CHAPTER 6
The Causal Model – Simulating Port Efficiency

6.1 Background

The causal model following the principle of System Dynamics has been developed in the ensuing section for the purpose of simulating port efficiency under different conditions. The causality between the factors has been established through the inferences drawn from the previous chapters namely, Chapter 2 and Chapter 5.

6.1.1 Literature Review - Causal Inferences

The research done so far established causality between the ships’ cost at port with the following factors:

i. Besides distance and containerization, the efficiency of ports is also important in determining maritime transport costs (Clark et al, 2004).

ii. The rate at which cargo is handled and the duration that cargo stays in port prior to shipment or post discharge (Kek Choo Chung, 1993). That is,
   - Stay at port increases with congestion at ports (Farrel, 2009).
   - congestion at ports depends on number of berths(Yan and Liu, 2010)
   - number of berths is a function of capital deployed (Yan and Liu, 2010)
   - stay at port or vessel turn round time (TRT) is highly correlated with crane allocation as well as the number of containers loaded and discharged (Yan and Liu, 2010)

iii. Variations in port efficiency are linked to excessive regulation, the prevalence of organized crime, and the general condition of the country’s infrastructure (Clark et al, 2004).

iv. Larger ports produced higher efficiencies (Martinez-Budria et al. 1999).

v. Operational efficiency does not solely depend on a port’s size and function (Tongzon 2008).

vi. Large-scale production tended to be associated with higher efficiency (Wang and Cullinane 2006).

6.1.2 Expert Group discussion - Causal Inferences

The expert group discussion held with the major stakeholders (shipping companies, importers, exporters and freight forwarders) led to the following inferences:

1. Stay at port also depends on same day sailing, which might not be possible due to non-availability of night navigation as observed in ports such as Kolkata and Haldia.
2. Port efficiency also includes the evacuation of cargo through effective connectivity with the hinterland. Adequate infrastructure supporting rail, road and inland waterways is a key to faster movement of cargo to and from ports.
3. A container port should be supported by ancillary services such as container freight stations, equipment, manpower and other service providers.
4. Navigable draft plays an important role in attracting ships. Ports with low draft reduce the parcel load resulting in increase in cost per tonne or per container.
5. Experienced pilot service is expected to result in lower clearance on the forward draft. (In port of Kolkata the vessels need to have 0.2 meters trim aft between stretch of Diamond harbour and Garden Reach, http://www.kolkataporttrust.gov.in/show_img.php?fid=712)
6. Low draft results in congestion and low-water surcharges to be levied from the shipper resulting in increase in cost.

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3 The **draft** (American) or **draught** (British) of a ship's hull is the vertical distance between the waterline and the bottom of the hull (keel), with the thickness of the hull included; in the case of not being included the draft outline would be obtained. Draft determines the minimum depth of water a ship or boat can safely navigate. The draft can also be used to determine the weight of the cargo on board by calculating the total displacement of water and then using Archimedes' principle.

4 "trim" is defined as the difference between the forward and aft drafts, (http://en.wikipedia.org/wiki/Draft_(hull))
7. Availability of Customs clearances on round the clock basis reduces the dwell time of cargo and vessels and hence the maritime logistics cost.

8. Port management efficiency determines the productivity and hence ships’ cost at ports

6.1.3 Data Envelope Analysis (DEA) - Causal Inferences

The DEA carried out for container handling ports and terminals yielded the following results:

i. Half of the ten container ports and terminals considered for the analysis are scale inefficient ports. However, whereas most of the publicly operated ports/terminals are scale inefficient (3 out of 4), most of the privately operated ports/terminals are scale efficient (4 out of 6).

ii. Among the scale inefficient ports, barring one port (Chennai Port) all (KDS, CoPT, JNPT and KPT) have decreasing return to scale (DRS). The OTE scores among the inefficient ports ranged from 0.241 for KPT (Kandla port) to 0.817 for CoPT.

iii. HDC, VPT, TPT, NSICT and GTICT (barring HDC all are privately operated) have the scale efficiency equal to one.

iv. Inefficiency in Indian port sector is due to both poor input utilization (i.e., pure technical inefficiency) and failure to operate at most productive scale size (i.e., scale inefficiency).

6.1.4 Principal Component Analysis

Two factors representing two dimensions namely, capacity dimension and efficiency dimension were identified.

6.2 The Maritime Cost Dynamics

Based on above findings the propositions leading to the dynamics of the port can be stated as follows:

i. “Carriers (Ships) prefer the port with low or no waiting time”.

Figure 6.1 shows the causal diagram of the dynamics based on System Dynamics approach.

The description of figure 6.1 is as follows:
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Ships entering a port may have to wait (average time to berth) for operation to begin, because of non-availability of berth, delay in processing of documents and/or non-availability of other resources. This phenomenon of ‘waiting time’ of a ship will lead to increase in operational cost per ship. Operational cost may be defined as the cost that a ship incurs on account of her maintenance and running the internal activities (such as power supply, water and bunker supplies, fuel, lubricants and spares to run the machinery and other overhead expenses) during her stay at port. In an efficient port the ‘idling cost’ is kept at minimum by reducing the waiting time of the ship. In addition, it incurs the opportunity cost. The increase in total cost to ship will in turn increase the relative cost of the ship. That is, its cost compared to cost incurred at other ports. In such an event this increase in relative cost is likely to affect the ships arrival at port. The port is likely to experience reduction in number of ship calls. Since a significant part of port revenue is earned on number of ships and her size, the total revenue is likely to decrease. The ships immediately cannot perceive the increase or decrease in its fixed cost. They may take some months to assess it. The perception delays by the carriers of the waiting time and satisfaction may play as a compensatory feedback loop, prompting wrong signal to the port management if not interpreted correctly. The causal diagram shown in figure 6.1 explains dynamics arising out of waiting time of ships and the cost of ship at port. The above causal diagram clearly describes a negative feedback loop.

Figure 6.1: The Ship-Cost-Revenue Dynamics of the Port
loop has a stabilizing effect on the dynamics. This negative loop explains the following dynamics:

ii. “Shippers prefer the port with lowest cost of handling cargo”

The total maritime logistics cost includes ship’s cost at port, port charges and the cost of cargo movement from the origin to the port or from the port to the destination (including insurance cost). Increase in any of these component increases the total cost of cargo handling. Figure 6.2 shows the dynamics arising out of total cost of cargo handling on the port operation.

**Figure 6.2: The Total Cost Dynamics**

Apart from the carriers, shippers (importer or exports) bear the cost for loading or unloading cargo at port and the cost of transportation from the port to the destination (in case of import cargo) or from the origin to the port (in case of export cargo). The total cost of routing the cargo through a port, finally, determines the choice of a port. The total cost comprises ship’s cost at port, port charges and the cost of cargo movement from the origin to the port or from the port to the destination. Port charges include charges on account of ship’s entry to port and stay at berth, and quantum of cargo handled at port. More the days a ship stays in a berth more it has to pay the berth hire charges.
Figure 6.2 shows the total cost dynamics of the Port. As the total cost increases, the relative total cost (cost compared to competing port or mode of transport) also increases. This in turn reduces the flow of cargo through the port. Number of ships visiting the port is a function of flow of cargo through the port. Reduction in cargo handling by the port reduces the ship arrival rate (Ships in). Decrease in cargo and ships reduce the revenue earned by the port. As the revenue decreases the productivity decreases (as spending on maintenance, capital investments and incentives would decrease). Stay at berth is a function of amount of cargo per ship and productivity. It increases if the productivity decreases. Increase in stay at berth will increase the revenue (as port will earn greater berth hire charges) but at the same time also increase the total cost of cargo handling at ports.

iii. “Ships prefer efficient ports, on other hand the waiting time of the ships depends on the rate of arrival of ships (Ships in) and capacity of the port” or in other words, “Improved capacity brings in new ships as the waiting time of ships decreases and also that productivity increases and hence the port earns more revenue”

If a port is efficient more ships would prefer to call at the port i.e., the rate of arrival increases leading to increase in waiting time. This in turn increases the total cost of handling cargo. The waiting time can be reduced on increasing the capacity. Figure 6.3 shows the capacity-ship dynamics.

Figure 8.3 shows the dynamics arising out variables such as capacity, time to berth, and cost of ship at port, ship call and revenue.

**Figure 6.3: The Capacity – Ship – Revenue Dynamics**
In the above causal diagram it is depicted that time to berth, i.e., waiting time of a ship is dependent on port’s capacity. Less capacity would mean increase in waiting time of the ship, which in turn would increase the ship’s operational cost. No ship would visit a port if the relative cost per ship for that port is high. Less ship would result in decrease in revenue. The perception delays by the carriers of the waiting time and satisfaction may play as a compensatory feedback loop, prompting wrong signal to the port management if not interpreted correctly. The capacity addition delay describes the time required to develop and install additional capacity. Port projects have long gestation period and as such this delay should be accounted for while planning. The project management tools and techniques can be used to control and monitor the delays.

6.3 The Integrated Causal Loop Diagram

The integrated causal loop diagram reflecting the interactions of all the major variables are exhibited in Figure 6.4 below.

Figure 6.4: Dynamics of the Port System
The above causal model explains the structure that governs the behaviour of a port system. It gives the causal linkage between the important variables. The delays in the system are clearly reflected in the model. A ship on arrival to the port may have to wait before being berthed. The time to berth or the pre-berthing delay may be due to various reasons such as non-availability of berth, document-processing delay etc. The stay at berth of the ship is dependent on its cargo handling time and time lost may be because of stoppage of work or other management inefficiencies. The revenue of the port is dependent on stay at berth of ships (levied as berth-hire charges that are charged on the basis of number of days a ship stays at birth), quantum of cargo it carries and the size of the ship. A ship, apart from paying port charges, also incurs cost for its own operation and maintenance during her stay at port. The total cost to the ship can be reduced on reduction of delays it experiences in the port. Increasing the capacity and improving the institutional mechanism can reduce pre-berthing delay. Stay time at berth can decrease on improvement of productivity and organizational efficiencies. The model depicts the effect of increase of total cost of handling of cargo through the port. The total cost of handling of cargo includes ship’s cost at port, port charges and the cost of cargo movement from the origin to the port or from the port to the destination. That is, the total logistics cost. As the total cost of handling of cargo through the port increases, the relative total cost (cost compared to competing port or mode of transport) also increases. This affects the potential demand of cargo through the port. The shippers and carriers cannot perceive the increase or decrease in total cost of handling of cargo through the port. They may take some months to assess it. The perception delays by them and satisfaction may play as a compensatory feedback loop, prompting wrong signal to the port management if not interpreted correctly. There is always a delay in increase in capacity. Port projects have long gestation period (5 to 10 years), and therefore, if this delay is not considered in the perspective plan of the port, the port may lose its market share by the time it enhances its capacity.

6.4 The Simulation Model

6.4.1 The Causal Diagram

The number of variables affecting the port dynamics are quiet large in number making the causal diagram complex to be developed as a System Dynamics model. The Factor Analysis
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carried out in chapter 5 identifies two dimensions namely, the efficiency and the capacity dimension. These two dimensions clearly corroborate with the findings described above.

Figure 6.5 shows the causality between the two dimensions of port performance, namely, capacity and efficiency-level with ATRT (average turn round time) and NO OF SHIPS (number of ships) calling at port

Figure 6.5: Causal Loop diagram showing causality between the two dimensions with ATRT and No. of Ships calling at port

It demonstrates that capacity and efficiency dimensions influences average turn round time (ATRT) which in turn affects the number of ships calling at port. The behaviour of the system is governed by the negative loop. This implies that when the ATRT increases reflecting poor performance of the port, the carriers are expected to avoid that particular port. As such number of ships calling at port decreases while the reverse is expected to be observed when ATRT decreases. At the same time the number of ships calling at port would impact the capacity dimension, as its increase will tend to demand for more berths and or equipment, meaning that the number of ships calling at port causes capacity constraint of the port, in turn affecting ATRT.

The policy implication of above model is that the decision maker has two different options to enhance its performance. One way would be to increase its capacity through increase in average ship day output (AOPSBD) (may be through modernizing or replacing the equipment, and/or training of manpower), and/or management restructuring (may be through
privatisation). The other option would be enhance efficiency, through enhancing “soft measures” relating to cargo handling processes viz, documentation, ICT and statutory inspections, and/or increase in draft (may be through dredging, better disposal ), and / or improved supervison resulting in reduction in non-working time of ships at the port.

The impact of efficiency level due to actions taken to improve the ATRT is not static, as improvement of ATRT is likely to increase number of ships arriving at port causing waiting time of ships to increase, meaning a low performance measured through ATRT. Beyond the permissible level of increasing efficiency, capacity addition through additional berths and associated infrastructure has to be done through investments. Hence, the impact of the changed decisions has to be simulated and results monitored to achieve the corporate goal. The above model can, therefore, be described as a dynamic model based on principles of causality.

6.4.2 The System Dynamics Model

The System Dynamics model using Vensim software has been developed. Figure 6.6 shows the level-flow diagram of the model.

Figure 6.6: Stock- flow diagram

SHIPS IN PORT is the level or the stock variable. SHIPS IN PORT increases or decreases depending on rate of arrival of ship and rate of departure of ship.

The causal tree arising out of above model is shown in Figure 6.7
Figure 6.7: Causal Tree arising out of above model

![Causal Tree](image)

Figure 6.7 shows that the departure rate of ships are affected by efficiency level and at the same time would also affect the arrival rate as port will be known as efficient or inefficient port. In case the efficiency level is low, the rate of arrival is expected to decrease, as ships would not prefer to suffer higher TRT.

The equation for SHIPS IN PORT is given by equation 1

\[
\text{SHIPS IN PORT} = \max (\text{SHIP ARRIVAL RATE} - \text{SHIP DEPARTURE RATE}, 0) \quad (6.1)
\]

Equation 2 gives the flow variable “SHIP ARRIVAL RATE”

\[
\text{SHIP ARRIVAL RATE} = \text{IF THEN ELSE(EFFICIENCY<1,RANDOM NORMAL(0,1,1)+1,RANDOM NORMAL(0,2,1,1)+1)} \quad (6.2)
\]

Equation 2 shows that the rate of arrival of ship is taken to be random normal with the following conditions:

If Efficiency < 1,
   Then minimum departure = 0
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Maximum number of ships departing per day = 1,
Mean number of ships departing per day = 1
Standard deviation = 1 (one) ship and
Seed value = 1 (one).

Else If Efficiency > 1,
Then minimum departure = 0
Maximum number of ships departing per day = 6 (six),
Mean number of ships departing per day = 4 (four),
Standard deviation = 1 (one) ship and
Seed value = 1 (one).

In other words the mean rate of arrival is expected to drop to 50 percent when the efficiency is less than one.

Equation 8.3 gives the flow variable “SHIP DEPARTURE RATE”

\[
\text{SHIP DEPARTURE RATE} = \min(\text{IF THEN ELSE}(\text{EFFICIENCY} < 1, \text{RANDOM NORMAL}(0, 4, 3, 1, 1), \text{RANDOM NORMAL}(0, 6, 4, 1, 1)), \text{SHIPS IN PORT}) \quad \text{....(6.3)}
\]

Equation 8.3 shows that the rate of departure of ship is taken to be random normal with the following conditions:
If Efficiency < 1,
Then minimum departure = 0
Maximum number of ships departing per day = 1,
Mean number of ships departing per day = 1
Standard deviation = 1 (one) ship and
Seed value = 1 (one).

Else If Efficiency > 1,
Then minimum departure = 0
Maximum number of ships departing per day = 6 (six),
Mean number of ships departing per day = 4 (four),
Standard deviation = 1 (one) ship and
Seed value = 1 (one).
In other words the mean rate of departure is expected to drop to 25% when the efficiency is less than one. Else the mean rate of departure is expected to be 4 per day. This is taken on the assumption that the port has 4 berths with productivity level leading to same day sailing of ships in each berth. In some cases the two ships a day can depart in any of the berths depending on the parcel load and hence a maximum of 6 ships can depart in a day. Thus, Capacity = 6 berths

With the above settings, the model can be simulated by varying the Efficiency level that affects both the arrival and the departure rates.

6.4.3 Simulation Runs

Simulation Run 1
Efficiency = 1
Capacity= 6 ships per day

Under ideal conditions, i.e., efficiency is equal to one, the results in figure 6.8 show that at any point of time 6 (six) ships are in port till 2370 days thereafter the number of ships in port increases to more than 6 ships meaning that 1 ship at any point of time is waiting and hence the port has to make investments to increase its capacity to 7 ships per day.
Simulation Run 2
Efficiency = 0.5
Capacity= 3 ships per day

Figure 6.9: Simulation Results with Efficiency <1

The above results in figure 8.9 show that when efficiency drops by 50%, the number of ships increases in port meaning congestion and in long run diversion of ships from this port to another port.

Policy makers at this stage may tend to taken capital investment decisions for building berths instead of increasing efficiency through better equipment, manpower and other resource planning. If efficiency is improved to 1 then the results as shown in figure 8.7 will be applicable.

Simulation Run 3
Efficiency = 1
Capacity= 7 ships per day
In this run the maximum ships that can depart in a day is set to 7 and mean departure rate set to 5 ships per day. Figure 6.10 below shows that less than 3 ships are port at any point of time. This would mean port can attract more ships without waiting time.
6.5 Chapter Summary

The propositions leading to the dynamics of the port can be stated as follows
   i. “Carriers (Ships) prefer the port with low or no waiting time”.
   ii. “Shippers prefer the port with lowest cost of handling cargo”
   iii. “Ships prefer efficient ports, on other hand the waiting time of the ships depends on the rate of arrival of ships (Ships in) and capacity of the port” or in other words, “Improved capacity brings in new ships as the waiting time of ships decreases and also that productivity increases and hence the port earns more revenue”

Based on the above propositions the interactions of the all the major variables that explains the structure that governs the behaviour of a port system is represented in an integrated causal loop diagram.

As the number of variables affecting the port dynamics are quiet large in number making the causal diagram complex to be developed as a System Dynamics model, two dimensions identified by the Factor Analysis carried out in chapter 5, namely, the efficiency dimension and the capacity dimension are used in the simulation model to show the causality between
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the two dimensions of port performance, namely, capacity and efficiency-level with ATRT (average turn round time) and NO OF SHIPS (number of ships) calling at port.

The model demonstrates that capacity and efficiency dimensions influences average turn round time (ATRT) which in turn affects the number of ships calling at port and can be described as a dynamic model based on principles of causality.

The policy implication of the model is that the decision maker has two different options to enhance its performance (i) increase its capacity through increase in average ship day output (AOPSBD) through modernizing or replacing the equipment, and/or training of manpower, and/or management restructuring through privatisation; (ii) enhance efficiency through enhancing “soft measures” relating to cargo handling processes viz, documentation, ICT and statutory inspections, and/or increase in draft (may be through dredging, better disposal), and/or improved supervision resulting in reduction in non-working time of ships at the port.

The impact of efficiency level due to actions taken to improve the ATRT is not static, as improvement of ATRT is likely to increase number of ships arriving at port causing waiting time of ships to increase, meaning a low performance measured through ATRT. Beyond the permissible level of increasing efficiency, capacity addition through additional berths and associated infrastructure has to be done through investments. Hence, the impact of the changed decisions has to be simulated and results monitored to achieve the corporate goal.

Simulation under ideal conditions, i.e., when efficiency is equal to one, with the capacity of six ships per day shows that at any point of time 6 (six) ships are in port till 2370 days. After which the number of ships in port increases to more than six ships meaning that 1 ship at any point of time is waiting and hence the port has to make investments to increase its capacity to seven ships per day.

When efficiency drops by 50 percent, the number of ships increases in port meaning congestion and in long run diversion of ships from this port to another port.
Policy makers at this stage may tend to take capital investment decisions for building berths instead of increasing efficiency through better equipment, manpower and other resource planning.

Simulation setting maximum ships that can depart in a day equal to seven and mean departure rate to five ships per day shows that less than 3 ships are at port at any point of time. This would mean port can attract more ships without waiting time.