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A Queue Model to Reduce Truck Waiting Time in Sea-Port: The Port of Chennai, India

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Abstract

With rising globalization and transportation revolution, international commercial activities through container shipping increase dramatically. Thus, port-related freight traffic increases accordingly. Policy makers aim to upgrade container port function for easing international business and reducing city road congestion. This study aims to analyze the interaction of sea-port and congestion. Considering rapid development of seaports in Asia, we have selected Chennai seaport, India for our case study. First, this study identifies the causes of congestion in a sea port. Three suggestions are provided to eliminate congestion. After that, we propose a queuing model to evaluate the solution strategies. We find that the implementation of ICT is the best solution considering mean waiting time. while, the expansion of entry gate capacity would minimize the maximum waiting time.

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Keywords: Queueing model; SARIMA model; Congestion; Waiting time; The port of Chennai; Time series

1. Introduction

Seaports, being major gateway of international business, are the main interface connecting sea and hinterland transportation in maritime supply chains. With rising globalization and transportation revolution, international commercial activities through container shipping increase dramatically. Container shipments account for 23.8% of seaborne trade in volume in 2016 and are estimated 4.5 percent growth rate (UNCTAD, 2017). Combined with rising ship dimensions, seaports face severe challenges to achieve the productivities demanded by their users. Furthermore, other stakeholders as the government, environmental organizations and residents impose demands on port companies regarding environmental and social aspects. Port authority becomes baffled to balance between the demands of port users and the other stakeholders. Though the opinions of the port users and the other stakeholders may vary on some operational strategies, all stakeholders have a consensus that traffic congestion in a port brings negative externalities to all port's stakeholders. Berechman (2007) finds that the additional road traffic due to a (modest) 6.4 percent container throughput growth at the Port of New York would induce annual 'social costs' ranging from \$0.66 billion to \$1.62 billion, over 60 percent of which is from road congestion costs (the time loss due to traffic conditions and drivers' discomfort). In Vancouver, Canada, truck traffic generated primarily by the port-related activities is becoming a conspicuous contributor to road congestion (Lindsey, 2008). In addition, the imbalances between the supply and demand of port capacities lead to high peak situations. Furthermore, some ports do not have a sufficient yard to store containers and trucks wait for longer time to pick or drop off the container. This situation accounts for a high percentage of the overall transportation cost and for a large proportion of truck arrivals at container terminals. Therefore, this study aims to analyze the effect of different scenarios on traffic congestion in a sea port and selects the Port of Chennai, India as a case study.

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Traffic congestion and the interaction between the port traffic and the city traffic become a major problem in the port of Chennai and surrounding cities. The Port of Chennai, where export containers are mainly brought by truck, observes the increasing trend of the port traffic. About 1500 freight vehicles in a day enter the city of Chennai to access the port from several cities. After dropping a container, some trucks wait to pick-up an import container while other trucks return empty. The turnaround time of truck is quite long in the port of Chennai. As the truck drivers get paid per successful trip, extensive waiting times lead to a low number of trips per day for the drivers and therefore to financial challenges. Figure 1 illustrates exemplarily the different stops for transporting an export container. The port of Chennai has limited yard space and trucks wait until they got a chance to load their cargo on a ship. Thus, truck undergoes through three staging points: (1) Entry gate where document checks are conducted, (2) X-ray point where cargos are checked by pre-installed machine, and (3) Loading-unloading point from ship. In this study, we focus on the queue occurring at the port-entry gate. The queue formed outside of the port-entry gate is too long that it can be stretched to some kilometers. Often the waiting time in the Port of Chennai is longer than the travel time from the origin of shipment to the Port of Chennai.

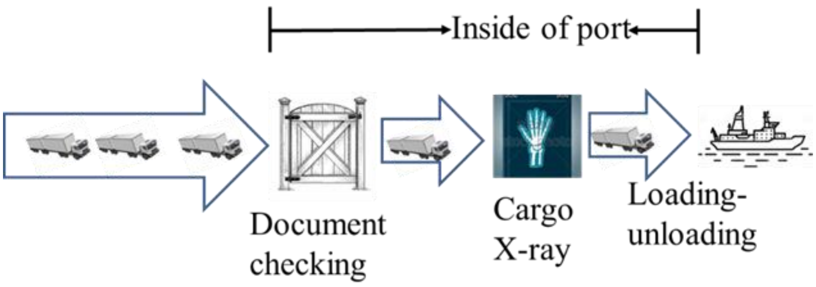


Fig. 1. Bottlenecks in the Port of Chennai, India

Thee (berth, quay, related yard areas and horizontal transportation) operations is not considered in this paper. The first aim of this paper is to present a classification scheme for approaches to reduce truck congestion at port entry gate. It bases on an extensive review of literature and practical projects during the last 20 years on seaport operations. The second aim is to apply a queuing model to analyze the effect of development schemes. While this challenge is mainly analyzed from a container terminal perspective, it also affects other stakeholders in the port as depots or freight stations.

The queues formed at the port-entry gate are analyzed for four scenarios: introduction of ICT for document processing (scenario 1); expansion of port capacities (Scenario 2); utilization of ICT for port accessing (Scenario 3) and implementation of modal shift approach (scenario 4). The outcomes of the study will be helpful a policy maker to decide the development strategies of a sea-port. This study is unique with the following distinctive features:

- This study analyzes interaction between sea-port and city. Since the congestion in seaport may stretched several kilometers, a policy maker needs to find an option for easing port access. The queueing model is utilized for evaluating four scenarios.
- This study utilizes Seasonal Auto-Regressive Integrated Moving Average model (SARIMA) model for traffic demand prediction.

The remainder of this paper is organized as follows. Section 2 represents existing study on sea-port and city analysis. Section 3 provides a brief literature review. Section 4 represents methodology of the study. SARIMA model for traffic flow prediction and queuing model for observing outcomes from each scenario is described in this section. Section 5 describes numerical analysis. Finally, the manuscript summarizes the outcomes in Section 6 and provides some suggestion for future studies.

2. Literature review

Henesey et al. (2004) have investigated the use of simulation as the basis for a decision support system in analyzing the assignment of berths to arriving container ships at a container terminal. The main objective was to improve the performance of the container terminal by efficiently utilizing the resources available. Efficient planning of berth allocation for container terminals in Asia was studied and discussed by Imai et al. (1997). The objective here was to utilize the terminal efficiently for container ports. The paper focuses on berth allocation that minimizes dissatisfaction of the ships in terms of berthing order and minimizing the sum of the time the ships spend waiting for berths. Vis (2006) presents a simulation study for the evaluation and comparison of different terminal systems with manned Straddle carrier (SCs) and rail mounted gantry crane (RMGs) in terms of costs and performances. The task is to perform a fixed number of storage and retrieval requests. The performance criterion is the (average) total travel time including empty and full travel distances, average hoisting times as well as average reshuffle times. Characteristics of each container, such as its location in the stack, the type of operation, or origin/destination are randomly generated. A sensitivity analysis is performed for obtaining fair results. The results show advantages for RMGs for a width of the stack up to nine containers. It is expected that the SC system outperforms the RMG system with a wider stack.

Cho et al. (2008) propose a framework for analyzing container terminal performance. The approach aims at figuring out best practices and providing benchmarks for decision making. The integrated analysis and simulation methods are based upon the

Delphi hierarchy process method with a dynamic environment. The method combines the well-known Delphi method using an expert panel for data collection, i.e., compiling and weighing performance criteria, and the mathematical model of the (fuzzy) analytic hierarchy process for the evaluation and integration of results. Example results are shown for Busan port container terminal cases.

The queue model is popular to analyze sea-port operations. Edmond and Maggs (1978) analyzed various queue models for imports and gave a guideline for investments and proved that increase in cranes and berth facilities does not reduce the queues in the same proportion. Holguin-Veras and Jara-Diaz (2006) discuss the practical implications of optimal space allocation and pricing. Opportunity costs of cargoes, handling costs and price elasticity of dwelling time are the main considerations. Horne and Irony (1994) discuss ship to shore transfer of cargo from ships that are located offshore. In this case, transport is done using smaller crafts. These crafts cycle back and forth. The queues discussed in this case are that of cargoes at loading and unloading points. Schonfeld and Sharafeldien (1985) looked at this problem from the point of view of optimizing berth and crane combinations in container ports. They optimized the design and operation of container at port. The model thus developed minimizes total port cost.

The above-mentioned studies have not considered the interaction between truck waiting time and container delivery. We aim to fill the gap by proposing a queue model for computing truck waiting time.

3. Congestion in port-city

The traffic through the Asian ports is increasing along with the economic development over the years. It is frequently observed that a queue of arriving trucks is formed and sometimes trucks must wait for a longer time before accessing sea port. This can be attributed firstly, to the limitation of capacity of the existing port facilities to meet the ever-increasing global trend and secondly, failure to inclusion of logistics in transport planning. Many Asian ports do not have yard space inside port facilities. We have listed the causes of congestion based on the reports of Japan International Cooperation Agency (JICA), (2013-2016). Besides, we have collected the opinions of experts about causes of congestion in port access and solution strategies.

When port-access roads and railways fail to meet transportation demand, heavy congestion occurs outside of a port-entry gate. Similarly, when port capacities fail to meet container demand, traffic congestion occurs inside a port area. However, the effect of limited port capacity can also be extended to outside of entry gate area. Herewith, the arrival time uncertainty of port-freight traffic increases logistics costs. Congestion at port entry gates occurs when many trucks arrive on same time.

Table 1. congestion at port

Location	Causes	Description of causes	Counter Measure
Congestion in the port access route	Road capacity limitation	• Poor pavement condition • Single vehicle lane • Poor geometry of road • Road damage	1. Road state improvement 2. Increasing vehicle lane 3. Establishing cargo only roads
	Access route shortage		4. Building new entrance gate
	Concentrated demand	• Time specific congestion	5. Sharing traffic information
Congestion at harbour facility	Entry gate capacity limitation	• Insufficient number of lanes • Vehicles without proper document	6. Introducing ICT for document checking 7. Creating truck waiting area
	Processing power at the harbor	• Shortage of yard space • Aging of machine	8. Expanding yard space 9. Expanding the entrance gate
	Imbalance between export and import		10. Modal shift

Table 1 shows the causes and countermeasures for the congestion. The location of congestion is classified in two groups: (1) congestion in the port access route and (2) congestion at the harbor facility. Five counter measures for relieving congestion in the port access route are suggested: improving road state, increasing vehicle lane, establishing cargo only road, building a new entry gate and sharing traffic information. Similarly, five countermeasures for relieving congestion at harbor facilities are identified. These are Introducing ICT for document checking, creating truck waiting time, expanding yard space, expanding the entrance gate and modal shift. One major cause of congestion at the harbor is the trucks without proper documents. Since trucks without proper documents take longer time to pass the entry gate, it creates congestion. Besides concentrated traffic, representing arrival of large traffic at a time, and uneconomical traffic, generated from unbalance between export and import, crates the congestion worse.

4. Methodology

The Port of Chennai utilizes two terminals, named as the DPW Terminal and the PSA Terminal, for importing and exporting goods through containers (JICA, 2016). Based on the counter measures mentioned in previous section, we propose a queue model for the Port of Chennai, India. Figure 2 represents overall framework of the study. We have utilized the Japan International Cooperation Agency (JICA) survey data for demand estimation by seasonal Auto-Regressive Integrated Moving Average model (SARIMA) model. We assume that demand is not sensitive to supply capacity. The survey data provides us the measures of existing supply capacities.

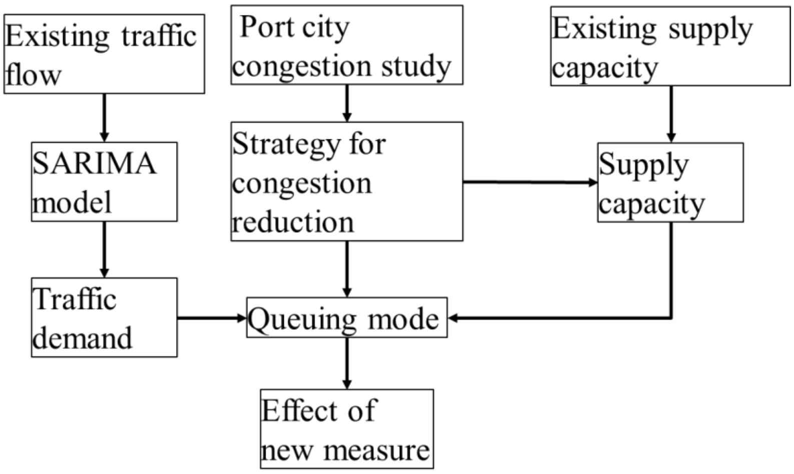


Fig. 2. Framework of the study

4.1. Modelling of Congestion Patterns using a SARIMA model

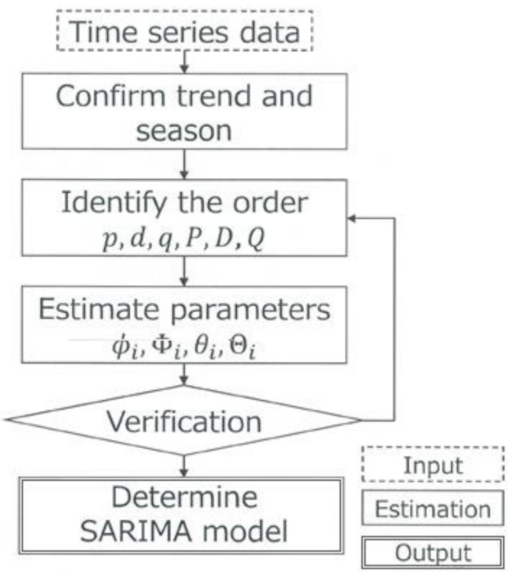
The congestion patterns are modelled in accordance with the time series analysis results. By removing random error, refined time series data can be generated. In this approach, it is assumed that the observed time series data $\{a_t\}_{t=0}^{T}$ is an instance of the normal stochastic process $\{a_t\}_{t=\infty}^{\infty}$ in an unbiased population. SARIMA model are utilized to analyze the congestion patterns. In this section, the modelling of time series data using a SARIMA model will be explained.

- Overview of SARIMA model

By using a SARIMA model, it is possible to model the inherent properties of time series data including short term elements such as how past data influences predicted values for the future and medium-length term elements such as "trends" and "periodicity". SARIMA models are defined by the following formulas.

$$(1-\sum_{i}^{p}\phi_i B^i)(1-\sum_{i}^{P}\Phi_i B^{si})\Delta_s^D\Delta^d a_t = (1+\sum_{i}^{q}\theta_i B^i)(1+\sum_{i}^{Q}\Theta_i B^{si})\varepsilon_t \quad (1)$$

ϕ_i, Φ_i, θ_i, Θ_i are the parameters for non-seasonal auto-regressive, seasonal auto-regressive, non-seasonal moving average and seasonal moving average respectively. p, d, q, P, D, Q are degrees representing the lag, s is the number of cycles, ε_t is the error term of $N(0,\sigma^2)$, B is the lag operator that satisfies $B^n a_t = a_{t-n}$, and Δ is the difference operator. For SARIMA model, the autocorrelation function and partial autocorrelation function of the original sequence are used to establish the approximate order and the parameters are estimated using the method of maximum likelihood. However, because it is difficult to determine the most



appropriate order, AIC (Akaike Information Criterion) is used to determine the most suitable model. A flowchart outlining the process for selecting a model is shown in Figure 3.

Fig. 3. Flowchart for parameters estimation of SARIMA model

- Estimation of SARIMA models

Following the flowchart in the previous section, a SARIMA model will be estimated.

Step 1(Test the normality of the original sequence): When modelling time series data, it is necessary to confirm the normality of the original sequence. In the case of the absence of the normality, the modelling is performed after generating normal data. To determine the normality of the time series data statistically, a unit root test is performed. There are various ways to perform a unit root test, however the Augmented Dickey–Fuller (ADF) test is commonly used. The unit root test uses the following model expression.

$$a_t = \alpha \cdot a_{t-1} + \sum_i \beta_i \, \Delta a_{t-i} + \varepsilon_t \tag{2}$$

Here *i* is the lag value, if *i*=*n*, then the time series data can be used as an explanatory variable up until *n* periods. For the ADF test represented by Equation (2), the null hypothesis $\alpha = 1$ is assumed and used to test whether the unit root exists or not. If the null hypothesis is rejected, it can be judged that the unit root does not exist and there is normality. Table 1 shows the results of the ADF test. From Table 1, when $d = 1$, the p-value is lower than 0.05 indicating that the null hypothesis has been rejected. The original series has a trend and it can be said that the normality of the original series can be guaranteed by taking the difference once.

Table 2. Dickey-Fuller statistic and p-value

Difference	$d = 0$	$d = 1$
Lag	4	4
DFr	-3.225	-4.913
p-value	0.091	0.010

Step 2 (Determine the period of the original series): The periodicity of the original series can be determined using autocorrelation function. Figure 4 shows the autocorrelation function of the original series in a correlogram. The horizontal axis is the lag value i, the vertical axis shows the autocorrelation function (ACF). The autocorrelation shows the correlation between a_t and a_{t-1}. Looking at Figure 4, it can be determined that there is a strong autocorrelation in the 12th order. Therefore, in this study, the period $s = 12$ will be assumed.

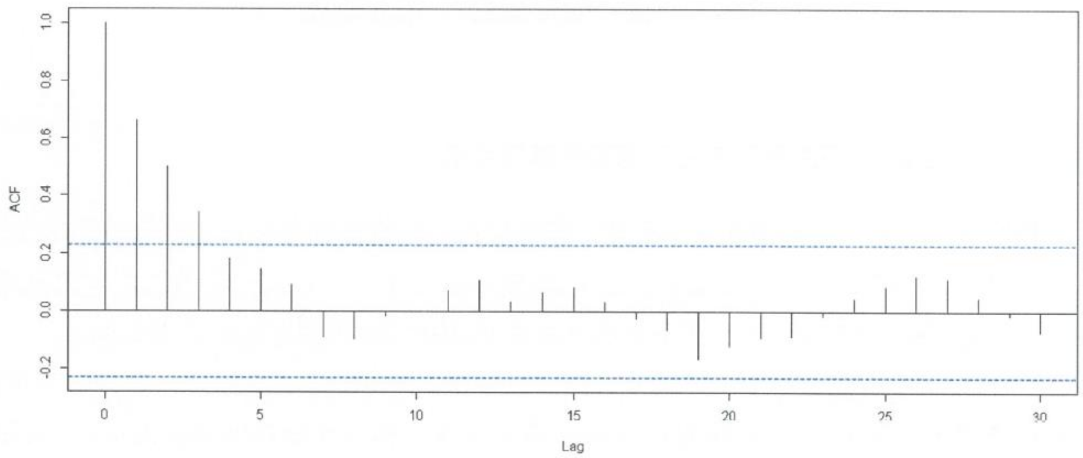


Fig. 4. Autocorrelation function of the original series

Step 3 (Use AIC to determine the best order, estimate the parameters): The orders of p, q, P, Q are determined by solving eq. (1) that takes arbitrary values for determining the order. The parameters ϕ_i, Φ_i, θ_i, Θ_i are estimated by using the method of maximum likelihood and determines the model with the lowest AIC value. As a result, SARIMA (0,1,5)(0,0,1)12 was identified and parameters as shown in Table 3 were estimated. Aside from the moving average (θ_2 for the second cycle, all parameters were estimated to be statistically significant with a 90% statistical significance level.

Table 3. Estimated results from SARIMA $(0,1,5)(0,0,1)_{12}$

parameter	estimate	t-value

θ_1	-0.359	-3.219	***
θ_2	0.093	0.630	
θ_3	-0.349	-2.614	***
θ_4	-0.404	-2.650	***
θ_5	0.226	1.361	*
Θ_1	0.223	1.611	*
AIC	714.040		
log likelihood	-350.020		
data count	72		

*10% significance **5% significance ***1% significance

Step 4 (Verify the autocorrelation of the residuals): It is important to check whether the residuals are auto-correlated or not. It is conducted by using the Ljung-Box test. The null hypothesis is that the residuals have no autocorrelation. Figure 5 shows the test results. The horizontal axis is the lag value i and the vertical axis is the p-value resulting from the test performed with lag data a_{t-1}. As can be seen from Figure 5, the p-value is constantly increasing by a value of 0.05, thus it cannot be said that the residuals have autocorrelation. In other words, there is a high likelihood that the residuals are a result of random error.

Step 5 (Select a model): The comparison of the original series and the estimated model is shown in Figure 6. The horizontal axis shows time and the vertical axis shows the number of vehicles in queue. The solid black line represents the observed values and the dotted red line represents the estimated values. From Figure 6, it can be confirmed that the error between the original series and the model is a random error.

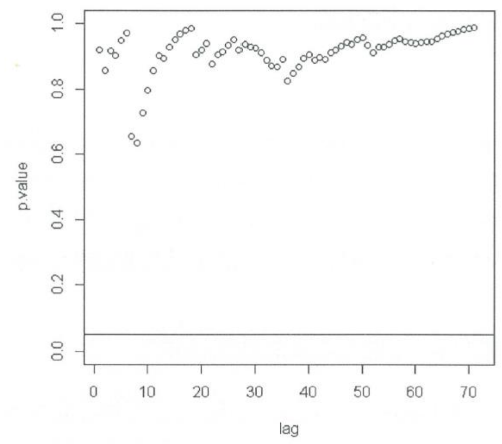


Fig. 5. Ljung-Box test

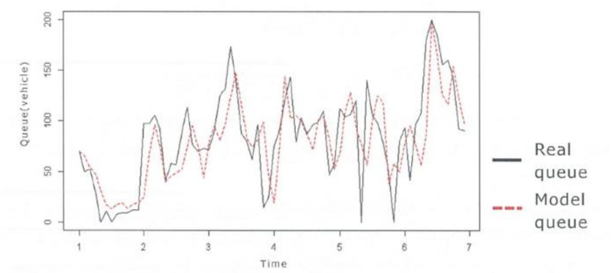


Fig. 6. Comparison of the real queue values and model queue values

4.2. Queue model

In this section, queuing theory shall be applied to reproduce the state of congestion at the terminal gate. The data collection period is the one-week span from 8:00 pm on Monday, October 27th, 2014, to 6:00 am on Monday, November 3rd, 2014.

- Estimation of Traffic Inflow Volume by Time

In this section, the amount of inflowing traffic by time will be estimated in accordance to queuing theory. This model explains the queue at the service window by assuming the number of service windows s, number of visitors m, system capacity K, service norm Z as fixed variables, and the client arrival time interval and service processing times as random variables of a specific probability distribution. The traffic queue in front of the gates is represented by a queue model which assumes completely random Poisson arrivals and a Poisson process where the number of clients and system capacity is unlimited and a First Come First Served (FCFS) service norm is adopted.

In queuing theory, the transition probability of n clients present for the service is defined by a Markov process called the Birth-death Process. Therefore, by analyzing the normal state it is possible to derive a theoretical formula for the number of clients waiting. The mean number of clients waiting L_q can be derived from the following equation.

$$L_q = \frac{\rho(s\rho)^s}{s!\,(1-\rho)^2} P_0 \quad (3)$$

$$P_0 = \frac{1-\rho}{(1-\rho)\sum_{n=0}^{s-1}\frac{(s\rho)^n}{n!} + \frac{(s\rho)^s}{s!}} \quad (4)$$

P_0 is the probability that the number of clients is 0, ρ represents the state of congestion of the system, if it becomes 1 then the waiting time diverges infinitely. Also, ρ can be calculated as ρ=λ/sμ where λ is the mean arrival rate and μ is the mean service rate. The volume of inflowing traffic can be calculated by comparing the observed number of vehicles in queue Q_T introduced in Section 3.1 and the theoretical number of vehicles in queue $L_q(T)$ calculated using queuing theory. Here, we let the number of service windows s=3, the mean service time 1/ μ = 1.7 and estimate the volume of inflowing traffic $Inflow_T$. The estimates for the volume of inflowing traffic and the resulted queue are shown in Figure 7. The horizontal axis is the time axis and the vertical axis shows the number of vehicles (volume), the blue bars represent the number of inflowing vehicles and the orange bars show the number of vehicles in queue. From Figure 7, as the number of vehicles in queue increases, the volume of inflowing traffic also increases. As the congestion disperses, the volume of inflowing traffic also decreases. The correlation coefficient between the inflowing traffic and the queue is 0.94 which indicates a strong correlation.

- Overview of the Queue Simulation

The steps in the queue model are as follows

Step 1: For given, $Inflow_T$, let the arrival rate at the period be $\lambda_T = \frac{Inflow_T}{T}$.

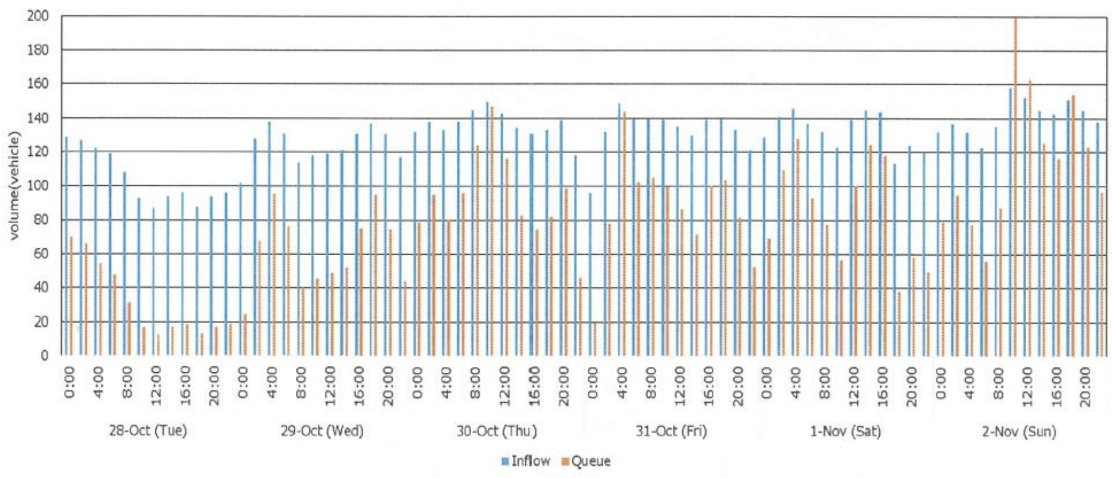


Fig. 7. Interaction of traffic inflow volume and real queue volume

Step 2: Let the arrival interval a_{ti} of each vehicle i and the service completion time follows an exponential distribution.
Step 3: Processes such as "gate entry", "arrival processing", "departure processing" are applied to each vehicle i as required. This is performed for every time step t within a specified time interval.
Step 4: Obtain the number of vehicles in queue at for the k-th time, Q^k
Step 5: Repeat the operation from *Step 2 to Step 4* K times to form $\{Q\}$ containing K number of congestion patterns.

5. Results

The congestion solutions proposed in Section 3 are analyzed into the queue simulation. Among ten suggested solution strategies, in this study we have simulated for the introduction of ICT, increasing service window, traffic information sharing and modal shift. Due to data limitation, we could not analyze the remaining solution strategies. An Intel Xeon CPU E5-2687 v4 @ 3.00GHz 48 Core server was used to perform the calculations. The programming language used was C++ using the g++version 4.9.2 compiler. The MPI used was OpenMPI version 1.6.5.x

November 1st, 2014 was selected as the period in scope for the numerical calculations. The total number of trucks i was 9,185 trucks, the initial number vehicles in queue Q_0 was 70, the number of lanes s was set to 3, the mean service time $1/\mu$ was set to 1.7 minutes, the number of simulations K was set to 10,000 and the time step Δt was set to 1 minute.

For this report, the following 4 scenarios were assumed:

Scenario 1: The introduction of ICT at the gate to decrease processing time ($1/\mu = 1.5$)

Scenario 2: Expansion of the entrance lane to increase the number of service windows ($s = 4$)

Scenario 3: Opening the gates at an earlier time and sharing traffic information to distribute inflowing traffic $Inflow'_T = \sum Inflow_T / T$

Scenario 4: Encouraging a modal shift to decrease the amount of inflowing traffic

$$Inflow'_T = 0.9 \times Inflow_T$$

Table 4. Comparison of mean waiting times and maximum waiting times

	Mean waiting time (minutes)	Maximum waiting time (minutes)
Original	86.5	109.00
Scenario1	38.34	72.11
Scenario2	5.54	57.75
Scenario3	3.36	76.57
Scenario4	30.31	76.63

For simplicity, the mean values for the simulation results were used for evaluating the scenarios. Fig. 8. shows the congestion pattern over one day for each scenario. From Fig. 8., it can be confirmed that each proposed scenario is indeed eliminating congestion. In scenario 2 and 3, the congestion is eliminated within a short amount of time.

To continue, the waiting time per vehicle in each scenario is compared. Table 4 shows the mean waiting time and the maximum waiting time for each scenario. From the perspective of mean waiting times, Scenario 3 is the optimal scenario. As the lowest mean waiting time also implies the lowest total waiting time, Scenario 3 is the optimal scenario for the system. In accordance to this, it can be expected that a socially optimal traffic state can occur through proper distribution of the traffic volume. On the other hand, looking at the maximum waiting times, Scenario 2 is the optimal scenario. The scenario with the lowest maximum waiting time is the scenario where user fairness is best maintained and therefore Scenario 2 can be said to be the optimal scenario for the users.

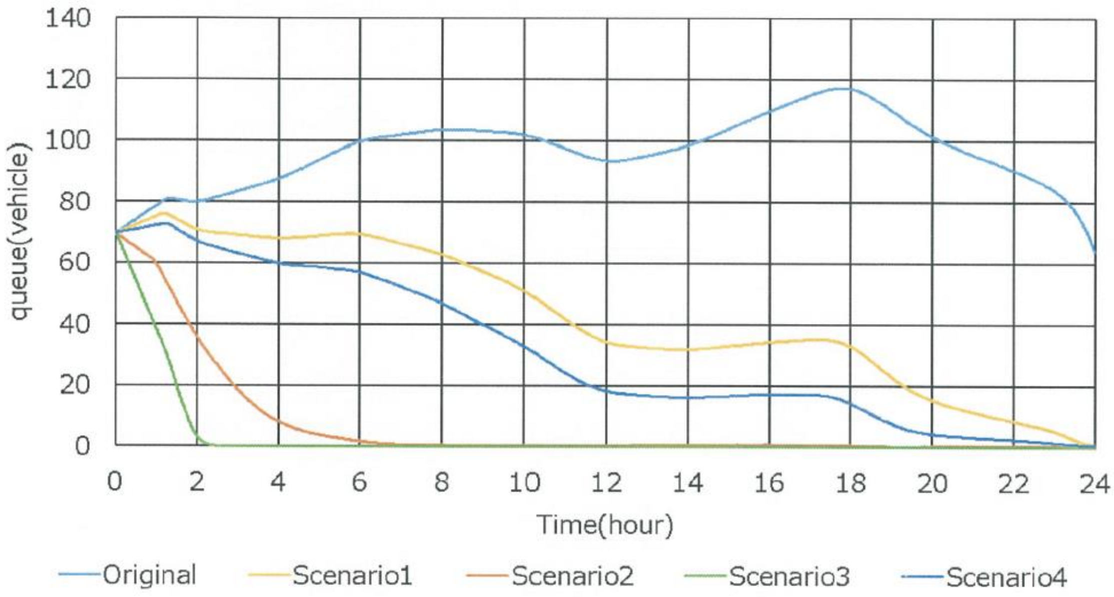


Fig. 8. Vehicles in queue over time for each scenario

6. Conclusions

The container management in a seaport becomes complex due to the involvement of several stakeholders. Being brought by a truck to a seaport, a container goes through several activities including document checking, scanning, storing container, and loading on ship. Since many seaports do not have container yard, the trucks loaded with containers makes queue outside of seaport entry gate. In this study, we have proposed nine countermeasures for solving congestions in three different points in a sea port. We have developed a queue model for analyzing the proposed counter measures. Here, we have presented the effects of four out of nine countermeasures.

The input data for the queue model was collected from the final report of JICA Chennai port project. A time series analysis was used to identify the arrival pattern of truck and the resultant queue. The seasonal variation of the arrival of container was also considered in the time series analysis. Next, the required parameters (capacity, and service rate) for a queue model were created. After that, alternative solutions are evaluated through the proposed queue model. Lastly, after assuming multiple scenarios, the simulation was run and the evaluation of each scenario was performed. In this paper, mean waiting times were used for the scenario evaluation. It is found that, there is an opposite trend between a mean waiting time and a maximum waiting time. Therefore, we can say that the optimal solution from a social system perspective and the optimal solution from a user perspective are different. The expansion of entry gate countermeasure

The study can be improved by considering investment criterion. The cost performance of each scenario should be considered. As the data of the investment costs for each scenario was not available, this study has drawn conclusions solely from the outcomes of the proposed model. Herewith, it is necessary to optimize the system. Lastly, the congestion at the port is caused by various phenomenon. To properly reproduce actual traffic congestion, it is essential to perform an evaluation of alternative solutions that consider the full optimization of delivery from the harbor all the way to the final shipping address.

References

Berechman, J., .2007. The social costs of global gateway cities, The case of the port of New York, The international conference on gateways and corridors, Vancouver, B.C.

Cho, J.J., Ozment, J., Sink, H., 2008. Logistics capability, logistics outsourcing and firm performance in an e-commerce market, International Journal of Physical Distribution and Logistics Management, 38(5),336–359.

Czerny, A. I., 2007. Maritime ports, capacities and door-to-door services, the International Conference on Gateways and Corridors, Vancouver, B.C.

Edmond, E. D., Maggs, R. P., 1978. How Useful are Queue Models in Port Investment Decisions for Container Berths?, Journal of the Operational Research Society, 29:8, 741-750.

Imai, A., Nagaiwa, K., Chan, W.T., 1997. Efficient planning of berth allocation for container terminals in Asia. Journal of Advanced Transportation 31, 75–94.

Japan International Cooperation Agency, 2013. Project for Comprehensive Urban Transport Plan of the Greater Yangon, Final Report.

Japan International Cooperation Agency, 2014. The Survey Program for the National Transport Development Plan in the Republic of the Union of Myanmar, Summary.

Japan International Cooperation Agency, 2015. Project on Master Plan for Development of Mombasa Special Economic Zone Final Report.

Japan International Cooperation Agency, 2016. The Project on Improvement of Chennai Port Operation.

Henesey, L., 2004. Enhancing Container Terminal Performance: A Multi Agent Systems Approach, PhD. Licentiate Thesis, Series 2004:06, Blekinge Institute of Technology, Karlshamn, Sweden.

Horne, G. E., Irony, T.Z., 1994. Queueing processes and trade-offs during ship-to-shore transfer of cargo, Naval Research Logistics, 41(2), 137-151.

Kozan, E., 1997. Comparison of analytical and simulation planning models of seaport container terminals, Transportation Planning and Technology 20 (3), 235–248.

Lindsey, R. 2008. Prospects for urban road pricing in Canada, Brookings-Wharton Papers on Urban Affairs:2008, Brookings Institution Press, pp. 235–93.

Noritake, M., Kimura, S., 1990. Optimum allocation and size of seaports, Journal of Waterway Port Coastal and Ocean Engineering 116, 287–299.

Notteboom, T. E., 2004. Container shipping and ports: an overview, Review of Network Economics, 3(2), 86–106.

Radmilovic, Z., Colic, V., Hrle, Z., 1996. Some aspects of storage and bulk queuing systems in transport operations, Transportation Planning and Technology 20, 67–81.

Schonfeld, P., Sharafeldien, O., 1985. Optimal Berth and Crane Combinations in Container Ports. Journal of Waterway, Port, Coastal and Ocean Engineering, 111(6), 1060–1072.

United Nations Conference on Trade and Development, 2017. Review of Maritime Transport, 2017, United Nations, New York and Geneva.

Vis, I. F. A., 2006. A comparative analysis of storage and retrieval equipment at a container terminal. International Journal of Production Economics, 103, 680-693.

Holguín-Veras, J., Jara-Díaz, S., 2006. Preliminary Insights into Optimal Pricing and Space Allocation at Intermodal Terminals with Elastic Arrivals and Capacity Constraint, Networks and Spatial Economics, 6(1), 25–38.