into “an urban centre strong enough to act as counter-magnet to Calcutta and to attract the abundant rural population in eastern India in their search for employment.”

1.2.3 Haldia Project: First phase of construction

The proposal for construction of the Haldia Dock at cost of Rs. 40 crores with foreign exchange component of Rs. 7 crores was approved by the Commissioners of the Calcutta Port in their meeting held on September 26, 1966. The proposal consisted of the following components (cost in Rs. In crores shown against each): land acquisition (2), lock entrance and approach jetty with pumps and other machinery (5.5), coal, ore and phosphate berths (1.6), two general cargo berths, one heavy lift berth and one grain berth (2.95), an oil jetty with equipment and protective bundh (2.66), coal and ore loading equipment, wagon tipplers, trimmers and conveyors (3.5), cranes, forklifts and other cargo handling equipment (1.3), locomotives (1), phosphate handling equipment (0.42), tugs and other vessels (3.23), offices and workshops (2), roads and drainage (2), residential quarters (1.1), and electricity, schools, markets (1). Along with miscellaneous, supervision and contingency because of devaluation, the total estimated cost came to Rs. 40 crores. These constructions were to be done in the first phase.

1.2.4 Haldia Project: Second phase of construction

The second phase of construction was estimated to cost Rs. 15 crores. A dry dock was estimated to be constructed at a cost of Rs. 4 crores. An estuarine dredger, a suction dredger, a grab dredger and a floating crane were to be procured at a cost of Rs. 6.5 crores. The devaluation of rupee enhanced the foreign exchange requirement by Rs. 4 crores.

1.2.5 Haldia Project: Dredging issues

In the same meeting of September 26, 1966 the Commissioners approved the project of entrusting the dredging under the Haldia project to Ivan Milutinnovic – PIM who successfully dredged for the Paradip Port project. The cost of Haldia dredging contract to the company was Rs. 2.86 crores. The contract involved dredging of 1.5 mcm of spoil in front of the oil jetty, at approaches to the lock entrance and the dock basin. The dredged spoils were to be pumped into the low lying areas near the dock. The works were to start in 1966 and be completed in 1969.

Dutch dredgers were deployed from 1973 to 1975. The hire charges were fixed at Rs. 1.49 lakhs per day of dredging. Dredger Ham-308 was deployed at Auckland (an island in the Hooghly river) and Dredger Delta Bay at Middleton (another island in the Hooghly river). The proposed estimations were that a 76 million cubic metres (mcm) of dredging will give 12.2m draft for 320 days, and 30mcm of dredging would give 10.67m all year round. The Dutch dredged 50mcm till 1977, and the total cost was Rs. 26 crores. By 1978, the total dredging was 82mcm: 50mcm in Auckland, 21 in Jellingham and 11mcm in Middleton. Despite of a dredging more than the estimated values, the improvement in navigability was not commensurate. The Haldia project was designed for a draft of 12.2m, but even after dredging more than required, the draft did not increase above 9.67m. At this level, the river stopped responding to dredging efforts. Hence, dredging was continued later on, only for the maintenance of the channel.

1.3 Current Status of Haldia Dock Complex

HDC is a part of the Kolkata Port Trust. Kolkata Port is the gateway of Eastern India for the rest of the world. This is the first Major Port in India, whose appearance in the maritime map dates back to 1870 and this is the 140th year of its existence. Kolkata Port is the only riverine major port in India. Its 232 kms long navigational channel is one of the longest channels in the world. The port has two dock systems viz. Haldia Dock Complex (HDC) and Kolkata Dock System (KDS).

Haldia Dock Complex, a modern dock complex of Kolkata Port Trust, was setup in 1977 for handling larger vessels, carrying bulk cargo with optimum economy, keeping Kolkata Dock System primarily for handling break bulk cargo, container, etc. The two dock systems of Kolkata port viz. KDS and HDC are complementary to each other.

Kolkata Port has a vast hinterland, comprising the entire Eastern India including West Bengal, Bihar, Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Rajasthan, Assam, North Eastern States and the two landlocked countries viz. Nepal and Bhutan. The industrial development, commerce and trade of this vast hinterland are inseparably linked to the life and development of Kolkata Port and vice-versa.

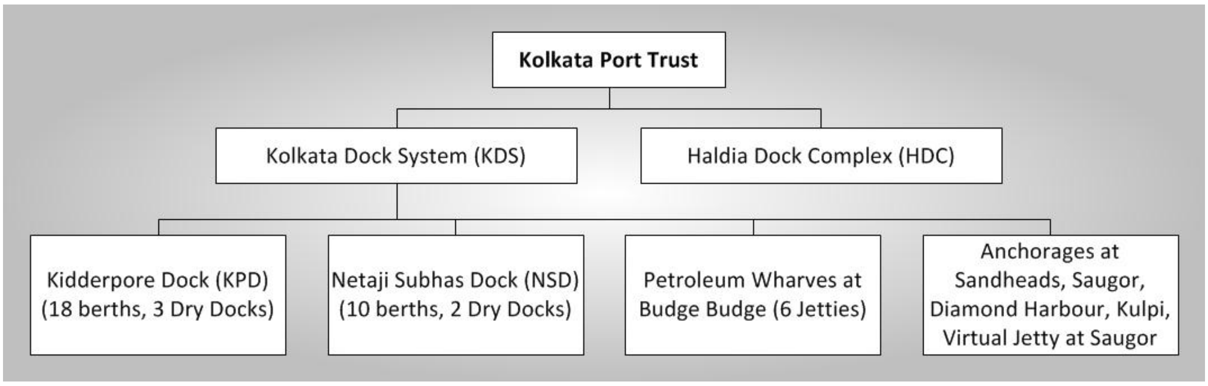

Fig 1.1: Organizational structure of the Kolkata Port Trust

1.3.1 Organizational Structure

Fig 1.1 represents the current organizational structure of the Kolkata Port Trust.

1.3.2 Berth Particulars

The facilities at Kolkata Port are as follows:

1) Haldia Dock Complex

- Haldia Oil Jetties (HOJ) – 3 Riverine Jetties
- 2 Mechanized Berths for handling Iron Ore / Thermal Coal
- 2 Berths for handling Containers
- 10 Multipurpose Berths
- 2 Riverine Barge Jetties

2) Kolkata Dock System

Kidderpore Dock (KPD)

- 17 Multipurpose Berths (including 3 Berths for Heavy-Lift Cargo)
- 1 Berth for Passenger-cum-Cargo Vessels
- 6 Buoys / Moorings
- 3 Dry Docks

Netaji Subhas Dock (NSD)

- 4 Dedicated Container Berths
- 1 Liquid Cargo Berth
- 1 Berth for Heavy-lift Cargo
- 4 Multipurpose Berths
- 2 Buoys / Morrings
- 2 Dry Docks

Budge Budge (BB)

- 6 Petroleum Wharves

Anchorages

- Diamond Harbour
- Saugor Road
- Sandheads
- Haldia Anchorage

1.3.3 Connectivity

Kolkata Port is well-connected with national and state highways, railways and national waterways. KDS is connected with NH-6, NH-2 and NH-34 through city roads. NH-41 connects Haldia with NH-6 and rest of the country. KDS is connected to Eastern Railway through Sealdah and Budge Budge Sections. Haldia is connected to the South Eastern Railway via Panskura. Kolkata Port is connected to National Waterway No. 1 (Ganga), National Waterway No. 2 (Brahmaputra) and Waterways through Sunderbans.

1.3.4 Performance highlights for 2009-10

Following are the performance highlights of the Kolkata Port for the financial year 2009-2010.

- Kolkata Port handled 46.423 million tonnes of traffic in 2009-2010. During the last eight-year period, from 2000-2001 to 2008-2009, Kolkata Port increased its cargo volumes by 24.22 million tonnes (80.73%). However, traffic decreased in 2009-2010 owing to decrease in POL crude.
- Container traffic at Kolkata Port crossed the 5 lakh TEU mark during 2009-2010. The number of containers handled by Kolkata Port during 2009-2010 increased to 5,01,622 TEUs from 4,29,417 TEUs in 2008-2009 registering a growth of 16.82% , which was the highest growth among all Indian Major Ports.
- Kolkata Port ranked Third amongst Indian Major Ports in terms of Container handling.
- KoPT ranked second in terms of volume of Coking Coal traffic handled amongst all Indian Major Ports. KoPT registered Second highest growth in Coking Coal traffic amongst Major Ports of India.
- Number of vessels handled at Kolkata Port during 2009-2010 was the highest amongst all Indian Major Ports. KoPT handled 17% of the total number of

vessels, which worked at Indian Major Ports in 2009-2010. 3510 vessels called at KoPT in 2009-2010 against 3494 vessels in 2008-2009.

- During 2009-10, high growths were registered at KoPT as compared to 2008-09 in respect of LPG, Vegetable Oil, Pulse, Log, Steel, Manganese Ore, Other Coal/Coke, Fly Ash, Sugar, Other General Cargo, IVW/IW Traffic, etc.
- In 2009-10, Kolkata Port incurred expenditure of Rs. 54.47 crores against an outlay of Rs. 58.91 crores, registering a high of 92.46% utilization of plan outlay.

1.3.5 Traffic handled at Kolkata Port

Table 1.1 summarizes the traffic handled at Kolkata Port from year 2005-2010.

Year	KDS	HDC	Total
2005-06	10.806	42.337	53.143
2006-07	12.596	42.454	55.050
2007-08	13.741	43.588	57.329
2008-09	12.428	41.792	54.220
2009-10	13.045	33.378	46.423

Table 1.1 a) Cargo Traffic (values in million tonnes)

Year	KDS	HDC	Total
2005-06	203481	110319	313800
2006-07	239432	109638	349069
2007-08	297287	128118	425405
2008-09	302169	127248	429417
2009-10	377510	124112	501622

Table 1.1 b) Container Traffic (values in TEUs)

1.3.6 Dry dock facilities

Kolkata port has five dry docks inside the impounded dock system to cater to the diverse repair and maintenance need of the vessels. The dry docks can serve vessels of dimensions as given below.

Dry Dock	Maximum Sizes of Vessels
N.S. Dry Dock No. 1 & 2	172.21m X 22.86m
K.P. Dry Dock No. 1	160.02m X 19.5m
K.P. Dry Dock No. 2	142.95m X 19.5m
K.P. Dry Dock No. 3	102.1m X 14.63m

Table 1.2: Dry dock facilities in the Kolkata Port Trust

In recent years, the ship repair facilities at the dry docks have been upgraded with modern equipment. The port has also rationalized its dry dock charges, making it an attractive destination for quality repair at competitive cost.

1.4 Ship Scheduling

Ship scheduling refers to the process of allocation of berths to ships, as well as determining the sailing schedules of all ships. With better scheduling, more ships can be operated in lesser time, which in turn increases the capacity of the port. Increased capacity leads to increase in revenue, and greater fulfilment of hinterland demand. Also, a ship requires crores of rupees of capital investment, and the daily operating costs of a ship can be in lakhs of rupees. With better scheduling, ships remain on the dock for a lesser time, and sail for a longer time, thereby increasing their value. Usually, we distinguish between three general modes of operation in shipping: *industrial, tramp,* and *liner* (Lawrence 1972). In industrial shipping, the cargo owner or shipper also controls the ships. Industrial operators try to ship all their cargoes at minimal cost. Tramp ships follow the available cargoes, like a taxi. A tramp shipping company may have a certain amount of contract cargoes that it is committed to carry, and tries to maximize the profit from optional cargoes. Liners operate according to a published itinerary and schedule similar to a bus line. These three modes are not mutually exclusive. A ship may be easily transferred from one mode to another, and a shipping company may simultaneously operate its fleet in different modes.

A satellite view of the Haldia Dock Complex to understand the riverine nature of the port is shown in figure 1.3.

Fig 1.2: Satellite view of HDC

1.4.1 Turn round time of ships

Turn round time is the total time needed for loading, unloading, and servicing a ship. It includes the idle time the ship may have to face while waiting for a berth or waiting for equipment for servicing. Sandhead is the place in Hooghly river that opens to the Bay of Bengal. In the context of HDC, the turn round time is the total time taken by a ship to sail from Sandhead, get serviced, come back and leave from Sandhead.

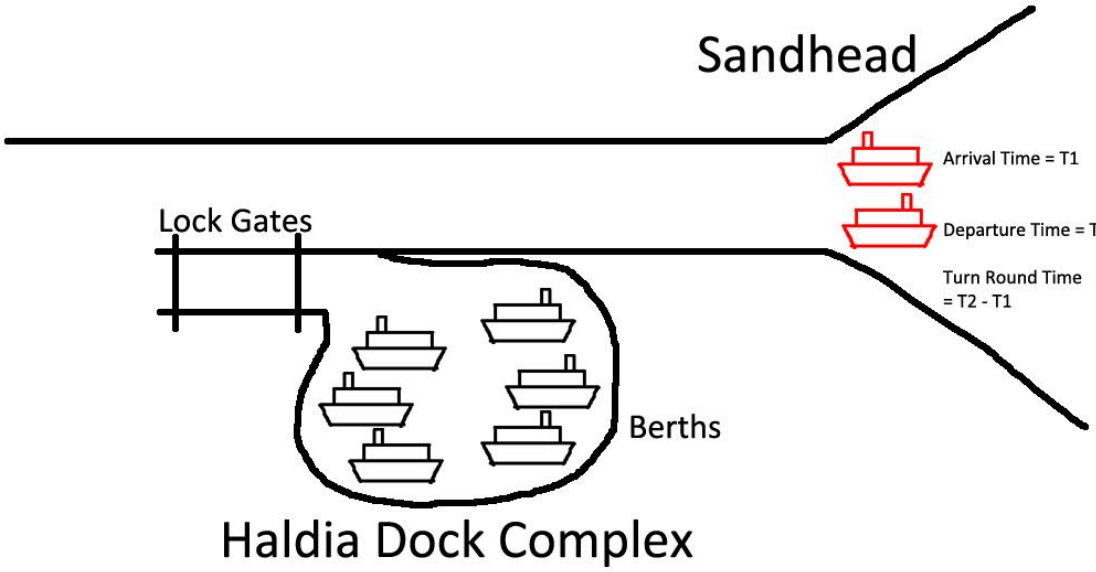

Fig 1.3: Depiction of HDC and turn round time.

1.5 Problems in ship scheduling at HDC

The problems in ship scheduling are:

i) Since it is a riverine port, it has to wait for tides for ship to enter.

ii) Lock gates can be operated for a specific frequency only, if they are operated for more number of times, it may become dysfunctional, and the whole port may be shut down.

iii) There are very few multipurpose berths at Haldia, most of them can handle only one type of cargo on them. This requires specific ships to be scheduled at specific berths only. This may lead to a huge queue on a specific berth if its demand is high.

iv) Availability of different equipment (like cranes, forklifts, etc) and tugboats to guide ships in the berth.

1.6 Objectives Project Work

The objectives of the project work are:

i) Study the port activities at Haldia Dock complex

ii) Identify the factors that affect ship scheduling

iii) Develop a model to formulate the ship scheduling problem, and find an algorithm to solve this problem

1.7 Outline of the report

This thesis is organized as follows: Chapter 2 presents the Review of Literature on the topic. Chapter 3 states the problem description. The following chapter 5, provides with the solution methodology to be. In chapter 6, we provide insights on the results obtained. Finally, we draw conclusions from the proposed works and provide some directions for future studies in chapter 7.

*Chapter 1:*This is the introductory chapter of the thesis. In this chapter, we introduce the port activities at Haldia. We also discuss the history of the HDC. Current status of HDC is also presented in this chapter. Finally, we end this chapter by discussing about ship scheduling, and objectives of the thesis.

Chapter 2: In this chapter, we perform the literature review. A compilation of earlier works on ship scheduling is presented in this chapter. We also compare various existing models of ship scheduling, and their relevance with Haldia Dock complex.

Chapter 3: In this chapter, we describe the problem and its mathematical formulation. We look for various factors affecting ship scheduling and also the local factors at Haldia that need to be considered for ship scheduling. We have also developed a mathematical formulation of the problem.

Chapter 4: In this chapter, we propose a search heuristic to minimize the total scheduling times of all ships. An example is also presented for the usage of the heuristic.

Chapter 5: In this chapter, we provide discuss the results.

Chapter 6: In this chapter, we provide with necessary recommendations and the scope for further work on the subject. We also identify 3 specific areas of improvement at HDC. We then provide alternatives to these areas, and feasibility of the alternatives.

This dissertation ends with the list of references.

Chapter 2: Review of Literature

2.1 Introduction

A port is a miniature model of the overall transportation network. It has access systems on the land and the water sides, which have channels, traffic lanes, intersections, and flow control of vehicle guidance systems. It has a berthing system that, on a gross scale, behaves just like many other multi-channel bottlenecks. Because of these, the port may become crowded or unused depending on the traffic condition.

Between the land and waterside berths, the port also has a cargo-handling system that involves crane and other sorts of specialized equipment (e.g. forklift trucks, conveyor belts, pipes, etc.) and manpower.

The major components of ship scheduling are the waiting time before berth allocation, and handling time by different equipment.

2.2 Berth allocation of ships

The task of berth usage scheduling determines the berthing time and position of every calling ship. The way ships are assigned to berthing positions can be either discrete or continuous. In the discrete method, the entire quay is partitioned into several berths, and allocations of ships are based on the berths. In the continuous method, the ship’s berthing is performed in a continuous location space. In this study we address the berth scheduling problem in the continuous sense. Due to practical considerations, ships cannot be assigned to any available quay space. In contrast, each ship has several preferred sections depending on the nature of cargo as well as storage/handling facility. The length of each preferred section is typically around one to three times the length of the ship, but they can differ from ship to ship and from location to location. Since the cost of loading/unloading, as well as the length of the working time, at different locations can be different, ships have different priorities for their preferred sections. There is also a maximum waiting time for each preferred section of each ship, which is the maximum amount of time the ship is willing to wait for that section. The maximum waiting time for the least preferred section is set to a large number to ensure that every ship can be berthed properly. Since each ship manager defines his own preferred sections independently, those of different ships are not related and frequently overlap with each other. We also assume that each arriving ship has an estimated time of arrival (ETA), which can vary from ship to ship.

Many factors affect berth scheduling in practice, including the ETA, the ship length, and required water depth. First-come-first-served is one of the most important rules. However, in practice this rule is sometimes negotiable if mutual agreement can be reached in the meeting. This typically happens when swapping the berthing order of two ships significantly benefits the later ship at a small cost to the earlier ship. When two ships have very different preferences (and thus there is no competition for berthing space), this rule is not important either. The nature of cargo is also an important factor because it determines the required loading/unloading equipment and the locations of corresponding storage facilities. The physical relationship between a ship’s berth location and its storage facility, as well as the available equipment at that location, can also affect the ship’s handling time. When the terminal is busy, the port authority can shift in-port ships to another location to enable another incoming ship to berth. However, as a tradition, shifting cannot happen in the first or last 4 hours of berthing, nor can a ship be shifted for more than 100 m. Shifting of a ship may or may not increase its berthing time. There are also situations where shifting is impossible, for example, when the ship at berth is connected to pipelines that limit its flexibility to shift. It is also required that the same ship cannot be shifted more than once. Finally, a ship cannot be shifted to a location outside its preferred sections.

The berth is the most critical resource for determining the capacity of container terminals because the cost of constructing a berth is very high compared to the investment costs for the other facilities in the terminal. An alternative way of increasing the capacity of the berth is to improve the productivity of the berth by utilizing it efficiently. Planners in container terminals usually construct a berth schedule, which shows the berthing position and the arrival time of each vessel. To construct a berth schedule, the calling schedule of vessels, favourable berthing location of vessels, and the number of available handling equipment must be considered simultaneously.

Lai and Shih (1992) studied the problem of assigning one of the discrete segments of a berth to vessels and suggested several simple rules for the assignment. By considering various practical constraints, Brown et al. (1995) formulated an integer programming model for assigning available sections of a berth to vessels. They also assumed a berth to be a collection of discrete berthing sections. Lim (1998) considered a berth to be a continuous line rather than a collection of discrete segments and discussed how to minimize the sum of the lengths of vessels that are supposed to berth at the same time by optimally locating the berthing positions. Li et al Li et al. (1998) considered the Berth-scheduling problem to be a scheduling problem for a single processor (Berth) that can simultaneously perform multiple jobs (vessels). They suggested various algorithms based on First-Fit-Decreasing (FFD) heuristics and tested the algorithms by a simulation study. Imai et al. (2001) also assumed a Berth to be a collection of discrete Berthing sections. They attempted to minimize the waiting time of vessels and provided a mixed-integer programming model for allocating Berthing sections to vessels. They also provided a heuristic procedure based on the Lagrangean relaxation of the original problem. Also, Nishimura et al. (2001) suggested genetic algorithms to solve the problem suggested by Imai et al. (2001) with a small computational effort.

2.3 Handling times of ships

Different commodities require very different treatments at a port. Because of this, and despite the appeal of multipurpose terminals, most ports segregate cargos by type onto specialized terminals: many large ports have break-bulk, container, and dry and liquid bulk terminals. Other terminal types also exist.

Break-bulk cargo (consisting of relatively small items or irregular shapes) can be handled by ship derricks or shore cranes; the ships are typically divided longitudinally into holds that open to the deck through a hatch.

Containerized cargo, being unitized into larger units, can be loaded and unloaded with many fewer moves (specialized containers exist for liquids, lumber, items that need to be refrigerated, etc.).

Queuing theory concerns itself with these kinds of problems, where one could visualize the ship as customers and the equipment as servers. In this context one would be interested in queue disciplines that would maximize the throughput and minimize delay. Formulas to predict these measures would also be desirable.

Existing queuing models do not reflect equipment usage properly; most queuing models do not allow customers (ships) to spread themselves among servers (cranes).

For the static case, where a finite number of ships have to be processed with minimum cost, the problem also seems related to the machine scheduling field (Johnson, 1954). The goal is to finish the jobs quickly, so as to reduce their time in the shop (berth). Although simple solutions to this problem exist (McNaughton, 1959), the situation at ports is not always that simple.

2.4 Existing models

There are a number of existing models that address the ship scheduling problems. They are based on rule of thumb, queuing theory, flow networks – GERT, simulation and layout algorithms – CRAFT. Advantages and disadvantages of each model is presented in Table 1.1.

Rule of thumb	
Advantages	**Disadvantages**
• Quick • Solution likely to be feasible • Easy to justify • Coordination of different groups easier	• Requires very experienced personnel • System likely to be over designed and expensive • Possibility (remote) that system is under designed and will not work

Queuing Theory	
Advantages	**Disadvantages**
• Simple • Easy Computation • Easy parametric variation • Easy to explain and visualize	• Limited set of solutions • Restrictive, sometimes unrealistic assumptions • Complicated systems must be separated into components losing some of the systematic interactions

Flow Networks - GERT	
Advantages	**Disadvantages**
• Complicated systems easy to model • Easy parametric evaluation • Hand solution possible • Applicable to continuous systems	• Complicated systems require computer to solve • Large data analysis required • will not work

Simulation	
Advantages	**Disadvantages**
• Easy to explain and understand • Most features of system can be modeled to detail required • Easy parametric evaluation	• Requires computer • Large fraction of effort devoted to developing computer programs, less to studying the problem • Random variable component in answer (results are frequently not repeatable)

Layout Algorithms - CRAFT	
Advantages	**Disadvantages**
• Considers many alternatives • Forces selection of objective evaluation criteria	• Considers few factors • Simple relations between factors

Table 2.1: Advantages and disadvantages of using various models for ship scheduling.

2.5 Comparison of the existing models vis-à-vis HDC

For the given models, we find that, all of these models are developed for seaports, i.e. the ports that are situated at sea coasts. But, the port at Haldia is a riverine port, and it has a big component of waiting time at Sandhead because of the tides and lock gates. Most of the above techniques are deterministic in nature. But, since the ship scheduling problem is an NP-hard problem, the above techniques would take a long time and consume a lot of computer resources to give the optimal result. So, we go for a search heuristic, which tries to explore for the possible results in the stipulated time.

2.6 Conclusions

The review of the literature as carried out helps in identification of some potential research issues pertaining to the areas of optimization of turn round time of ships at a port. It is observed that although several approaches for accomplishing the above-mentioned optimization tasks have been proposed by the researchers in the existing literature, research is required from the perspective of adequately addressing a few issues, specific to the port at Haldia. We find that we need to look for a non-deterministic algorithm to solve the NP-hard problem. This heuristic will fill many gaps since most of the current scheduling at HDC is done by the rule of thumb. We would then need to collect data, and prescribe norms for assessment. We may also opt for improvement options by involving experts and concerned people in a brainstorming discussion using the Nominal Group Technique (NGT).

Chapter 3: Problem Description and Formulation

3.1 Introduction

The objective here is to develop optimal berthing locations and sailing schedules for all ships. We start this chapter by listing down the factors affecting ship scheduling, and then the local factors at Haldia Dock Complex. A lot of factors that are presented in section 3.2, like factors relating to passenger ships, are not present at HDC, because only cargo ships are operated at HDC. We then end this chapter by creating a mathematical model to represent the ship scheduling problem.

In the mathematical model, we go for a simple model, because the port being an extremely complex system involving many stakeholders, it would be very difficult to cover every aspect of ship scheduling in one model. This scheduling problem is an NP-hard problem. We have tried to solve the problem in single stage only.

3.2 Factors affecting ship scheduling

Ship scheduling is affected by the following factors:

1. The overall number of ships and their availability
2. The types of ship available, in particular their size (length, beam and draught) and any special characteristics such as the need for special equipment loading and discharging cargo. Some ships may be suitable for cruising; others, by virtue of their size may be able to operate only between ports with deep water berths. Hence, in general a large fleet of small vessels has more operational flexibility than a small fleet of large vessels restricted to a limited number of ports able to accommodate them.
3. The plying limits of individual ships, and in the case of liner tonnage, any conditions imposed by liner conference agreements. It is the practice for liner conference members to agree the sailing programme and the allocation of

berths at the ports and ship disposition having regard to surveys and market demand.

4. The volume, type and characteristics of the traffic. This requires very close analysis, and options must be examined to establish whether the service could be improved and capacity utilized more productively if the distribution method were changed. For example, the development of containerization has transformed many traditional distribution methods and thereby raised the demand for such services. In the cargo liner trade the situation should be examined in the context of combined transport.
5. Seasonal traffic fluctuations.
6. Maintenance of time margins where services connect. For instance, a passenger vessel may be served by a connecting rail service. The schedule must provide adequate time to ensure that connections are maintained and make allowance for delays caused by bad weather, service disruption or other factors. Inland surface transport is generally more flexible than sea transport; with the development of combined transport, this aspect is becoming more important.
7. The availability of crew and suitable change-over ports. A shortage of key certified personnel could delay the ship's departure; fortunately, this is a rare occurrence.
8. Arrangements for dealing with emergencies. All ship operators must lay down the procedures to be followed in the event of a service disruption, which may be classified as a major or a minor incident. Few ship-owners nowadays have standby vessels, particularly in peak periods, so that in the event of a major incident involving the withdrawal of a vessel, they may charter a replacement ship, increase the service speed of remaining vessels in the fleet and/or speed up port turnround time, divert traffic to another operator, or switch a vessel from elsewhere in the fleet. The choice made will depend on the cost, service quality, resource availability and, nor least, the expected duration of the

disruption. If it will last a few days, fairly simple measures can be introduced, such as giving urgent or perishable commodities priority over other traffic; if it will continue longer, some more extensive measures will have to be taken.

9. Climatic conditions. Some ports are ice-bound at certain times of the year, thus preventing the movement of shipping. This is particularly relevant to the St. Lawrence Seaway, Artic regions and the Baltic Sea. In recent years, the Russians have developed nuclear powered ice-breakers to keep their shipping lanes open as long as possible in winter. When a port is closed, ships will obviously sail to the nearest port and the cargo will complete its transit overland, usually by rail.
10. Competition. Liner conferences were developed to restrict competition to service quality rather than rates, which were standardized. This has greatly facilitated the elimination of under-cutting, although the fierce competition that remains in many trades tends to lead to overcapacity, with the attendant risk that operators will offer unprofitable services. In order to counter competition and generate market goodwill, ship-owners may feel obliged to provide additional services and in doing so occupy berths that could otherwise be occupied by competitors of the port.
11. General availability of port facilities and dock labor, and any tidal restrictions affecting times of access and departure. This is a critical factor which requires particular attention if a vessel is switched from one service to another involving different ports. In devising any service of a regular nature, reliability is a paramount consideration, so that it is important that the port facilities provide are adequate and reliable and that the tides do not seriously impair continuous access. As the cost of fuel continues to rise, increasing attention is being paid to reducing port turnround time in order to allow slower passages. Much can be achieved in this regard through the advance planning of transshipment arrangements and developments of the stowage plan. Many

major ship operators are using computers to determine shipboard stowage and to produce the cargo documentation.

12. Time required for terminal duties at the port. This will embrace such activities as discharging, loading, customs, bunkering (filling ship's bunker with coal or oil) and victualling (taking nourishment) and should also leave a margin to allow for reasonable
13. Any hostile activities taking place or expected along vessel's route. Hostilities tend to increase insurance rates and thereby overall voyage and freight costs. The implications of re-routing the services must be carefully examined; in many cases a diversion will be unavoidable.
14. The use of canals such as the Suez Canal and Panama Canals as alternative routes. There is a growing tendency to route services via maritime canals in order to save passage time and fuel. The canal dues have to be set against the cost of taking the longer route in terms of additional fuel consumption, longer passage time, crew costs and less favorable fleet utilization.

3.2.1 Local factors affecting ship scheduling at HDC

Haldia Dock Complex is a riverine port. There are a couple of additional considerations to be taken care of in case of a riverine port:

1. Lock gate performance and tidal time
2. Ship's draft and siltation
3. Tug boat availability

3.2.2 Lock gate performance and tidal time

Since HDC is a riverine port, the water level at berths is to be maintained using caisson lock gates. HDC is an impounded dock system. There are in total 3 lock gates, but only 2 of them are necessary at any point of time. Fig 3.1 shows the mechanism of ship entering the dock through the caisson gates.

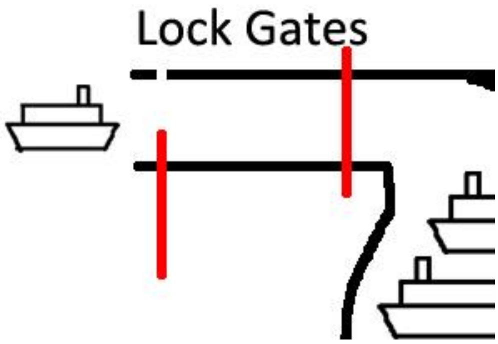

Fig 3.1 a) The first lock gate opened for the ship to enter.

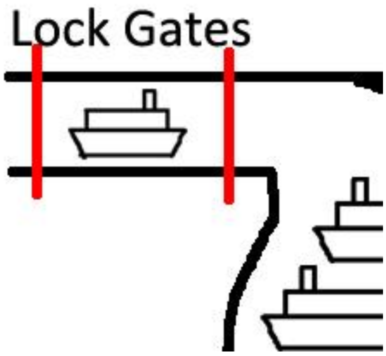

Fig 3.1 b) The ship in between the two lock gates

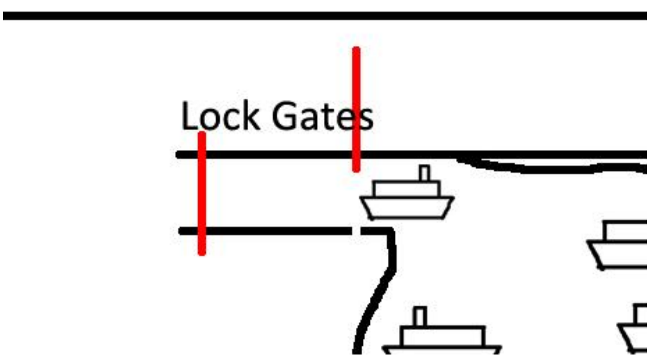

Fig 3.1 c) The ship finally entering the dock

In the above figures (Fig 3.1a, 3.1b and 3.1c), we can clearly visualize that the water level at berths is maintained.

Water level outside the lock gates, i.e. in the river Hooghly, is dependent on tides. During low tides, the water level in the river is lower than the water level in the dock and during high tides, water level in river is greater than, or equal to the water level in the dock. The high tides occur two times in a day. Only during high tides, the lock gate is opened to preserve the water level in the dock. If the water inside the dock gets lower for some reason, there are high power pumps that pump the water from outside the lock gate, to inside the dock, to maintain a consistent water level. Lock gates at HDC are quite old, and they have a specific daily frequency. If they are operated at a higher frequency than specified, there is a risk of lock gate breakdown, which may lead to complete inoperability of the port.

3.2.3 Ship's draft and siltation

A ship's draft is the depth of water needed to float a ship. A ship's draft depends upon the weight of cargo it is carrying, as well as the density of the cargo. A slight decrease in the depth of a waterway means that a vessel must decrease its draft (i.e. reduce the amount of cargo that it is carrying). For example, a 1,000-foot vessel will lose 270 tons of cargo for each inch reduction in its draft! Fig 3.2 shows the draft of a ship.

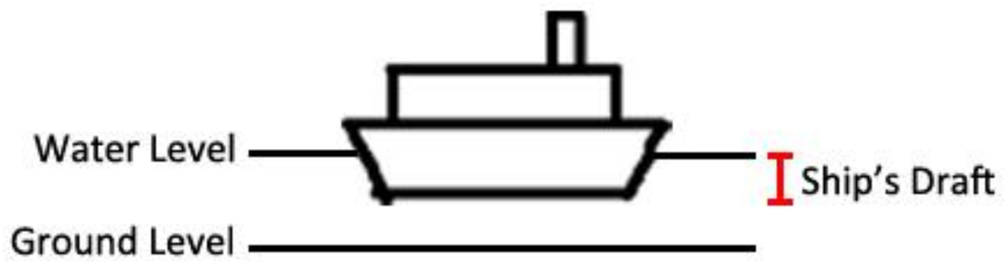

Fig 3.2: A ship's draft

Since HDC is a riverine port, the banks are constantly eroded, and the river basin is accumulated with silt. This leads to decrease in water level. With decreased water level, only ships with a lower draft can visit the dock, which leads to a lower capacity of the dock. Dredging involves the periodic removal of accumulated sediments on the bottom of waterways, ports and shipping complex. The process of dredging is very expensive, and requires expertise.

3.2.4 Tug boat availability

When the ship is near to the lock gates, ship engines are turned off. At this point, only small ship movements are required. These small movements are provided by tugs boats. These tug boats help in moving, as well as stopping the ship. At-least 2 tug boats are required to stop a ship. To stop, or turn a ship, the two tug boats pull the ship in opposite directions (with variable magnitude). Fig 3.3 shows tug boat functionality to move a ship.

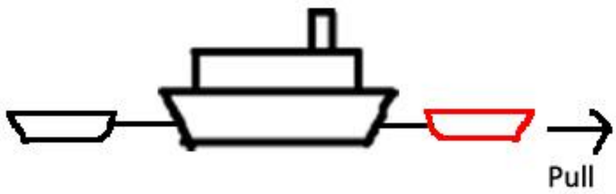

Fig 3.3 a) The tug boat on right pulls to move the ship in forward direction

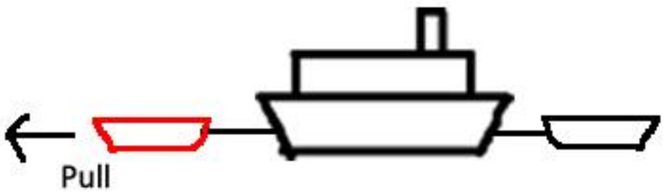

Fig 3.3 b) The tug boat on left pulls to move the ship in backward direction

Fig 3.3 c) Both the tug boats pull (at varying magnitudes) to stop or turn the ship

3.3 Model considerations

At HDC, the order of operation of ships is dependent upon their arrival at the port. It follows the First-come-first-serve (FCFS) rule. However, in certain conditions, this rule may be altered. Examples of such rules may be, Tata Steel at Jamshedpur requesting the port to discharge coal ship as early as possible. In cases like this, FCFS criteria may not be obeyed.

3.3.1 Setup time and completion time

As shown in the line diagram in Fig 3.4, we consider the setup time to be the time taken after the ship arrives at Sandhead, and before it starts getting processed. The components of the setup times are sailing time from Sandhead to berths, idle time if any (due to low tides) and the setup time of equipment (like forklifts, cranes, etc) to be operated on the ships. The completion time is the total time taken by the ship at the port. It is the same as turnround time as discussed in section 1.4.1.

3.3.2 Model inputs and the outputs

The inputs of the model are the time taken by each ship on different berths and their priorities (according to FCFS). The output is the optimal schedule of the ships on different berths.

3.4 Mathematical formulation

The problem can be formulated as follows. There exists a set of *m* berths B_j, $j = 1, \ldots, m$, and a set E of *n* ships T_i, $i = 1, \ldots, n$. Ship T_i requires time p_{ij} when operated on berth B_j. We denote $O(T_i)$ the ship, if any, which can be released only if T_i ship has started operation on any berth. In the rest of the thesis, we refer to $O(T_i)$ as the immediate successor of T_i. $O^2(T_i) = O(O(T_i))$, and $O^q(T_i)$ is similarly defined for $q > 2$. Similarly, we denote $O^{-1}(T_i)$ the ship, if any, which is the immediate predecessor to T_i, i.e. which should be started before the starting of T_i. In a feasible schedule, each ship must be operated on some berth, and each berth operates at most one ship at a time. The berth which starts an operation of a ship finishes it within a pre-defined time period. If a particular ship can't be operated on a specific type of berth (e.g. liquid cargo on a container berth), the value of p_{ij} is kept as a large number to strongly discourage that kind of a possibility. T_i begins at time S_i and completes at time C_i. The goal is to find a feasible schedule that minimizes $C_{max} = max_{i \in \{1, \ldots, n\}} C_i$.

3.4.1 Line Diagram

The components of S_i and C_i can be shown in the line diagram in Fig 3.4.

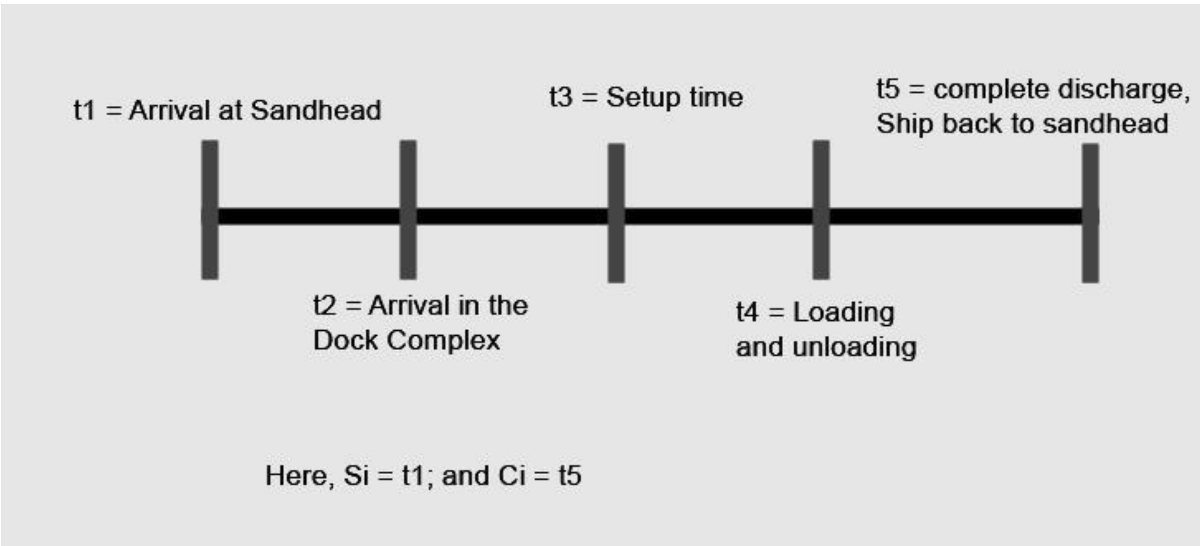

Fig 3.4: Line diagram showing the start time S_i and completion time C_i.

3.4.2 Analogy with machine scheduling

Here we can clearly find out that the ship scheduling problem is analogous to the machine scheduling problem. Table 3.1 shows this analogy.

Ship Scheduling	Machine Scheduling
1. m number of berths	1. m number of machines
2. n number of ships	2. n number of jobs
3. minimize total completion time and the total delay of shipping operation	3. minimize total makespan and total tardiness
4. Specific ships can be operated on specific berths	4. A variation of the classical problem may include specific jobs to be operated on specific machines.
5. There is a priority rule of FCFS	5. There might not be any priority rule

Table 3.1: Analogy between Ship Scheduling and Machine Scheduling

3.4.3 Objective function and constraints

We are trying to minimize the maximum completion time taken by any of the ships on any of the berths, i.e. minimize $C_{max} = max_{i \in \{1, \ldots, n\}} C_i$

Objective function:

Minimize $Z = C_{max}$

Subjected to the following constraints

$C_i \leq C_{max}$ for all $i = 1, 2, \ldots, n$ (This implies C_{max} is the maximum of all completion times)

$C_i = S_i + \sum_{i=1}^{n} \sum_{j=1}^{m} p_{ij} \times x_{ij}$ for all $i = 1, 2, \ldots, n$

p_{ij} is the time taken for operation of Ship i on Berth j and x_{ij} *is the decision variable which tells if ship i is operated on Berth j.*

$\sum_{j=1}^{m} x_{ij} = 1$ for all i = 1, 2, …, n (means one ship can be operated on only one berth at a time)

$\sum_{i=1}^{m} x_{ij} = 1$ for all j = 1, 2, …, m (means one berth can operate only one ship at a time)

$S_i \geq S_{i-1}$ for all $i = 1, 2, …, n - 1$ (This gives the FCFS criteria assuming ships come in order 1, 2, …, n. The FCFS criteria may be changed in certain situations, depending upon the ship's importance. In this case, this constraint may be changed)

$S_i \geq 0, C_i \geq 0$ for all $i = 1, 2, … n$

$x_{ij} = \{0,1\}$ It is a binary variable, can't assume any other value than 0 or 1.

3.5 Conclusions

We began with pointing out the different factors that affect ship scheduling. We then also pointed out the lists of local factors affecting ship scheduling at Haldia. This was succeeded by the mathematical formulation of the problem. We also drew analogy between machine scheduling and ship scheduling. We ended this chapter by providing the objective function and the constraints for the ship scheduling problem.

Chapter 4: Solution Methodology and Its Applications

4.1 Introduction

The solutions to the mathematically formulated problem can be obtained by applying various techniques. But, since the problem set is huge, and dynamic with changing schedules, it becomes difficult to address the problem using the existing techniques. We have already discussed the advantages and disadvantages of other techniques in section 2.4. Since the problem is NP—hard, no solution is possible in polynomial time. Hence, we go for a different heuristic that can provide an optimal solution. Here, we propose a search heuristic to look for the best shipping schedules.

4.2 Steps Involved

The steps involved in the overall project work, including the solution the problem are –

i) Visit HDC, and study the port activities
ii) Identify a critical problem, in this case, it is ship scheduling
iii) Identify the factors affecting ship scheduling
iv) Model ship scheduling in mathematical terms
v) Develop an algorithm to find solution to the problem
vi) Identify the deficiencies and improvement options
vii) Documentation and information specifications of the ship scheduling model
viii) Implementation steps

4.3 Heuristic to Solve the Ship Scheduling Problem at HDC

For the problem considered in section 3.4, we use the following heuristic to solve it. This heuristic assigns the ships to the berths and defines the schedule simultaneously. The basic principle of this heuristic is very simple: it consists of scheduling the ship at each iteration which could lead to late schedule of some other ships in future.

Let $k = 1$. E_k is the set of unscheduled ships at iteration k. Let $E_1 = E$. F_k is the set of ships that could be scheduled:

$F_k = \{T_i \in E_k : O^{-1}(T_i) = \phi \cup O^{-1}(T_i) \notin E_k\}$.

For each T_i *in* F_k, apply the following algorithm:

1. $S_i^0 = C_k$ if $O^{-1}(T_i) = T_k$; $S_i^0 = 0$ if $O^{-1}(T_i) = \phi$
2. For $j = 1, \ldots, m$:
   - 2.1 μ_{ij} = min($t: t \geq S_i^0$ and berth B_j is idle during $(t, t + p_{ij})\}$
   - *2.2* $q = 1; S_i^q = \mu_{ij} + p_{ij}$
   - 2.3 If $O^q(T_i) = \phi$, go to 2.7. Else, define $r: T_r = O^q(T_i)$.
   - 2.4 For $h = 1, \ldots, m$
     - 2.4.1 μ_{rh} = min{$t: t \geq S_i^q$ and berth B_j is idle during $(t, t + p_{rh})\}$
     - 2.4.2 $\theta_{rh} = \mu_{rh} + p_{rh}$
   - 2.5 $S_i^{q.i} = \min_{h=1,\ldots,m} \theta_{rh}$
   - 2.6 $q = q + 1$. Go to 2.3
   - 2.7 $\theta_{ij} = S_i^q$
3. Pick $j(i)$: $\theta_{ij(i)} = \min\{\theta_{ij} : j = 1, \ldots, m\}$

Let T_{i*} be the ship to schedule next.

$i^* : \theta_{i*, j(i*)} = \max \theta_{i, j(i)}$,

$S_i = \mu_{i*.j(i*)}$,

$C_{i*} = S_{i*} + p_{i*, j(i*)}$,

$E_k = E_k - \{T_{i*}\}$

Schedule $B_{j(i*)}$ to begin T_{i*} at time S_{i*}.

Repeat for *k = 2, …, n*.

Let us consider the following example which concerns two berths and seven ships.

4.4 Example of the Heuristic

The processing times are given in Table 4.1. Furthermore, based on the priority of scheduling, we have the order:

$O(T_1) = T_3$, $O(T_3) = T_7$, $O(T_2) = T_6$

	T_1	T_2	T_3	T_4	T_5	T_6	T_7
B_1	3	4	8	2	5	9	3
B_2	9	5	2	6	10	4	8

Table 4.1: Processing times of different ships at different berths

The solution to this problem is reached after 7 iterations. The results obtained at each iteration are gathered in Table 4.2, where

- F_k is the set of ships in which the next ship to be scheduled is to be selected,
- $\theta_{i*, j(i*)}$ is the earliest time when the last successor of T_{i*} can be completed if T_{i*} is assigned to $B_{j(i*)}$,
- T_{i*} is the selected ship
- $B_{j(i*)}$ is the processor which will perform T_{i*}.

k	F_k	$\theta_{i*, j(i*)}$	T_{i*}	$B_{j(i*)}$	S_{i*}	C_{i*}
1	$\{T_1, T_2, T_4, T_5\}$	8	T_1	B_1	0	3
2	$\{T_2, T_3, T_4, T_5\}$	9	T_2	B_2	0	5
3	$\{T_3, T_4, T_5, T_6\}$	10	T_3	B_2	5	7
4	$\{T_4, T_5, T_6, T_7\}$	11	T_6	B_2	7	11

5	**{T_4, T_5, T_7}**	**10**	**T_7**	**B_1**	**7**	**10**
6	**{T_4, T_5}**	**15**	**T_5**	**B_1**	**10**	**15**
7	**{T_4}**	**5**	**T_4**	**B_1**	**3**	**5**

Table 4.2: Results gathered in each iteration

4.5 Conclusions

We started the chapter by listing out the important steps to be carried out during the research work. Then, we proposed a search heuristic that can improve upon its solution in different iterations. This heuristic is easier to understand and can be implemented on a computer with minimal programming effort. This heuristic may be further improved upon by including the tidal times at the port.

Chapter 5: Results and Discussions

We studied the port activities in detail, and pointed out the important factors that affect the scheduling of ships at ports. The port operations at Haldia were also studied in detail. We then tried to formulate the relationship between ship scheduling and its factors. A search heuristic was proposed to solve the problem. The search heuristic was then applied to an example to solve it. This heuristic is a very simple and preliminary heuristic. This can be easily improved upon to include other factors like tidal times and lock gate frequency. For that, the setup times for each ship would change, but the operation time would remain the same. This is a preliminary algorithm which can be applied to other riverine ports also, and can be adjusted depending upon their specific needs.

Chapter 6: Recommendations and Suggestions for Improvement

The relationship between ship scheduling times and its factors are identified. This model could be validated with real life data. Since, at HDC, mostly rule of thumb is used, we can try to implement this model to see the difference. Table 6.1 shows 3 key areas of improvement to reduce turn round times of ships, and their alternatives, with their feasibility and criticality.

Deficiency	Criticality	Alternatives	Feasibility of Alternatives
Lock Gate Performance – The lock gate frequency is restricted.	Critical	1. Better maintenance of lock gates. 2. Install new lock gate system 3. Optimize the number of lock gate frequency	1. Technically feasible, less investment, in-house expertise available 2. Technically very difficult, very high cost, no in-house expertise 3. Technically feasible, investment required for research, in-house expertise unavailable
Multi-purpose berths – types of ships that can be operated on a berth is limited	Critical	1. Construct new berths in existing Dock Complex. 2. Construct new Dock Complex near HDC.	1. Very huge investment is required (Rs. 4 crores per berth), no in-house expertise and technology 2. Very huge investment is required, no in-house expertise and technology. But, this project is being considered by HDC as

			HDC-II
		3. Add extra facilities at the existing berths to make it multipurpose	3. Huge investment is required, no in-house expertise and technology.
Dredging – The ships's draft is less throughout the year, better dredging would provide higher traffic.	Critical	1. Have better dredgers 2. Go for large fleet of small ships instead of small fleet of large ships	1. Huge investment is required, no in-house expertise and technology. 2. Port will have to sign contracts with other shipping companies. Huge investment is required, no in-house expertise and technology.

Table 6.1: Key areas of improvement and their alternatives.

In Table 6.1, the criticality values for each area of concern may be

1. Highly critical – they have serious impact on the performance of the port, should be performed immediately.
2. Critical – they have lesser impact on the performance of the port, they may be be done within 1 year
3. Less critical - they currently have very less impact on the performance of the port, they can be delayed till further study. But, a less critical problem can become a critical problem if not addressed over time.

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