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A SIMULATION MODEL TO GENERATE MEANINGFUL SET OF SERVICING FACILITIES FOR AN INTERNATIONAL PORT

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Abstract

The present work aims to design a Monte Carlo Simulation Model for an international port and identify a meaningful set of facilities namely, hooks, forklifts, mobile cranes and electric cranes that would minimize the average service time per ship and the average waiting time per ship and thereby provide faster service. This model takes into consideration the different costs involved.

1 Introduction

The present work was carried out in an International Port in India. The central aim of this organization is to provide prompt, efficient and safe services on water and on shore at optimum cost and to ensure quick turn around of ships. Ships from many nations carrying variety of cargos call at this port and they are berthed in appropriate berths. Due to the increase in the traffic of sea trade and limited existing facilities and number of berths, the port is not in a position to accommodate all the ships in their berths. This leads to congestion in the port resulting in ships waiting for service. The following are the facilities used:

Hooks (one hook consists of thirteen laborers)

Fork Lifts

Mobile Cranes

Electric Cranes.

Twenty different berths and the type of cargo that is handled in a particular berth are shown in **Table -1.**

By increasing the servicing facilities appropriately, the average service time per ship can be reduced. Thus the number of ships waiting outside the harbor can be reduced. The waiting of ships is analyzed as a problem of Queueing As the various parameters involved in the analysis, namely, arrival time, service time, type of cargo, tonnage of cargo are subject to random fluctuations and as they do not lend themselves to easy mathematical analysis, simulation technique is used to find the expected waiting time of the ships, taking various constraints into account. Details of the various ships that arrived at the port during the year 2005 were collected from the port. The problem was then formulated into a Monte Carlo Simulation Model and with the collected data as input to the model, a desirable set of servicing facilities required for servicing the ships were identified.

Pumps are used for servicing oil ships and giant cranes are used for tilting iron ore ships. These two kinds of ships are not taken into consideration for the study because no immediate change can be made either on the pumps or on the giant cranes used for servicing these two kinds of ships.

2 Queueing Systems

Consider a facility at which work is done or a service is performed. Things requiring work or service arrive at the 'service facility'. These things are called 'customers'. They may be letters requiring signatures, cars to be parked, ships to be unloaded, parts to be assembled, people waiting for services etc. If the customers arrive too frequently, they will have to wait for service or do without it. If they arrive too infrequently, the service facilities will have to wait (i.e) remain idle until additional customers arrive. Waiting customers form a waiting line or queue. There are many types of queueing systems, but all can be classified according to the following characteristics:

1.**The input or arrival process:** This includes the distribution of the number of arrivals per unit of time, the number of queues that are permitted to form, the maximum queue length, and the maximum number of customers desiring service (source).

2.**The service process:** This includes the distribution of the time to serve a customer, the number of servers and the arrangement of servers (in parallel, in series etc.).

3.**queue discipline:** This is the manner in which customers form a queue (first come first served, random selection, and priority selection).

Though formation of waiting lines is a common phenomenon, decisions regarding the amount of capacity to provide must be made frequently in industry and elsewhere. However, since it is normally impossible to accurately predict when units will arrive to seek service and how much time will be required to provide that service, these decisions often are difficult ones. Providing too much service would involve excessive costs. On the other hand, not providing enough service would cause the waiting line to become excessively long at times. Excessive waiting is also costly at times, whether it be a social cost, or the cost of lost customers. Therefore the ultimate goal is to achieve an economic balance between the cost of service and the cost associated with waiting for that service. Queueing theory contributes vital information required for such a decision by predicting various characteristics of the waiting line such as the average waiting time etc.

The objective would be to determine the level of service which minimizes the total of the expected cost of service and the expected cost of waiting for that service. The problem on hand is a single queue multi-server system. It is assumed that ships are let inside the harbor one by one only.

3 Statement of the Problem

The following facilities are generally available in a port for servicing ships:

1. Hooks (One Hook consists of 13 Laborers)
2. Forklifts of 1 1/2T, 2 1/4T, 3T and 10T capacities
3. Mobile Crânes of 3T, 5T, 6T, 10T and 15T capacities
4. Electric Cranes of 3T, 5T, 8T, 10T and 13T capacities and
5. Berths (to service different kinds of ships).

Due to inadequate availability of the above facilities, ships berthed at a particular harbour have to spend considerable amount of time for servicing. This makes quite a number of ships to wait for their turn.

By increasing the service facilities appropriately, the average service time of a ship can be reduced. Thus the number of ships waiting outside the harbor can be reduced.

4 Objective

The present work aims to design a Monte Carlo Simulation Model for the port and identify a meaningful set of facilities, namely, hooks, forklifts, mobile cranes and electric cranes that would minimize the average service time per ship and the average waiting time per ship and thereby provide faster service. This model takes into consideration different costs involved.

Let S_n (where n takes values from 1…n) denote the set of various facilities used for servicing the ships. Let S_1 denote the existing set of facilities, namely, hooks, forklifts, mobile cranes and electric cranes available with the port for servicing ships. New set of facilities are denoted by $S_{2,}$ $S_{3......}$ S_n. S_1 is compared against

$S_{2,}$ S_3 ….. S_n using the results obtained from the Monte Carlo Simulation Model. Cost Benefit Analysis is done in order to choose the desirable set among the different sets of facilities used as inputs to the Monte Carlo Simulation Model.

For each set S_n, the corresponding average service time per ship and average waiting time per ship are calculated using the Monte Carlo Simulation Model. By comparing the average service time per ship, the average waiting time per ship and the savings corresponding to each new set of facilities ($S_{2,}$ S_3 ….. S_n) with the corresponding values of the existing servicing facility S_1, the desirable set of facilities is found out. (i.e., Is the new set better than the existing set S_1 ?). Cost Benefit Analysis is done by taking into consideration different costs involved. From the final results, the facilities corresponding to the desirable and feasible set S_n is recommended.

5 Data Collection

Details of the various vessels that arrived at the International Port during the year 2005 were collected from the records to serve as the input data for simulation. The required data were collected from the past records of the port. The venue of the vessel, arrival date, berthing time, sailing time, type of cargo and tonnage of cargo were noted from the ledgers. The supply of Hooks, Forklifts, Mobile Cranes and Electric Cranes were collected from the Hook Slips. Data have been collected from 1009 ships as shown in **Table- 2.**

The important parameters needed for the study are given below:

1. Arrival pattern of the customer (ships): Frequency distribution of inter-arrival time.
2. Servicing facilities provided: Frequency distribution of servicing facilities used, namely, Hooks, Forklifts, Mobile Cranes and Electric Cranes.
3. Number of berths.
4. Queue discipline: the order in which service is provided such as first come first served, random selection, and priority selection.
5. Types of cargo handled.
6. Tonnage of cargo handled.

The time between the arrival of successive ships (inter-arrival time) was found out and the number of ships that arrived within one hour of the previous ships, two hours of the previous ships and so on are calculated using Tally Sheets. Thus the frequency tables for all the other parameters were prepared.

The various frequency distributions used in the present work are given below:

1. Frequency distribution of inter arrival time…………………………1
2. Frequency distribution of type of cargo…………………………....1
3. Frequency distribution of service time for phosphoric acid………….1
4. Frequency distribution of tonnage of cargo for different types……...7
5. Frequency distribution of hooks used for servicing different types of cargo ships…....................…7
6. Frequency distribution of fork lifts of 1 ½T, 2 ¼T, 3T and 10 T capacities used for servicing different types of cargo ships………… (3*7) = 21
7. Frequency distribution of mobile cranes of 3T,5T,6T,10T and 15 T capacities used for servicing different types of cargo ships…………..(4*7) = 28
8. Frequency distribution of electric cranes of 3T, 5T, 8T, 10T and 13 T capacities used for servicing different types of cargo ships ………… (4*7) =28

Total number of frequency distribution tables used for simulation = 94

The following data were also collected:

1. List of facilities used.
2. Life of facilities used.
3. Average rate of unloading per hour.
4. Servicing cost for different types of cargo ships.
6. Actual facilities available for service per day (three shifts).
7. Cost of facilities provided.
8. Average waiting time cost of a ship per day.

The frequency distribution of inter-arrival time is shown in **Table -3.** The frequency distribution of types of cargo handled is shown in **Table- 4.** Frequency distribution of tonnage of cargo corresponding to ships carrying general cargo is given in **Table -5.**

Frequency distribution of service time of phosphoric acid is shown in **Table- 6.** Frequency distribution of hooks used for servicing ships carrying general cargo is shown in **Table- 7.** Frequency distribution of FLT 1½T used for servicing ships carrying general cargo is shown in **Table- 8.** Similarly all other frequency distribution tables for ships carrying general cargo were generated **(Table- 9 to Table- 18).** In the same way, frequency distribution tables for ships carrying other types of cargo were also generated.

5.1 Rate of Unloading

When all the servicing facilities are in operation (hooks, forklifts, mobile cranes and electric cranes), the average rate of unloading is 12 tons/hour. Though the capacities of individual units (servicing facilities) are different, when these different units of forklifts, mobile cranes, electric cranes and the hooks are working together, practically they can unload cargo only at an average rate of 12 tons per hour.

6 Flow Chart

The flowchart corresponding to the Monte Carlo Simulation Model is shown in **Figure -1.**

7 Experimentation and Analysis of Results

The programming instructions corresponding to the Monte Carlo Simulation Model were written in C++.

The simulation model was experimented using various data shown in previous sections. The results of the simulation run is shown in **Table -19.** Servicing cost for different types of cargo ships is shown in **Table- 20.**

Cost Per Day

The following are the annual costs of the facilities provided (annual costs include operation cost, maintenance cost, depreciation and interest on capital):

1.	Hooks	–	Rs. 2,38,13,000
2.	Forklifts trucks	–	Rs. 1,59,77,000
3.	Mobile cranes	–	Rs 97,46,000
4.	Electric cranes	–	Rs 2,03,57,000

From the annual cost, cost per day is calculated. This cost per day corresponds to set S_1. Cost per day corresponding to S_2, S_3 and S_4 are calculated from the cost per day of S_1. Cost per day corresponding to S_1, S_2 , S_3 and S_4 are shown in **Table- 21.** Details regarding cost benefit analysis are shown in **Table -22.**

Waiting Time Cost

The average waiting time cost of the ship is Rs 30,000 per day.

Details regarding the life of facilities provided are given below:

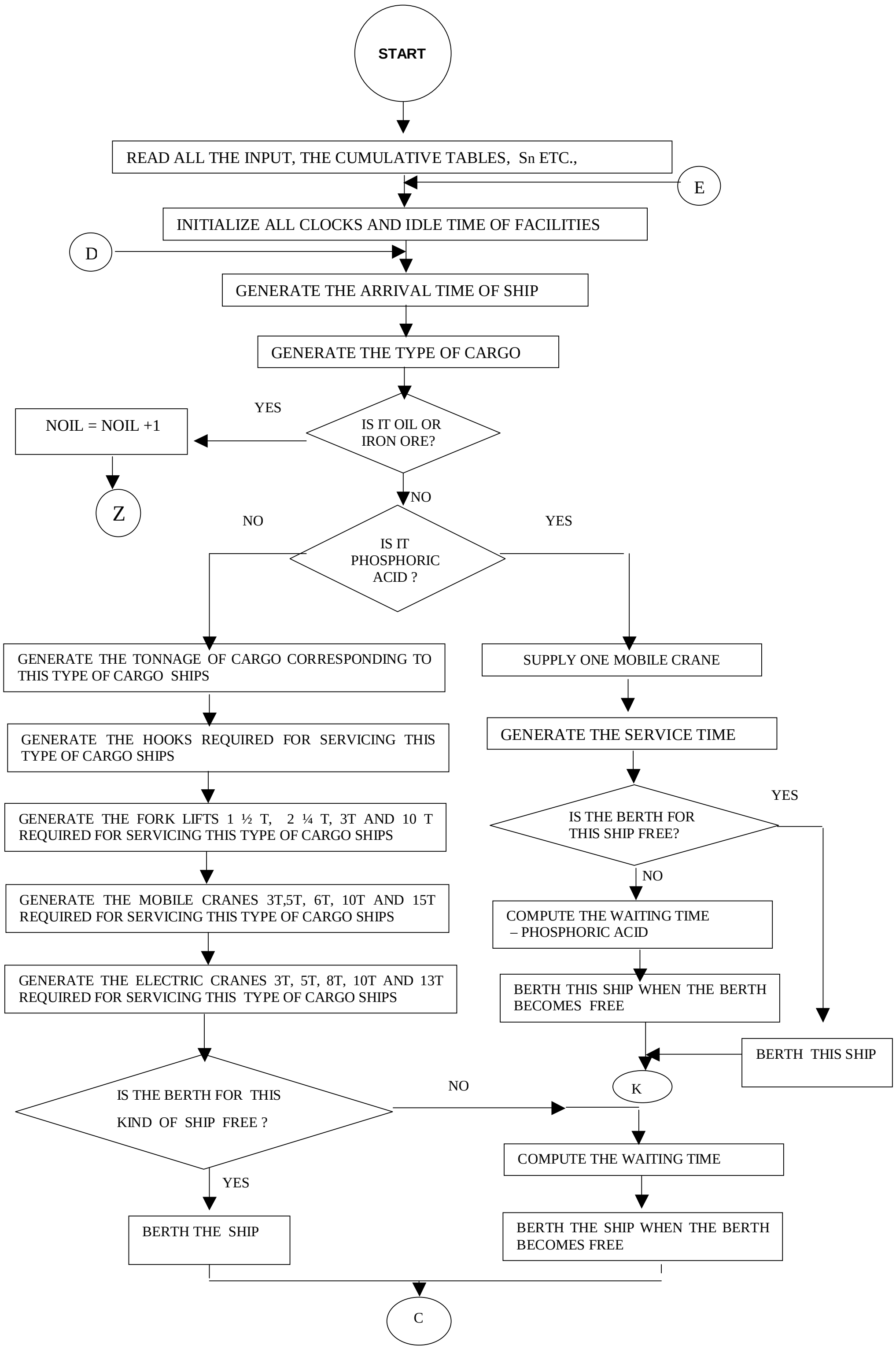

Figure 1 Flowchart corresponding to the Monte Carlo Simulation Model

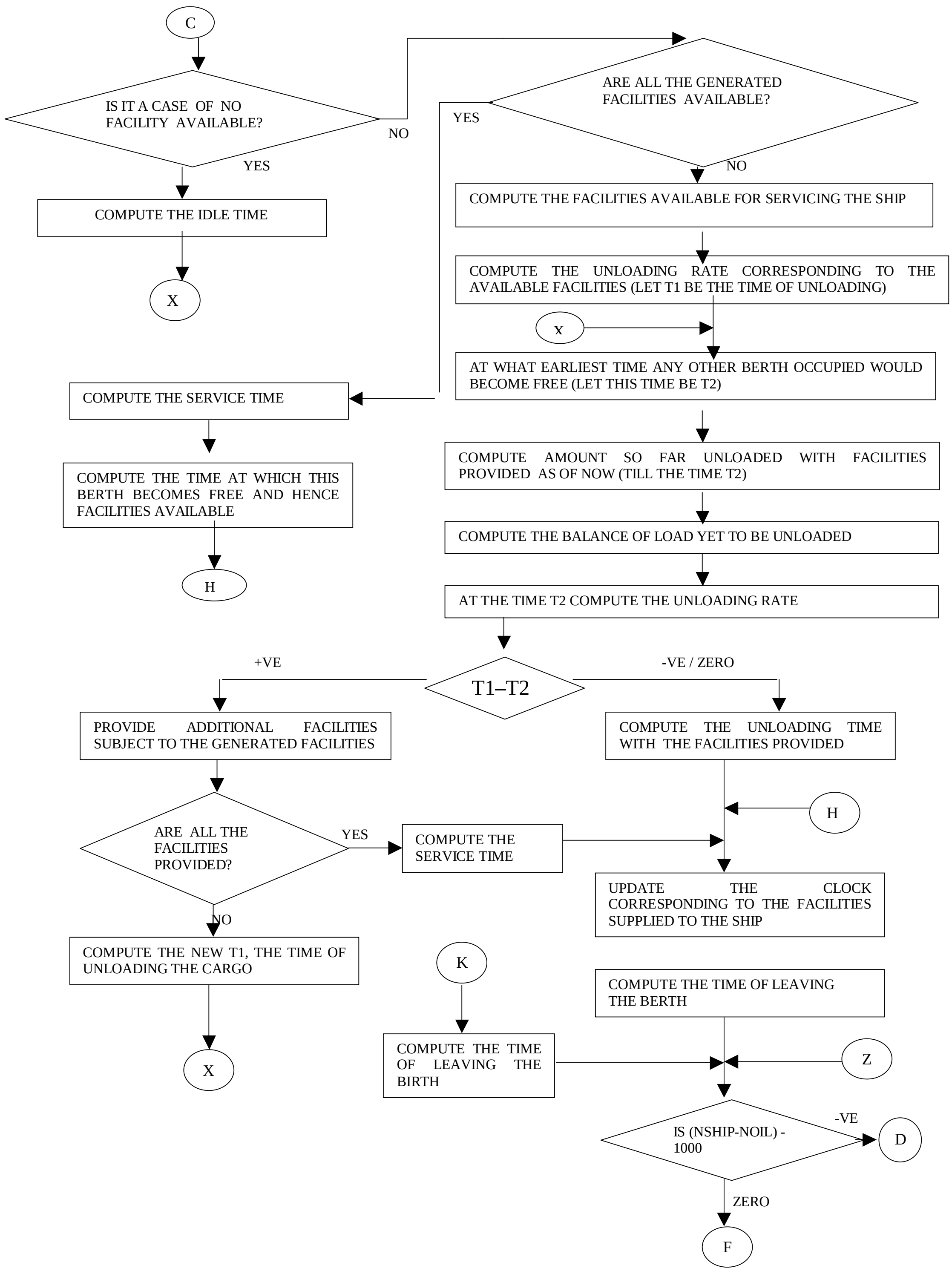

Figure 1 Flowchart corresponding to the Monte Carlo Simulation Model (continued)

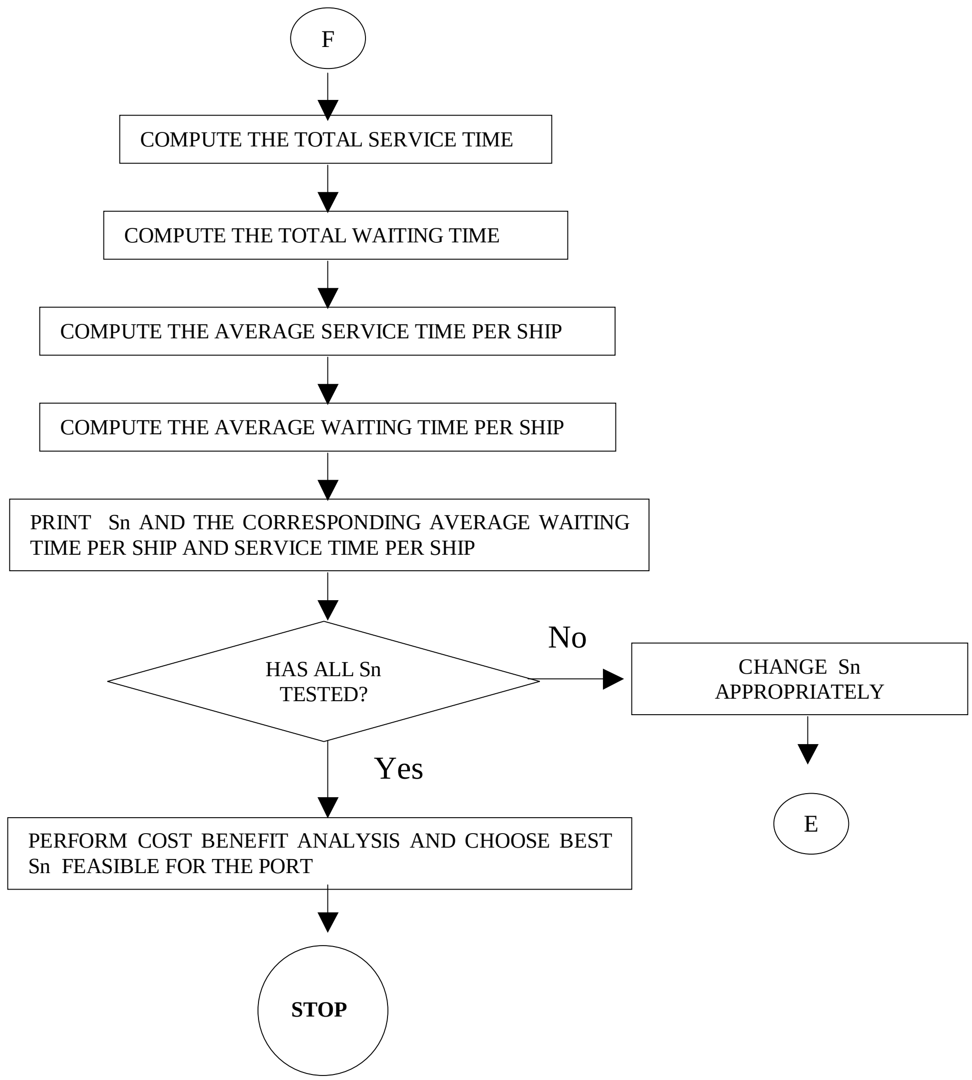

Figure 1 Flowchart corresponding to the Monte Carlo Simulation Model (continued)

1. Life of forklifts and mobile cranes — 15 yrs

2. Life of electric cranes — 30 yrs

By comparing the average service time per ship and average waiting time per ship for various sets of facilities (S_1,S_2, S_3, …..S_n), it was found that the output for average service time per ship and average waiting time per ship were minimum for S_4. Hence by increasing the facilities to the requirement stated in S_4 **(Table -21)**, the average service time per ship and the average waiting time per ship for the ships served at the port can be greatly minimized. The associated cost benefit analysis is also demonstrated in **Table- 22.** Increasing the investment beyond this will be too costly for the port.

8 Conclusion

The management has accepted all the recommendations of this research report. The overall profit for the port will improve once the port management implements the results of the Monte Carlo Simulation Model.

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Table 1 Details about the different types of cargo and births

Serial Number	Berth	Type of Cargo
1	Berth 1	Passenger
2	Berth 2	General cargo
3	Berth 3	General cargo
4	Berth 4	General cargo
5	Berth 5	General cargo
6	Berth 6	Fertilizer/ General cargo
7	Berth 7	Fertilizer
8	Berth 8	Other ores/ Open cargo
9	Berth 9	Other ores/ Open cargo
10	Berth 10	Coal
11	Berth 11	Coal
12	Berth 12	Open cargo
13	Berth 13	General cargo
14	Berth 14	Phosphoric acid/ Open cargo
15	Berth 15	General cargo
16	Berth 16	Open cargo
17	Berth 17	General cargo
18	Berth 18	Open cargo
19	Berth 19	Oil
20	Berth 20	Iron ore

Table 2 Details of ships

Serial Number	Types of cargo	Number of ships for which data were collected
1	General cargo	470
2	Steel	72
3	Fertilizer	36
4	Barytes	38
5	Cement	17
6	Wheat	15
7	Coal	12
8	Phosphoric acid	29
9	Oil/Iron ore	320

Table 3 Frequency distribution of inter- arrival time

Class interval in hours	Midvalue	Frequency	Cumulative frequency	Cumulative probability
0-2	1	221	221	0.219
2-4	3	125	346	0.343
4-6	5	79	425	0.421
6-8	7	93	518	0.513
8-10	9	78	596	0.591
10-12	11	56	652	0.646
12-14	13	90	742	0.735
14-16	15	60	802	0.794
16-18	17	41	843	0.835
18-20	19	24	867	0.859
20-22	21	27	894	0.886
22-24	23	18	912	0.904
24-26	25	21	933	0.925
26-28	27	14	947	0.939
28-30	29	13	960	0.951
30-32	31	5	965	0.956
32-34	33	5	970	0.961
34-36	35	5	975	0.966
36-38	37	5	980	0.971
38-40	39	4	984	0.975
40-42	41	1	985	0.976
42-44	43	6	991	0.982
44-46	45	4	995	0.986
46-48	47	5	1000	0.991
48-50	49	9	1009	0.999

Table 4 Frequency distribution of type of cargo handled

Type of cargo	Frequency	Cumulative frequency	Cumulative probability
General cargo	470	470	0.47
Steel	72	542	0.54
Fertilizer	36	578	0.57
Barites	38	616	0.61
Cement	17	633	0.63
Wheat	15	648	0.64
Coal	12	660	0.65
Phosphoric acid	29	689	0.68
Oil/iron ore	320	1009	0.99

Table 5 Frequency distribution of tonnage of cargo corresponding to ships carrying general cargo

Class interval in tones	Mid value	Frequency	Cumulative frequency	Cumulative probability
500-3000	1750	399	399	0.85
3000-6000	4500	46	445	0.95
6000-9000	7500	15	460	0.97
9000-12000	10500	5	465	0.98
12000-15000	13500	5	470	0.99

Table: 6 Frequency distribution of service time of phosphoric acid

Class interval in hours	Midvalue	Frequency	Cumulative frequency	Cumulative probability
10-20	15	15	15	0.52
20-30	25	5	20	0.69
30-40	35	6	26	0.90
40-50	45	2	28	0.97
50-60	55	1	29	0.99

Table 7 Frequency distribution of hooks used for servicing ships carrying general Cargo

Number of hooks	Frequency	Cumulative frequency	Cumulative probability
1	160	160	0.34
2	210	370	0.79
3	80	450	0.96
4	10	460	0.97
5	10	470	0.99

Table 8 Frequency distribution of FLT 1 1/2T used for servicing ships carrying general cargo

No. of FLTS	Frequency	Cumulative frequency	Cumulative probability
0	337	337	0.72
1	102	439	0.93
2	31	470	0.99

Table 9 Frequency distribution of FLT 2 1/4T and 3T used for servicing ships carrying general cargo

No. of FLTS	Frequency	Cumulative frequency	Cumulative probability
0	72	72	0.15
1	184	256	0.54
2	112	368	0.78
3	102	470	0.99

Table 10 Frequency distribution of FLT 10T used for servicing ships carrying general cargo

No. of FLTS	Frequency	Cumulative frequency	Cumulative probability
0	266	266	0.57
1	204	470	0.99

Table 11 Frequency distribution of MC 3T used for servicing ships carrying general cargo

No. of MCS	Frequency	Cumulative frequency	Cumulative probability
0	286	286	0.61
1	170	456	0.97
2	4	460	0.98
3	10	470	0.99

Table 12 Frequency distribution of MC 5T and MC 6T used for servicing ships carrying general cargo

No. of MCS	Frequency	Cumulative frequency	Cumulative probability
0	123	123	0.26
1	316	439	0.93
2	31	470	0.99

Table 13 Frequency distribution of MC 10T used for servicing ships carrying general cargo

No. of MCS	Frequency	Cumulative frequency	Cumulative probability
0	419	419	0.89
1	51	470	0.99

Table 14 Frequency distribution of MC 15T used for servicing ships carrying general cargo

No. of MCS	Frequency	Cumulative frequency	Cumulative probability
0	307	307	0.65
1	163	470	0.99

Table 15 Frequency distribution of EC 3T and EC 5T used for servicing ships carrying general cargo

No. of ECS	Frequency	Cumulative frequency	Cumulative probability
0	143	143	0.30
1	194	337	0.72
2	102	439	0.93
3	31	470	0.99

Table 16 Frequency distribution of EC 8T used for servicing ships carrying general cargo

No. of ECS	Frequency	Cumulative frequency	Cumulative probability
0	439	439	0.93
1	31	470	0.99

Table 17 Frequency distribution of EC 10T used for servicing ships carrying general cargo

No. of ECS	Frequency	Cumulative frequency	Cumulative probability
0	450	450	0.96
1	20	470	0.99

Table 18 Frequency distribution of EC 13T used for servicing ships carrying general cargo

No. of ECS	Frequency	Cumulative frequency	Cumulative probability
0	399	399	0.85
1	71	470	0.99

Table 19 Results of the simulation run

Facilities used for servicing ships/ shift	S_1	S_2	S_3	S_4
Hooks	38	40	42	44
FLT 1 ½ T	3	4	5	6
FLT 2 ½ T	12	14	16	18
FLT 3 T	14	16	18	20
FLT 10 T	2	3	4	5
MC 3 T	3	4	5	6
MC 5 T	2	3	4	5
MC 6 T	3	4	5	6
MC 10 T	1	2	3	4
MC 15 T	1	2	3	4
EC 3 T	18	20	22	22
EC 5 T	4	5	6	6
EC 8 T	2	3	4	5
EC 10 T	2	3	4	5
EC 13 T	4	6	6	7

Table 20 Servicing cost for different type of cargo ships

Type of Cargo	Servicing cost per ton (rupees)
General Cargo	42.33
Steel	42.33
Fertilizer	43.92
Barytes	42.33
Cement	42.33
Wheat	41.49
Coal	55.59
Phosphoric Acid	44
Oil	5.86
Oil/Iron ore	35.46

Table 21 Cost per day details

Facility	Total hooks available for service /shift	Total FLT available for service /shift	Total MC available for service /shift	Total EC available for service /shift	Hooks cost per day (rupees)	FLTs cost per day (rupees)	MCs cost per day (rupees)	ECs cost per day (rupees)	Total cost per day (rupees)
S_1	38	31	10	30	65241.09	43772.6	26701.37	55772.6	191487.7
S_2	40	37	15	36	68674.84	52244.72	40052.06	66927.12	227898.7
S_3	42	43	20	42	72108.58	60716.84	53402.74	78081.64	264309.8
S_4	44	49	25	44	75542.32	69188.95	66753.43	61799.82	293284.5

Table 22 Cost benefit analysis details

Policy	Average service time/ ship (hours)	Average waiting time /ship (hours)	Cost/day (rupees)	Increase in cost/ per day with respect to S_1 (rupees)	Reduction in avg. service time/ship with respect to S_1 (hours)	Reduction in avg. waiting time/ship with respect to S_1 (hours)	Savings with respect to S_1 per ship = (reduction in waiting time per ship with respect to S_1) * (waiting time cost per hour) (rupees)
S_1	29	21	1,91,487.66				
S_2	26	19	2,27,898.74	36,411.08	3	2	2500
S_3	25	18	2,64,309.80	72,822.14	4	3	3750
S_4	24	16	2,93,284.52	101,796.86	5	5	6250