Theoretical Framework for the Freight Movements Through a Multicommodity Port

P. Oliver jayaprakash, A K.Gunasekaran

Abstract --Port based freight movement planning is a complicated task that could be carried out efficiently to handle the cargo, optimally utilize the infrastructure and plan the future infrastructure requirements. The nature of activities at the port is dynamic with uncertainties,since the operationsare time bound, scholastic and probabilistic.As the huge capital is involved in port infrastructure, the inter-relationship between port activities need to be understood and a system model enveloping the relationship among the variables is much needed for optimal utilization of existing facilities and to predict the future infrastructure requirements. The conventional four step model approach for modeling the person trips would not effectively reflect the commercial scheduling constraintsand requirements of freight trips. This research workattemptsto model the port operations, to assess the level of service of roads and gate operations as subsystems to understand the interdependencies between the variables and the impact on the port operations as a whole.

Key Words: System, Modeling, Multicommodity port, dynamic commodity flow, Turnaround time, Vessel arrival.

I. INTRODUCTION

The performance of the port is denoted by the turnaround time of vessels (VTT) it handles. Time series techniques such as ARMA,ARIMA and GRANN were used to quantify the vessel arrivals, movement of commodities from port to city centres.Several researchers (Daniel pena,1995, Amaury Lendasse,1998, Siem JanKoopman,2006,Vedatyoruchu,2003,Kalekar Prajakta,2004,Nghiep Nguyen,2008) explored a periodic time series analysis.A Hybrid model s such as Grey Relational Artificial Neural Network (GRANN) and ARIMA was proposed by the researchers (Ram pendyala, 2002, Rosalina Sallehuddin, 2007,Krishnamurthyss,2010). (Dhingra,et.Al,1993) adopted the time series analysis technique to study the good traffic in four predominant corridors accounting for major truck movement in Bombay metropolitan region for modeling. Ten candidate models of ARMA & ARIMA family were investigated to represent the corridors based on the significant weekly periodicity. Kwon Lee and Kap Hwan Kim (2012) proposed a method for determining an optimal layout of container yard. Kek choo chung (1993) evolved a rational formulae for port operations performance based on the suggestions of World bank based UNCTAD. Wadhwa (1990), Kasypi Mokhtar&Mohd.Z.Shah (2006) modeled the VTT with Regression Model (R^2, 0.99) for port throughput and performance and concluded that, by reducing the VTT High throughput could be achieved.

Peter Marlow & Ana Paixao casaca (2003) pioneered the qualitative and quantitative approaches for measuring the port performance and introduced a new concept of Lean port and conditions for agile port. Agile ports share information about capacity utilisation by linking with neighbor ports with information sharing with advance Information technology and do cargo share when other port is redundant. Jose Tongzon (1995), Ng Siew Ming &Mohd.Z.shah (2008) developed a VTT Model for container vessels using service hours and number of quay crane used and throughput at port klang. Asperen E.Vanet. Al (2010), Daniela Ambrosino and Elena Tanfani (2009) Borgman et.al (2011) Petering (2011) used a discrete event simulation model to evaluate online container stacking rules in container terminal. Su Min Jeon et.al (2011) suggested a routing method based on route for automated guided vehicles in port terminals that uses the Q-learning technique. YounJu Woo and Kap Hwan Kim (2011) suggested method for allocating storage space to groups of outbound containers in a container terminal. Yan Wang and Kap Hwan Kim (2011), Haitham Al-deek (2007) –Freight trip generation model using regression analysis and back propagation neural networks to predict the cargo truck traffic of Miami port. With a sizeable database neural network model performs better than regression. Nathan Huynh,et.al (2007) developed a systems dynamics model for truck turn time analysis with respect to crane availability and deployment. The model used for Houston port to demonstrate the number of yard cranes needed to achieve a desired truck turnaround time (T-tat). Rodrigo Garrido and Felipe Allendes (2002) used the navigation system, loading and unloading, transfer and storage of containers in their queuing based analytic model to compute the container terminal efficiency. Khalid Bichou and Wisineewisetjindawat (2006),Amelia Regan and Rodrigo Corrido (2002) developed a freight distribution modeling.Tylor (1976),kia (2002), DimitrisPachakis and Kiremidjian (2003),Hanne LoviseSkartveit et.al (2003) developed a methodology for vessel traffic modeling using regression based simulation model considering vessel length,draft and capacity. Dahal et.al. (2003) Port simulation model to optimize the bulk port handling system through a meta heuristic approach. An evolutionary approach based GA was developed to provide an optimal capability of the port simulation tool. Sampsa Ruutu (2008) system dynamics based forecast model for Finnish port using casual mechanisms to determine the behaviour of the entire system. The model studies the changes in macro economy to the transport system. Carlucci and Cira (2009) adopted multi-criteria technique and system dynamics approach to test the policies of Maritime transport. Shabayek and yeung (2002) developed a simulation model to predict the container operations of Kwai chung container port.

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El Naggar (2010) devised a methodology to support the decision making process by developing port infrastructure to meet the future demand. Using the queuing analysis estimated the optimum number berths and minimizes the total port costs at the Alexandra port in Egypt.**L**imited studies on Bulk cargo ports and modeled their operations.

The focus of past research was on containerized cargo movement and analyzing the port problems visualizing the causes discretely and failed to address the related subsystems of a port in a holistic manner. Hence, a comprehensive integrated port operations model was built to

simulate the operations of cargo port handling multiple commodities.

II. OBJECTIVE& METHODOLOGY

The objective of the research was to develop models to predict the relationship between the major aspects of freight movements and their influencing variables and to build a system model to depict the complete operations occurring at a multi-commodity port and formulate scenarios, to estimate and evaluate the various extent of utilization for the future requirements.Fig.1 depicts the methodology followed in the research.
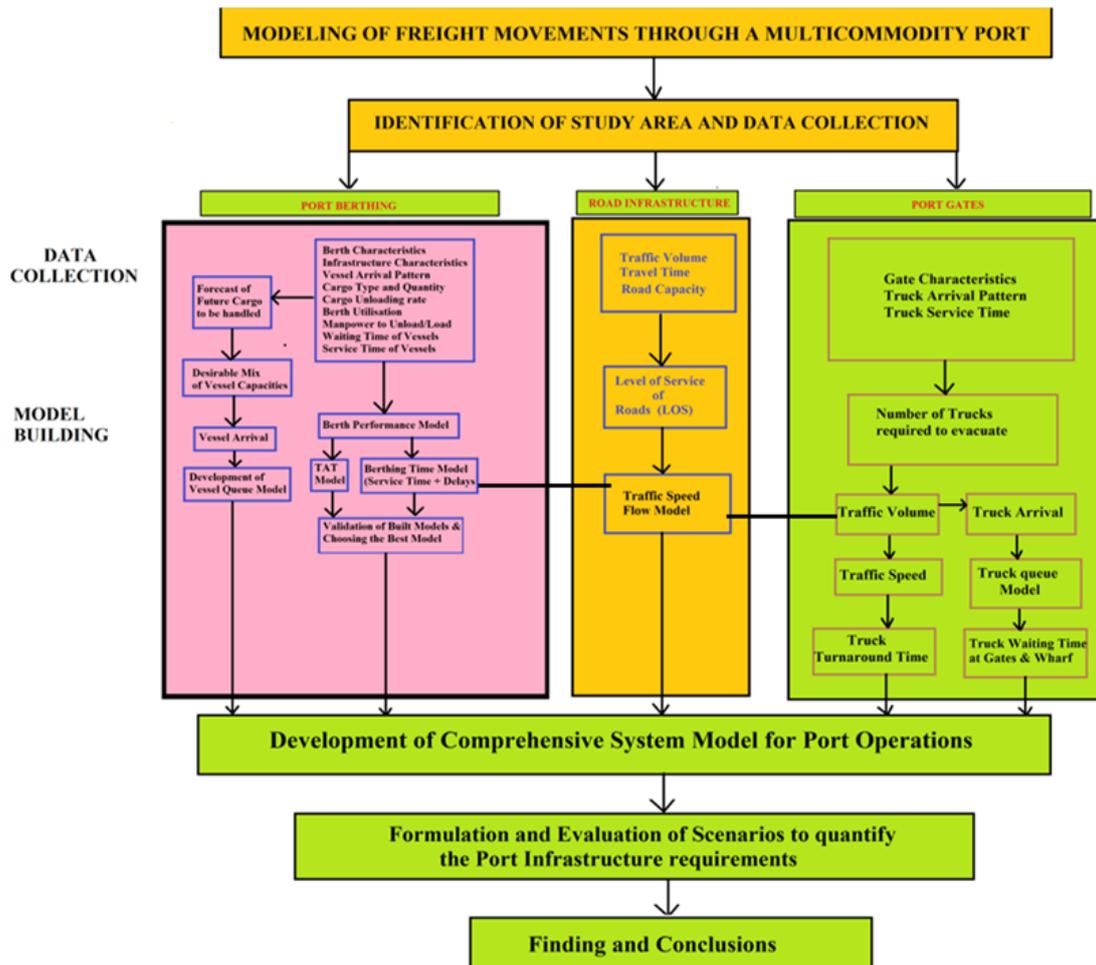

Fig.1 Methodology of the Study

VOC port located at Tuticorin was chosen as Study port shown in Fig.2. It is near to world Maritime route,Most preferred port by Commodity handlers due to simplified and fast document processing. Maximum cargo handling capacity is 25 Million Tons per year, It has Tuticorin port trust labour pool) with dedicated fleet of 180 trucks for port. It serves as a Distributor for Containers from Columbo port (USA, Africa, Europe, Arab countries).Cargo handled is classified as break-bulk cargo consists of food, constructionmaterials, rockphosphate, sugar, wheat,gypsm, Bulk cargo consists of granite, timber logs, stone slabs, machinery parts,
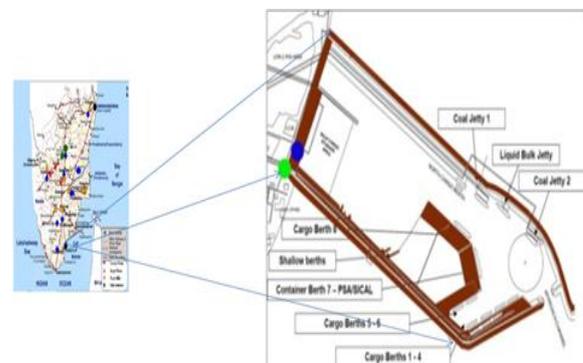

Fig.2 Study Port - Tuticorin, Tamilnadu

Dusty cargo consists of Thermal Coal, Industrial coal and Containers includes goods varying from seafood to electronics. The traffic flow on port roads, travel time and delay, hourly arrivals and delay faced by shunt trucks at port gates were collected during the peak ship arrival period. Details of ship arrivals, vessel size, capacity, service time, delay, berth occupancy, berth priorities were collected for break-bulk, bulk, dusty cargo (coal) and containers during the period 2005-2009. Vessel Turnaround time (VTT) is to be minimum for achieving maximum productivity of the port. The VTT is much influenced by the delay component of vessels. At Indian ports vessels need to wait at outer habour for a duration called pre berth detention. i.e. waiting for the berths to be free to occupy. This phenomenon is unique for Indian ports, since the foreign ports' capacity is much larger than their demand. Indian Ports are handling more than their capacity. It is the prime factor influencing the vessel delay in addition to the other resource deficiencies and lack of networking of ports for cargo sharing and diversion. Delay at berths faced by Indian ports is significant but varying   between 20 to 55% as shown in Fig.3. Tuticorin Port faced the 2% delay for Containers (since fully automated) whereas Bulk cargo faced the 26% delay due to manual handling of commodities and lack of resources at berth. This is much pronounced due to the pre berthing detention and other factors such as manpower required and unloading rate at berths. The issues connected with the flow of commodities in a multimedia port are given in Fig.4.

III.   BASIC HYPOTHESIS

The relationship between the freight movements and influencing variables are dynamic and varying with uncertainty.The basic hypothesis is to estimate the future monthly ship arrivals and to predict the ship queues and truck queues at port entry and exit gates. Models were built to study the relationship between freight movements and their influencing variables using MLR, NLR and ANN. ARIMA was used to forecast future monthly ship arrivals, queuing models were built to simulate the ship queue at berths and truck queues at port entry and exit gates, speed flow relationship model was developed to understand the quality and quantity of truck flow on the roads of port.Upon validating all the developed models, a comprehensive port systems model incorporating various operations involved in port berths, port road infrastructure and port gates subsystems was developed.The system model built, incorporates all uncertainties such as vessel arrival at berths and evacuation of cargo from berth to storage area and queuing of vessels at outer harbour and queuing of trucks at port entry gates, etc.

Hence, it was decided to build the system model to simulate the operations of a multi-commodity port

comprehensively. The port systems model developed depicts the complete performance of the port operations. It could be used to simulate and forecast the future vessel arrivals and the resource requirements based on tonnage of the vessel and capacity of cranes, gang strength and berth utilization rate. It includes all uncertainties and has an inbuilt flexibility for inclusion of any new parameters as and when required. The study findings are summarized based on the observations, inferences from the traffic surveys, model development, sensitivity analysis of models and scenario analysis results.
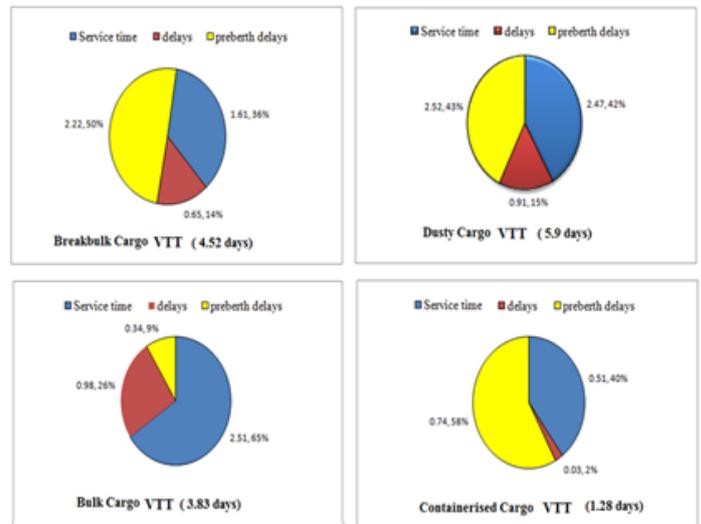

Fig. 3 Components of VTT of the Study Port (VOC port, Tuticorin)

IV.   CARGOARRIVAL FORECASTING

The forecast of cargo arrival to ports is seasonal and depends on various factors. But it was found to follow a definite pattern. The ARIMA model (Autoregressive Integrated Moving Average) based time series models were developed to forecast the cargo arrival using 2005-2009 commodity wise monthly arrival. The accuracy of the ARIMA model was tested for break-bulk monthly arrival in 2010 by comparing the observed monthly cargo arrival with the model predicted values. The accuracy was 87.2%. The ARIMA could be used for predicting the season trend of cargo arrivals to the port. The other factors that may influence the monthly cargo arrival such as role of stevedores, vessel agents, customers, regional demand/production, economic impact, government policies are not accounted but it is assumed that their influence would be same as in the previous years.
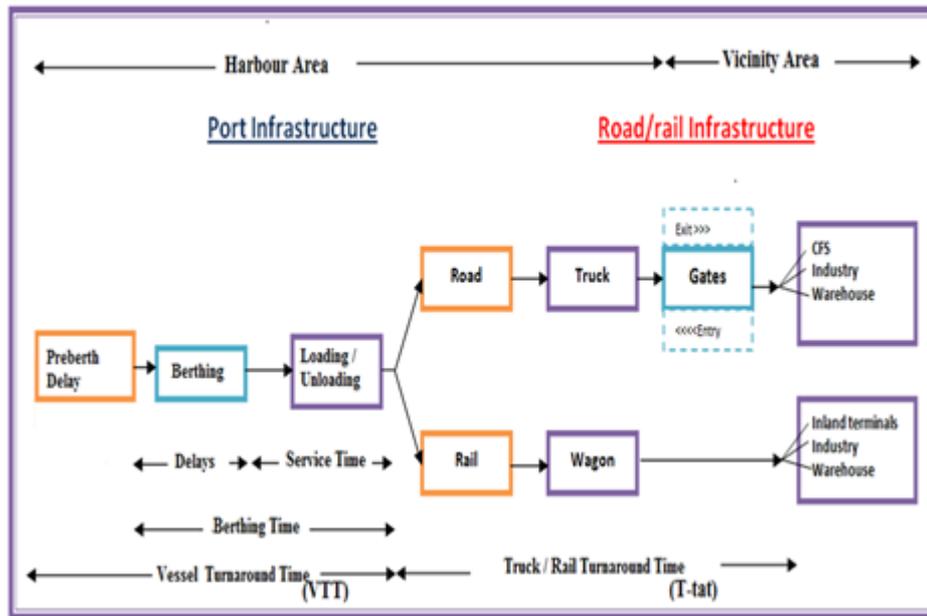
Fig.4 Issues in connection with the Cargo Movement through Ports

A. Vessel Capacity

The study port falls under the category of third generation port. It currently handles the coastal (3000 tons), small (10000 tons), handy (30000 tons) and handymax (45000 tons) category of vessels. The small and handy vessels are periodically calling the port to handle break-bulk cargo, bulk cargo and containers. Whereas, dusty cargo (coal) is carried by the handymaxtypevessels regularly.On review of the composition of vessel capacity for the period 2005-2009, the share of large vessels (15000 tons capacity and above) visiting the port is gradually increasing. The capacity of vessel calling the port is mostly decided by the vessel agents, cargo clearing and forwarding agents, stevedores and customers. The draft level of the port berths also has an impact on composition of vessels. However, port authorities can suggest the mix of the vessels expected in future, by pre

assessing the infrastructure capabilities and based on the future cargo forecast (demand).

The impact on variation of vessels percentage share with varying capacity was analysed to help the port management to take a policy decision on mix of the vessel arriving based on capacity To demonstrate the impact of mix of vessels on the effective time required at the berths, 4 proportions of vessel capacities for a monthly break-bulk cargo arrival of 0.25 Million Tons (MT),0.5MT, 0.75MT and 1MT were considered (Table). The preferred mix is suggested as the one that requires less cumulative berthing time for the month. 3 berths are taken as reserved for break-bulk cargo vessels with a unloading rate is 4500 TPD, the manpower employed is 30 numbers and berth occupancy is 40%. The berthing time is computed by summing the estimated service time and vessel delay at berths. Service time of vessels and delay at berths were computed using the developed models.

Table 1. Percentage Mix of Cargo Vessels Expected to Visit the Study Port

Mix	Mix of Vessels with Capacity (in tons)								
	3000	9000	15000	21000	27000	33000	39000	45000	Total
Mix1	9%	13%	39%	4%	33%	2%	0%	0%	100%
Mix2	4%	7%	39%	6%	37%	2%	3%	2%	100%
Mix3	1%	1%	39%	9%	39%	3%	4%	4%	100%
Mix4	0%	0%	35%	9%	43%	3%	5%	5%	100%

B. Vessels' Service Time

Service time of vessel got affected by several factors. The influence of operational characteristics such as type of cargo, loading rate, manpower and berth occupancy on service time is analyzed. The service time increases with the capacity i.e. effective time required for loading / unloading increases with the quantum of cargo to be handled.Fig.5 shows the berthing time of vessels required based on the arrival pattern based on mix of vessels.
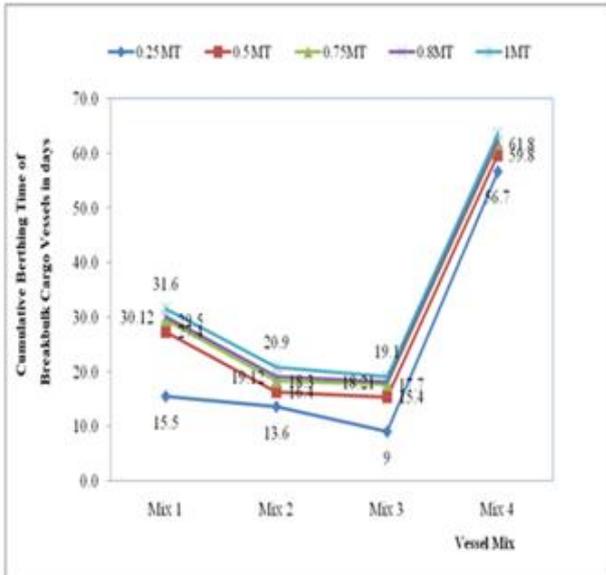
Fig.5 Cumulative berthing times for various mixes of Break-bulk cargo

Fig. 6 Influence of unloading rate on service time of breakbulk ships

C. Unloading Rate of Cargo

The service time increases modestly with increase of unloading rate, (up to 21000 Tons capacity vessels) irrespective of the cargo carried by them. The service time of the vessels was computed with the developed models (as Equations (Equations A2.5, A 2.6, A2.7 and A 2.8) for unloading rates 1000, 2000,4000,6000 and 8000 tons per day. The optimum unloading rate is 4000 tons per day for break-bulk cargo, 6000 tons per day for bulk cargo and dusty cargo. From this analysis the optimum level of unloading rate could be decided for the preferred service time and the vessel capacity. The decision to upgrade crane capacity could be decided by the port authorities based on the capacity of vessels visiting the port. Service time for the given gang size of 30 numbers and berth occupancy of 40%, thebreak-bulk cargo handling needs unloading rate of 2000 tons per day to unload vessels up to 9000 tons. Whereas for 15000 tons capacity vessels when unloading rate of 8000 tons per day is engaged the service time required is 3.15 days. When unloading rate of 4000 tons per day is engaged the service time of 7.43 days is needed. Crane with 4000 tons per day may be utilized vessels of 15000 tons capacity or lessis expected. If the vessel capacities with the range of 15000 tons to 33000 tons are expected then cranes with unloading rate of 6000 tons per day may be utilized. For vessels with capacity more than 33000 tons, cranes with unloading rate of 8000 tons per day would be optimal. The cranes for bulk cargo handling are to be selected with respect to the service time requirements. The Influence of Unloading rate on Service time is depicted for various combinations of unloading rates.
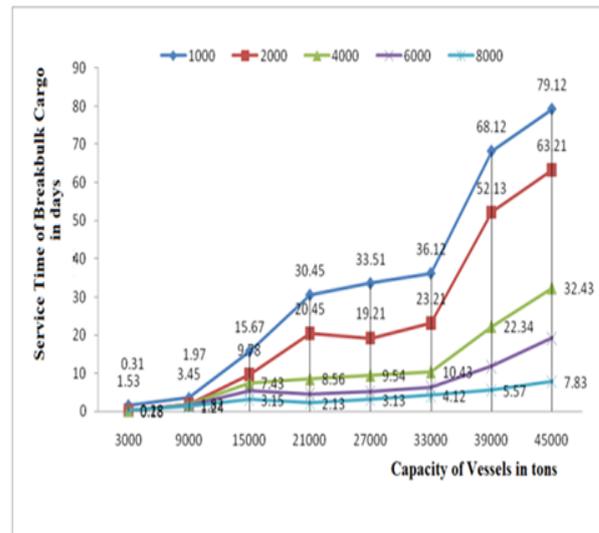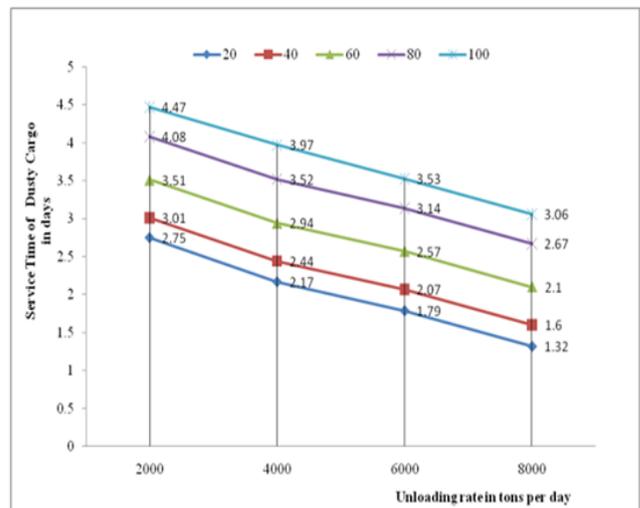

Fig.7 Effect of Berth Occupancy on Service time of Dusty cargo ships

D. Berth Occupancy

With the increase in occupancy in neighbouring berths, the service time of vessel increases moderate (due to the increased turnaround time of the trucks (T-tat) engaged for evacuation of the cargo) irrespective of category and capacity of vessels. To study the influence of berth occupancy on service time, the service time was calculated using the developed models (Equations A2.5, A 2.6, A2.7 and A 2.8) with the berth occupancy of 20%, 40%, 60%, 80% and 100% for unloading rate of 2000, 4000, 6000 and 8000 tons per day. For the unloading rate of 4000 tons per day and berth occupancy of 20%, the service time required is 2.17 days. The service time increases to 2.44 days with 60% berth occupancy. Whereas for 80% berth occupancy the service time required is 3.52 days. The optimal berth occupancy is in the range of 60 %- 80 % for higher unloading rates. When berth occupancy increased above 60% (for unloading rate less than 6000 tons per day) the service time increases drastically.

The effect of berth occupancy on service time break-bulk cargo is shown in Fig.7 and Fig.8. The analysis helps to decide the desirable vessel reception for the existing berth occupancy. Port authorities can make policy decisions based on occupancy analysis to avoid unnecessary congestion of port infrastructure, non availability of grab cranes, and shortage of trucks for evacuation from the berths. The manpower requirements of loading / unloading operations have significant influence over service time of breakbulk, bulk and dusty cargo vessels. However, the container vessels' service time is not influenced by manpower requirements; since containers are handled fully by machineries.

E. Delay of Vessels

The delay caused to the vessels at berth varied from 15% to 55% of the vessel turnaround time (VTT). Delay is much influenced by the congestion at road, gates, and resource mobilization at berths. Truck turnaround time (T-tat), number of trucks, trip distance, truck capacity and unloading facilities at warehouses and at berths, administrative procedures to be followed, cleaning and towing of vessels and weather conditions are the other factors influencing vessel delay.Delay models built for non-containerized cargo using regression techniques. The delay of vessels at berths carrying non-containerized cargo is best explained by linear regression model with R^2 value of 0.899. With the increase in number of evacuation trucks due to increased travel time on the roads and additional waiting time at gates, the vessel delay also increased. Truck turnaround time (T-tat) is influenced by truck capacity, number of trucks, operations at entry/exit gates and the level of service of port roads. The distance between wharf/berth to the centriod of warehouses zone is 4 km. The optimum truck turnaround time (T-tat) was 1 hour 50 minutes. It is clearly understood from Fig.9 that the vessel delay at berths due to impact of the truck turnaround time (T-tat) is almost constant for 40 to 80% berth occupancy. Berth occupancy greater than 80% had significant influence on the vessel delay. It is preferable to permit vessels at berths so that ports' berth occupancy does not exceed 80% When due to future vessel arrivals berth occupancy is expected to increase beyond 80% expansion of port has to be planned.
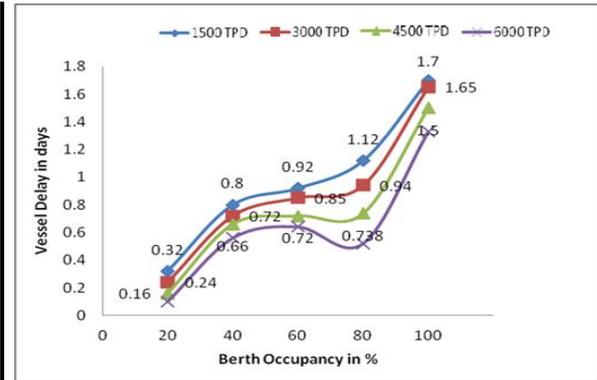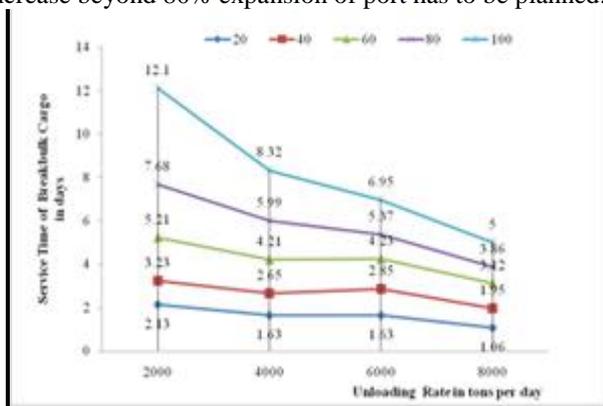

Fig.8 Effect of Berth Occupancy on Service time of breakbulk cargo shipsFig.9 Effect of Berth Occupancy on Vessel delays

Fig.10 Vessel Queuing System

F. Pre-berth delay

Pre-berth delay is the delay faced by vessels at outer harbour due to waiting for berth allocation, vessel repairs, poor weather and other factors. If there is a shortage of berths then the preberth delay happens. Also, it is understood on policy decision on size and capacity of vessels calling in is expected to have an impact on the preberth delay. Queuing models were developed to simulate the vessel queue for berths. The vessel arrivals pattern for the season was represented with the probability distribution functions. The vessel queuing system is shown in Fig.10.

V. BERTH PERFORMANCE MODELS

Two approaches to estimate turnaround time (VTT) of vessels were formulated and compared.

1. Prediction of VTT using the model for vessel turnaround time.
2. Prediction of VTT by summing the estimated service time and delay at berths using the exclusive models with estimated preberth delay of Vessels predicted using queuing model.

The percentage error of predicting VTT of vessels byadopting second approach is much lesser than first model. Hence, it is recommended to estimate VTT of vessels using the second approach for multi-commodity ports where delay is expected to be significant.Conventional VTT model overestimates the delay and dwell time of ships.

It is fit to use under conditions, where the delay component is very less and there is no preberth delay. Whereas the proposed second approach, berthing time based VTT model accounts exactly the preberth delay as queuing model is used. The observed, conventional and berthing time approaches are depicted in Fig.11 and Fig. 12.
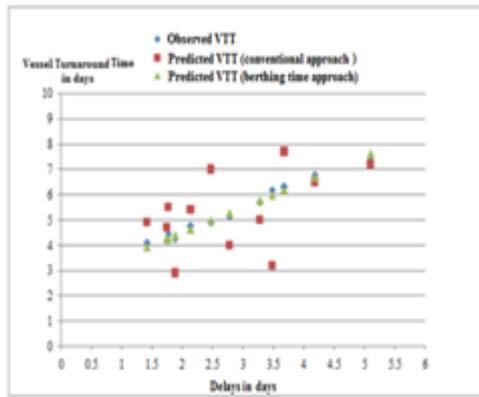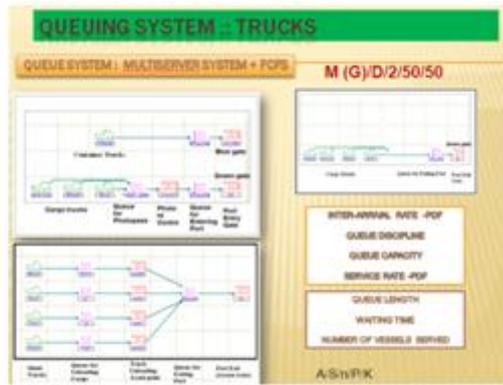

Fig. 11 Delays Vs VTT

Fig.12 Ship queuing model

A. Truck Queuing Model

Truck queuing models were developed to simulate the truck queue at port gates and to predict the truck waiting time. The truck arrivals were given input to the truck queuing model as a probability distribution functions. The hourly arrival pattern of outgoing / incoming trucks at port exit gates were described using probability density functions developed using the recorded truck service time at port gates. The number of truck movements anticipated per hour and the numbers of gates operated during the hour were considered as inputs and the average time spent at gates was computed (Fig.13).Truck queuing model is an effective way of estimating the truck queue length and truck delay at port gates. The results would help the port authorities to take policy decisions to construct the optimum number of gates and to operate the required gates for the anticipated truck movements.

Fig. 13 Effects of Number of Trucks on Gate delay

VI.   PORT SYSTEM MODEL

The system model built incorporates all uncertainties such as vessel arrival at berths, evacuation of cargo from berth to storage area, queuing of vessels at outer harbour, queuing of trucks at port entry gates, etc. The port model developed with system dynamics approach (Fig.14) was validated as per the recommendations of forrester (1961), Senge (1980), Barlas and Carpenter (1990). The accuracy of the port system model was 84% when the service time of break-bulk vessels compared with observed service time values of vessels for the year 2010. Hence, the proposed port model could be used to simulate the cargo transshipment operations through a multi-commodity port with the practical constraints and operating characteristics to forecast the future developments and evaluate the existing capacity of port infrastructure and improvements.

The scenarios formulated and evaluated are;

Scenario 1: Base Scenario

Scenario 2: Variation in Vessel Mix based on Capacity

Scenario 3:   Increase in Unloading Rate to 85% of Capacity of Existing Crane

Scenario 4:   Further Increase of Unloading Rates by High Capacity Cranes

Scenario 5A: provision of 2 berths

Scenario 5B: provision of 4 berths

Scenario 5C: provision of 8 berths

Scenario 5D: provision of 10 berths

Scenario 5AG: provision of 2 berths with 1 pair of gates,

Scenario 5BG: provision of 4 berths with 3 pairs of gates,

Scenario 5CG: provision of 8 berths with 7 pairs of gates and

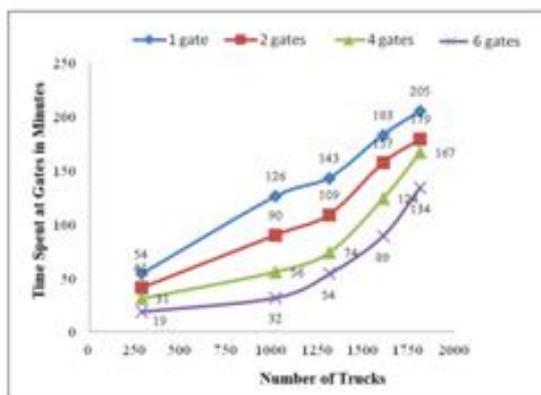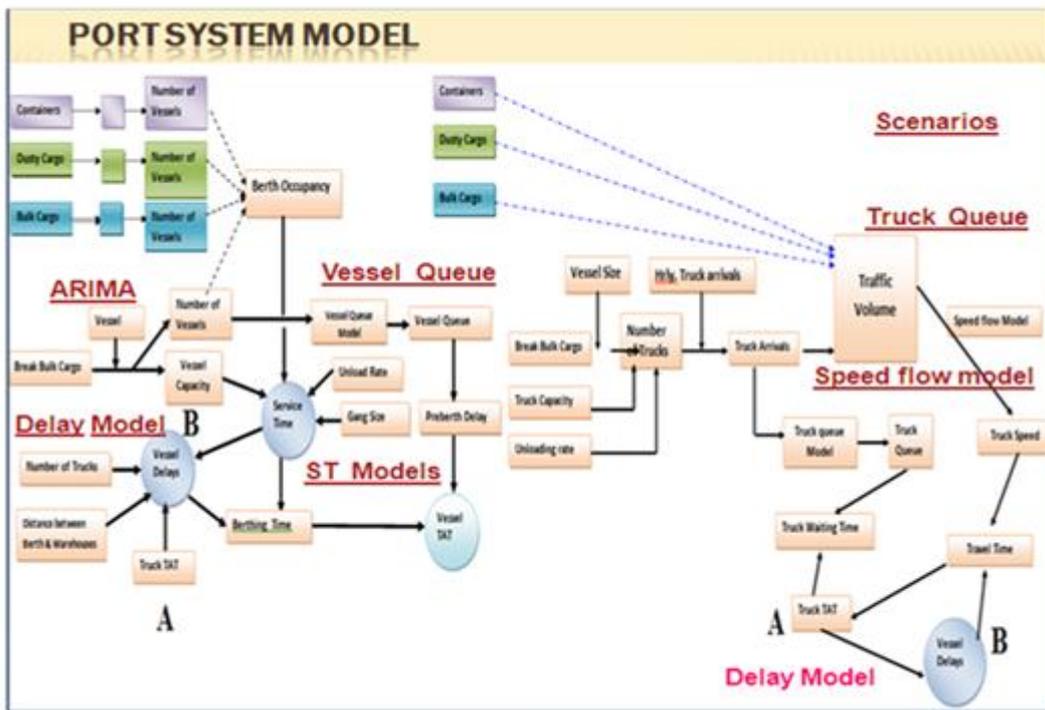Scenario 5DG: provision of 10 berths with 9 pairs of gates
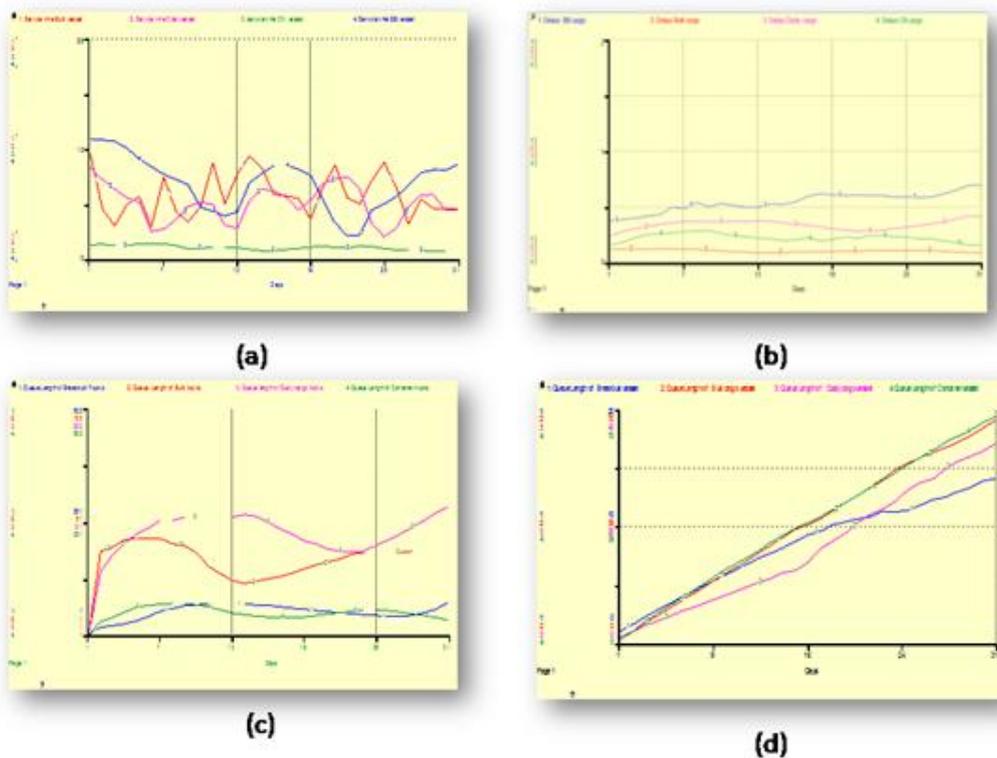
Fig.14 Port system model

Fig.15 Outcomes of Simulated Port Model

a) Service time of cargo vessels   b) Delay of cargo vessels
c) Queuing length of cargo trucks   d) Queuing length of cargo vessels

On installing higher range of unloading / loading cranes the service time was found to improve. For scenario 2 the service time reduced by 59 % when the unloading rate was increased from 2000 tons to 5000 tons, berth occupancy reduced by 14% when the vessel's capacity ranges from 3000 tons to 15000 tons are replaced by vessels with capacity ranging from 15000 tons to 45000 tons. On addition of berths (Scenarios 5A, 5B, 5C & 5D) the service time of vessels at berth reduced but there was an increase in

vessel delay at berths due to increase in turnaround time of trucks (T-tat). When addition of berths with gates (Scenarios 5AG, 5BG, 5CG & 5DG) are made, it resulted in the reduction of delay and truck turnaround time (T-tat). The berthing time (service time + delay at berths) of break-bulk cargo vessels also decreased (Fig.14).
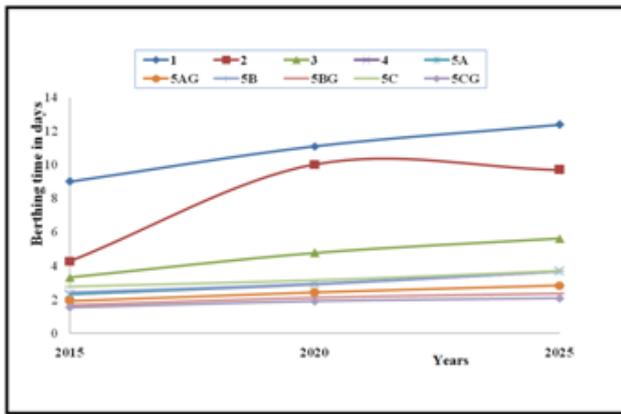
Fig.16Comparison of Vessel berthing time for various scenarios (Break-bulk cargo vessels)

The mean queue length of break-bulk vessels reduced significantly during 2015- 2020. The mean queues length reduced by 84% from 0.69 to 0.11 number for addition of 2 berths and 1 set of gates (scenario 5AG), 85% from 0.62 to 0.09 number for addition of 4 berths and 3 gates (scenario 5BG), 85% from 0.56 to 0.09 number for provision of 8 berths and 7 gates (scenario 5CG) and 88% from 0.52 to 0.06 number for provision of 10 berths and 9 gates (scenario 5DG) in the year 2015. In the year 2020, the mean queue length reduced by 86% from 0.7 to 0.1 numbers with scenario 5AG, reduced by 100% to no queue situation for scenarios 5BG,5CG& 5DG. It reduced by 5.3 % from 1.9 (scenario 5A) to 1.8 numbers for Scenario 5AG, reduced by 7.6 % from 1.72 to 1.59 numbers for scenario 5BG, reduce by 33% from 1.2 to 0.8 numbers with scenario 5CG and reduce by 14 % from 0.93 to 0.8 numbers with scenario 5DG in the year 2025.

By administering a policy decision of having higher share of high capacity vessels the port could have the reduction in berthing time of the vessels, scenario 3 (Change of unloading rate) and scenario 4 (installation of new high capacity cranes) reasonably reduce the service time of vessels for shorter time period between the year 2015 to year 2020. Hence, from the scenarios formulated and simulated, it is evident that further reduction of berthing time could be achieved by reducing the truck turnaround time (T-tat) by providing adequate number of berths with gates. The provision of gates reduces the delay of trucks at gates and truck turnaround time (T-tat) significantly. Hence, the vessel delay at berth is reduced with reduction of truck delay at gates (Figures 6.10). The gate delay reduced from 90 minutes to 45 minutes by adding one set of gates in 2015, further reduced to 25 minutes with installation of 2 berths and 1 set of gates. The gate delay reduced to 12 minutes when 10 berths and 9 gates are installed. Fig.17 shows the delay at Gates over the scenarios.
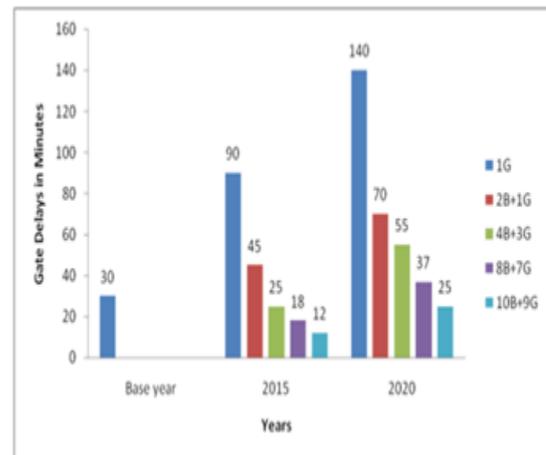

Fig.17 Delay at Gates for various scenarios

The truck turnaround time got reduced from 234 minutes to 144 minutes by adding one set of gates in 2015, further reduced to 104 minutes with installation of 2 berths and 1 set of gates. The truck turnaround time reduced to 78 minutes when 10 berths and 9 gates are installed for the year 2015.The mix of the vessel capacities visiting the port varies with the cargo type. The vessel arrival patterns, unloading rate, clearance at gates, capacity and utilisation of infrastructure and other port operations of the multi-commodity port were studied. The study port falls under the category of third generation multi-commodity port. The level of throughput by the port is 25.72 Million tons of cargo (including liquid, LPG and chemicals) during 2010-2011. The port handles vessels carrying break-bulk, bulk, dusty cargo and containers.

The ARIMA based time series models used to predict the future cargo. The accuracy of break-bulk model is 87.2%, bulk cargo is 75.5%, dusty cargo is 85.5% and containerised cargo is 85.2%. The speed flow relationship model was developed (R^2 value of 0.12) for the port roads. Queuing models were developed to simulate the vessel queue for berths and to predict the vessel waiting time. The vessel arrivals were given input to the vessel queuing model as a probability distribution function. Truck queuing models were developed to simulate the truck queue at port gates and to predict the truck waiting time. The truck arrivals were given input to the truck queuing model as a probability distribution functions. The hourly arrival pattern of outgoing / incoming trucks at port exit gates were described using probability density functions developed using the recorded truck service time at port gates.Multiple linear and nonlinear regression based models were developed to predict the relationship between the major aspects of freight movements and their influencing variables. The models were validated.The accuracy of the multiple linear regression based service time models is better. The R^2 value of break-bulk cargo is 0.82, bulk cargo is 0.90, dusty cargo is 0.86 and the container is 0.42. The service time of vessels carrying break-bulk cargo, bulk cargo and dusty cargo is best explained by the nonlinear regression models developed with R^2 values of break-bulk cargo regression model is 0.99,bulk cargo is 0.94 and dusty cargo is 0.91.

Theoretical Framework for the Freight Movements Through a Multicommodity Port

The accuracy of multiple linear regression based Delay model (for non-containerized vessels) is 89 %. Two approaches to estimate turnaround time (VTT) of vessels were formulated and compared. The percentage error of predicting Turnaround time of vessels by adopting second approach by summing the estimated service time and delay at berths using the exclusive models with estimated preberth delay of Vessels predicted using queuing model is much lesser than VTT model (Figure 18,19 and 20). Hence, it is recommended to estimate turnaround time of vessels using the second approach for multi commodity ports where delay is expected to be significant.
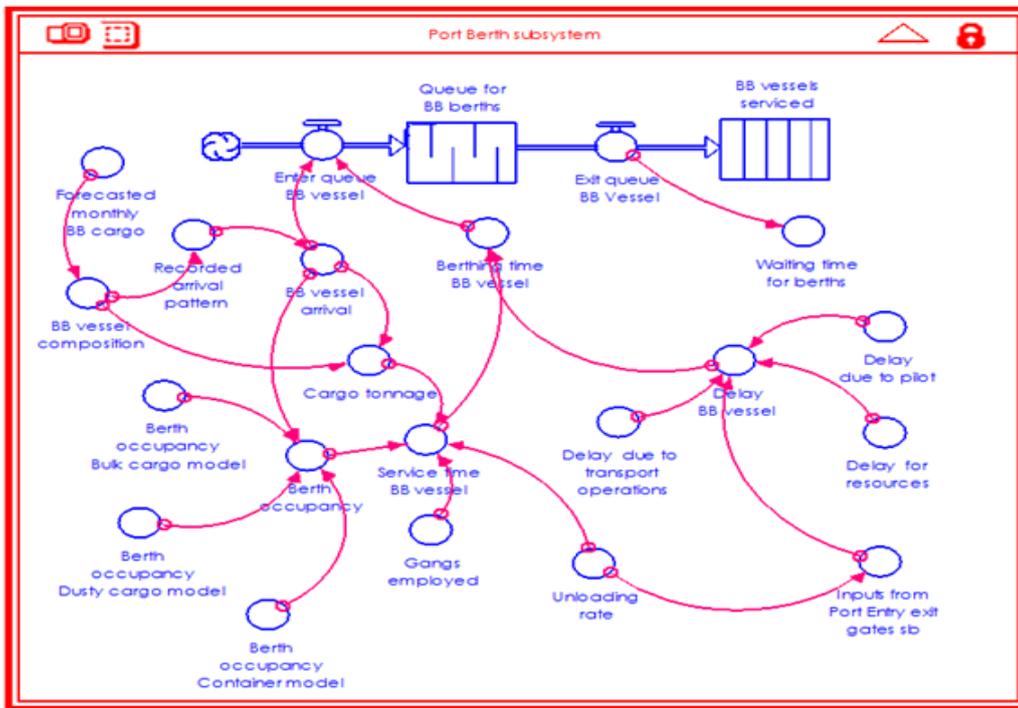

Fig.18 Stock and flow diagram showing Port berthing subsystem for break bulk cargo
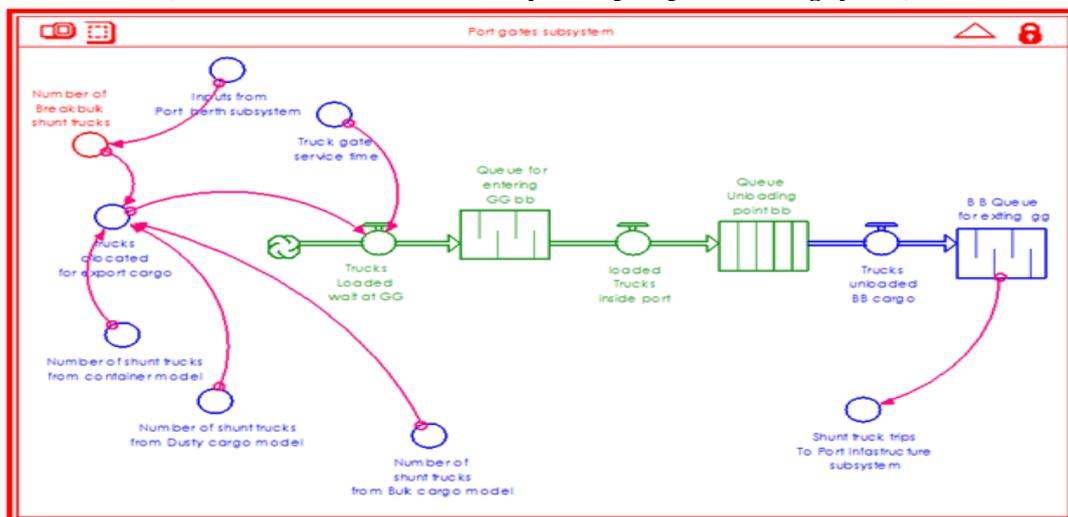**(Source: Stella IV software analysis output: port berthing system)**

Fig. 19 Stock and flow diagram for Port entry / Exit subsystem for break bulk Cargo
Application of port system model to the study port

A comprehensive port operations model was developed to depict the dynamism of the cargo handling operations through a multi-commodity port. It could be used to simulate and forecast the future vessel arrivals and the resource requirements based on category of cargo, tonnage of the vessel, capacity of cranes, manpower (numbers of gang to unload/load cargo) and berth utilization rate, etc. From the scenarios developed and tested, the port authorities can formulate the policies to attract more high capacity vessels instead of small capacity ones to reduce the number of vessels visiting the port to required size. The berth occupancy could be prefixed for improving the port performance by minimizing the berthing time of vessels. The unloading rate affects the vessel dwell time, number of trucks required and delay at gates. Hence, the port authorities should opt for periodic revision of unloading rate by upgrading loading cranes with the high capacity.

The up gradation of port infrastructure will result in reduction of berthing time and queuing of vessels and the queuing of trucks at gates. Hence, the port berth and gates expansion have to be carried out after analyzing the effect of the berth addition and gate addition to the port.The underlying models of the port system model were developed (Figures 15,17,18,19) after considering the impact of the independent variables on the port performance indicators (dependant variables) such as service time, delays, turnaround time (VTT). The port system model was built integrating the various models developed. The data collected during 2005 – 2009 were used for model building and the validation was done using the 2010 data. The port system model has the prediction accuracy of 84% for vessel service time and 96.3% for vessel turnaround time.

VII. APPLICATION OF PORT MODEL TO NEIGHBORING PORTS

The port operations model developed has incorporated all micro level operations of a typical multi-commodity port, the frame work of the model could be utilized for developing models of other multi-commodity ports having the similar characteristics as that of the study port.The port operations model has the following limitations while it is put into use.The model runs simulations effectively to the vessel sizes ranging from 3000 tons to 45000 tons capacity.The model performs the simulation of cargo handling operations with cargo unloading rate ranging from 1000 tons per day to 12700 tons per day. The model performs better with the gang size (manpower used for unloading operations) range of 10 to 50 numbers. The model can take four different variety of major cargo types namely, Break-bulk, bulk, dusty cargo and containers and not applicable for liquid cargo (Petroleum, oil and lubes). The break-bulk cargo movement was simulated for the year 2010 and the model predicted the vessel traffic with an accuracy of 84%. Similarly, the models for other cargo vessels were built and integrated to form a port system model. Several scenarios were developed and their performance using the port system model was evaluated.

VIII. CONCLUSIONS

Conventionally infrastructural additions are carried out in piece meal form. The influence of an activity or facility on the other is not analysed in a holistic manner. The study was carried out by developing a system model incorporating the inter relationship of the components and dynamic nature of port activities. Further, the systems model can be used to study the behaviour of the system for variation in utilization and infrastructure additions in a port.

Port is a dynamic system with complex relationship with its sub systems such as port berths, road infrastructure and port entry/exit gates. The present research is limited to study of the relationship of the subsystems to port system and development of a comprehensive port system model. The influence of economic growth of the region in cargo forecast could be attempted. The role of freight forwarders, third party logistics (3PL) operators in cargo handling and their influence in the vessel calling and number of truck deployment could be studied. The feasibility for networking of major ports with the other neighboring ports could be validated with the real time data.

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