Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

SIMULATION OF TRUCK CONGESTION IN CHENNAI PORT

Gayathri Devi Rajamanickam
Gitakrishnan Ramadurai

Department of Civil Engineering
Indian Institute of Technology
Madras – 600 036
Tamil Nadu, INDIA

ABSTRACT

The primary focus of this study is to understand the current port operating condition and recommend short term measures to improve traffic condition in the port of Chennai. The cause of congestion is identified based on the data collected and observation made at port gates as well as at terminal gates in Chennai port. A simulation model for the existing road layout is developed in micro-simulation software VISSIM and is calibrated to reflect the prevailing condition inside the port. The data such as truck origin/destination, hourly inflow and outflow of trucks, speed, and stopping time at checking booths are used as input. Routing data is used to direct traffic to specific terminal or dock within the port. Several alternative scenarios are developed and simulated to get results of the key performance indicators. A comparative and detailed analysis of these indicators is used to evaluate recommendations to reduce congestion inside the port.

1 INTRODUCTION

Ports function as an important gateway of international trade and they tend to be regarded as major accelerators of local economic development in the age of globalization. Over the past several decades the seaports in Asia have developed rapidly and the container throughput in 2008 show that 20 of the 30 top ports were located in Asia.

The Port of Chennai is a vital part of Tamil Nadu's growing economy, particularly for the growth in South India's booming manufacturing sector. Chennai port is a 130 years old artificial port and is one among the major ports having terminal shunting yard and running their own railway operations inside the harbor. At present the Chennai Container Terminal Limited (CCTL) handles the first container terminal and the second container terminal is operated by Chennai International Terminals Pvt. Ltd (CITPL), they are referred as terminal A and B in the report. Ro-Ro terminal for transshipment of automobiles is situated in the Dr. Ambedkar dock. The port also contains 24 berths and three docks namely Bharathi dock, Jawahar dock and Dr. Ambedkar dock. The port has a capacity to handle 3 million TEUS. Chennai port handles a variety of cargo including granite, fertilizers, petroleum products, containers, automobiles and several other types of general cargo items. Chennai port caters to major industries/factories that produce vehicles, rubber, and fertilizers, electrical and engineering products.

Chennai port handled imports/exports of goods such as automobiles, motorcycle, industrial cargo and other bulk products with an annual container volume of 1.523 million TEUS in 2010-2011. Chennai is the base to several international car makers namely Ford, Nissan, BMW, and Hyundai and is ranked as number one in the Ro-Ro car terminal in the country with terminal volume of 272345 units. There are plans to open a third container terminal which is expected to increase the capacity by 200% in the year 2017. Chennai port contributes 10% of the annual average cargo share of the country.

2 PURPOSE OF STUDY

Chennai port is the second largest port in the country and is losing its importance due to the prevailing traffic congestion inside as well as outside the port. Traffic congestion is a major problem in Chennai port. About 1500 freight vehicles (Chennai port 2014) are reported to enter Chennai city to access the port from nearby states and cities. The congestion inside the port affects the smooth transshipment of both import and export of goods by increasing the travel time, delay and number of stops from the port gate to terminal and vice versa. Often the delay inside the port is longer than the travel time from the origin of shipment to the Chennai port. More efficient processing of the traffic flow can help improve the capacity of the ports. The consequences associated with the port congestion have effects on a number of agents related to container terminals. One way of handling congestion is to increase capacity by increasing physical expansion or better utilization of available resources (Legato and Mazza, 2001). Chennai port is situated in the heart of the city, surrounded by residential area and implementation of physical expansion of the port and the terminal is not viable. This project aims to find the causes of congestion and recommend alternative measures - both physical improvements and regulations - in the port road network. The short to mid-term recommendations suggested in this paper are based on the utilization of available resources and improved traffic flow routing in Chennai port.

3 LITERATURE REVIEW

Congestion inside the port is not only experienced by Chennai but is reported in several major ports in India and abroad including Navi Mumbai, Vishakhapatnam, Los Angeles, Long Beach, and Manila. Congestion in the port is contributed by the growth in international trade together with the reality that many port facilities are running at or near capacity leading to traffic and port congestion (Vacca, Bierlaire and Salani 2007). The port operators are concerned about the longer truck waiting time, lower operation efficiency and the downgrade of overall freight productivity. A study commissioned by National Chamber Foundation of U.S. Chamber of Commerce (2003) states that "... a typical congestion at port gates is worse than that experienced on freeways during rush hours in metropolitan areas."

Various port operation studies discusses that one of the reason for congestion is queuing of trucks at the terminals which could be due to work breaks at gate, trouble in transaction, or climatic condition. The trucks with improper documents cause delays by increasing the processing time at terminal gate as well as the congestion since they tend to stay inside the port waiting for the correct documents. In port of Houston, webcams installed at the terminal entry and exit gates were monitored to find the cause of congestion. It was observed that ‘trouble transaction’ accounted for 3% and the average processing time for each truck was 3 to 4 min (Huynh et al. 2011). Implementation of technology together with truck appointment system, RFID or working with trucking companies to reduce transaction problems was suggested to relieve delay at terminal. (Huynh et al. 2011).

Numerous studies (Huynh and Hutson, 2005; Huynh and Walton, 2008) have discussed about an efficient truck appointment system to reduce truck waiting time. A successful appointment system will result in guaranteed entry times, reduced queue lengths, and shorter truck turn times. Huynh and Walton (2008) evaluated the effect of truck arrival patterns on truck turn times and crane utilization rates through a heuristic search process. The introduction of ‘HiTS’ (Hakata Port Logistics IT system) in 2000 at Hakata Port, Japan has decreased the delay at gate from 2 hours to 15 minutes and the processing time from 4 minutes to 1 minute (Motono, et al.). Nagoya port, one of the largest ports in Japan reported that about 13% of the trailers did not have proper documents and it took 5-60 minutes to process each of these trucks (Motono et al.). Two-stage document screening center at the inbound gate in Nagoya port was implemented to verify transaction problems before entering the terminal. The Tioga Group (2011) have verified the effectiveness of the document screening system for considerable reduction in service time and congestion in Nagoya port.

Congestion is also caused by the fluctuation in truck arrival times i.e. majority of the trucks enter port from 8.00 am to 6.00 pm Sherif et al. (2011) suggested the use of agent based simulation and solution by El Farol model to minimize congestion at seaport terminal gates based on the observation from live views of their gates via webcams. The terminals in Los Angeles and Long Beach, have chronic congestion problem and the state legislature has passed “Lowenthal Bill" that imposes a $250 fine per violation on terminal operators if trucks with appointments wait for more than 30 minutes at the terminal gates. The bill was implemented in July, 2003 (Mongelluzo, 2003).

To date solutions for congestion of port were focused on reduction of waiting time and turn time with policies such as extended gate time, and truck appointments. The congestion inside the port is also contributed by the inefficient operation of terminals such as longer checking time, time breaks, and under performance of utility equipment. O’Brien and Griffin (2014) recommend streamlining the movement and operation of trucks and cargo handling equipment to alleviate congestion in terminal. The simulation of Chennai port shows that service time plays a vital role impacting the performance of the port and increasing congestion at terminal and at the port gates.

An optimization model for truck appointment based on Genetic Algorithm (GA) and Point wise Stationary Fluid Flow Approximation (PSFFA) was proposed by Zhang et al (2014). This model was designed to calculate the truck turn time and queue length accurately and was successful in decreasing the truck turn time and waiting time efficiently.

Operational changes leads to improved productivity and efficiency of the supply chain. The operational changes such as the use of “virtual” container yards that allow empty trucks to locate near the export pick-up site eliminates a non-revenue trip to a terminal (Chang et al. 2006; Davies, 2006). The other operational strategy is the diversion of truck freight to rail or short sea shipping (Le-Griffin and Moore, 2006; Banister and Berechman, 1999) or gate appointments which allow truckers to make a scheduled pick-up or drop-off (Giuliano and O’Brien, 2006; Yahalom, 2001). None of the existing studies have focused on traffic flow within the ports as a reason for delay. This is a motive of the study. We describe the port infrastructure in detail in the next section.

4 EXISTING PORT INFRASTRUCTURE

a. Gate: Chennai port consists of six gates namely Gate 0, Gate 2, Gate 2A, Gate 5, Gate 7, and Gate10 but only Gate 0 is operational throughout the day for both inbound and outbound freight movement. The road from Gate 2 leads to residential area and the road infrastructure can handle only small trucks hence Gate 2 caters to inbound loaded/empty small trucks, oil containers and outbound empty small trucks. Gate 2A is open from 9.00 pm to 5.00 am. Gate 5 and 7 cater to passenger traffic. Gate 10 is situated on a major arterial road and is operational only at night from 10.00 pm to 5.00 am for both inbound and outbound freight trucks. This gate is closed during the day because of road safety issues and the existing city traffic regulations that seek to avoid the interference of freight traffic with the passenger traffic.

b. Road Infrastructure: There are 7 major roads namely: Firefighting road, Marshalling yard road, south quay road I, south quay road II, south spring haven road, road between gate 8 and 9, and road adjacent to Dr. Ambedkar road. Most of the roads are 2 lanes with no median or separation between the lanes for the opposite direction. The most common observations in the port road are sudden reduction of the road width at certain sections of the road. At several other locations, the effective width of the road was reduced due to random parking of trucks along one or both the sides of the road.

5 METHODOLOGY AND DATA COLLECTION

Initial trips were made to the port to get an understanding of the port layout, port facilities, port operation, and to locate the spots to conduct surveys inside the port. Our team interviewed truck drivers entering and exiting the port gates to understand the process involved and the documents required for loading and unloading the freight at the terminal. Data collection included a questionnaire survey, GPS survey, port register data, terminal records, and a service time study.

5.1 Data Collected

A questionnaire survey was carried out to get information about the duration of time spent by the vehicle inside the port and terminal, the causes of delay, congested roads, etc. The survey was conducted at exit gate of port for five days with three shifts per day depending on the operational timing of the gate. About 495 samples were used for the analysis. One day's data from each gate register were collected and compiled to create a database with data such as vehicle number, time of entry/exit of the vehicle, and vehicle entry/exit gate number. The entry times for the sampled trucks were obtained from the entry registers based on the unique truck registration number.

The truck's entry and exit records for a period of one week was obtained from both terminals (Terminal A and Terminal B). The data was used to analyze dwell time inside the terminals, the travel time from entering the port gate to terminal, and travel time from terminal to exit gate.

5.2 Service time study

The freight handled from and to the port is very sensitive and is a national security issue too. The port authority together with the terminals inside the port verifies the document proof supporting the freight transaction. Check points are located at the entry and exit of port gates and terminals. Document verification in each check point may take a minute but there will be an additional time lapse (time between the two services). Huynh et al (2011) had observed that the average processing time in a terminal was 3-4 mins per truck. The service time and lapse time (time between the two truck services) recorded in field at various check points (Table 1) are in the same range.

Table 1: Average service time and lapse time at check points in Port.

Location	Empty Truck		Loaded Truck	
	Service Time	Lapse Time	Service Time	Lapse Time
Gate 0 inbound	0:01:03	0:00:34	0:01:03	0:00:34
Gate 0 outbound	0:01:32	0:03:04	0:02:12	0:03:08
Terminal B – Inbound	0:02:45	0:03:00	0:04:08	0:02:25
Terminal B – Outbound	0:00:49	0:00:54	0:02:48	0:02:18
Gate2 – Inbound	0:00:35	0:00:45	0:00:35	0:00:45
Gate 10 – Inbound	0:01:00	0:00:34	0:01:00	0:00:34
Gate 10 – Outbound	0:01:51	0:01:15	0:02:33	0:01:14

6 ANALYSIS

6.1 Distribution of freight vehicles

Questionnaire survey data was used to calculate the distribution of number of trucks entering/exiting through the different gates to various terminals, docks, and yards. Tables 2 and 3 show that most of the trucks enter/exit through gate 0. About 58% trucks from gate 0 and 66% trucks from gate 10 go to Terminal A. Similarly 95% trucks from Terminal B and 87% from Terminal A exit through gate 0 and very less percentage of trucks exit through gate 10.

Table 2: Number of vehicles entering through different gates to terminal.

In -Gate	Terminal A		Terminal B		Yard and Docks		Both Terminals	
	Number	Row %	Number	Row %	Number	Row %	Number	Row %
Gate 0	186	59	105	33	7	2	19	6
Gate 2	27	44	10	16	22	36	2	3
Gate 10	50	66	14	18	12	16	0	0

Table 3: Number of vehicles exiting through different gates.

Location	Gate 0	Gate 2	Gate 10

	Number of trucks	Row %	Number of trucks	Row %	Number of trucks	Row %
Terminal A	230	87	0	0	35	13
Terminal B	125	95	0	0	6	7
Yard	1	4	11	38	17	6
Dr. Ambedkar	1	14	6	86	0	0
Jawahar	0	0	0	0	1	1
Both	21	0	0	0	0	0

6.2 Hourly volume of freight vehicles to port

The gate register data was used to calculate the hourly truck flow through different gates. During the day time (5.00 am to 10.00 pm), about 70% of the freight vehicles enter and 82% exit through gate 0. Figure 1 shows the hourly distribution of the freight vehicles entering and exiting port through gate 0 for one complete day. The graph shows that the trucks entering/exiting through gate 0 are more between 9.00 a.m. to 6.00 pm and less during night. Sherif et al (2011) and Motono, shows that majority of the trucks enter port from 8.00 am to 6.00 pm.

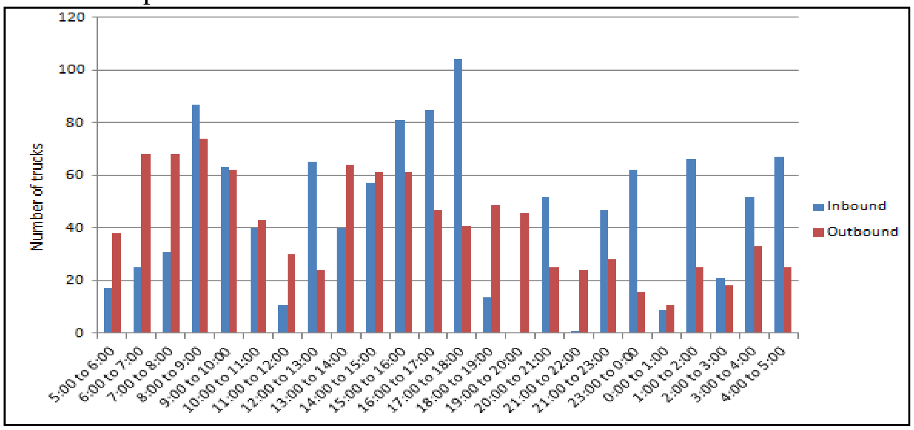

Figure 1: Hourly volume of vehicles - inbound and outbound at gate 0.

6.3 Vehicle turn-around time analysis

Turn-around time analysis was performed based on the terminal register data shared by Terminal B and Terminal A. Vehicle turn-around time is a measure of efficiency and the acceptable duration is between 25 to 30 minutes. The turn-around time in terminal B for loading/unloading (Table 4) was approximately 1 hour similar to the median turnaround time of Los Angeles – Long beach (51 minutes, Owen et al., 2011). The turnaround time in the port is of little concern since the truck gets stuck in the traffic outside the terminal and the terminal has no control over this situation. The table shows that it takes 10 hours (on an average) for one round trip from entry to exit of port whereas the turnaround time of the terminal is 1 h 6min.

Table 4: Average duration of trip time spent inside the port – Terminal B.

Gate / Time	Total Vehicles	Average Duration			
		In-Gate to Terminal B	Inside Terminal B	Terminal B to Out Gate	Total Hours
Gate 0 (5 am - 10.00 pm)	185	3h13 m	1h12m	3h 5 m	8h 15m
Gate 0 (10.00 pm - 5 am)	4	4h 34m	1h 42m	3h 35m	9h 11m

Gate 2 (5 am - 10.00 pm)	23	5h 23m	0h 35m	5h 05m	11h 08m
Gate 2 (10.00 pm - 5 am)	4	5h 22m	1h 03m	5h 27m	11h 52m
Gate 10 (5 am - 10.00 pm)	9	4h 19m	1h 12m	4h 02m	9h 33m
Gate 10 (10.00 pm - 5 am)	3	1h 29 m	0h 51m	5h 39 m	7h 19m

7 SIMULATION USING VISSIM

7.1 Importance of Simulation

Container port operations can be considered as one of the most complex tasks in the transport industry. These tasks can be generally divided into quay transfer operations along berth, storage system in container yards, and transfer operation from yard to final destination. This paper focuses on the land side issues of the port operation. Managing various processes efficiently and effectively reduces the problems that arise at port terminals. The paper uses microscopic traffic simulation software VISSIM to identify and analyze the problems of traffic congestion inside the port.

Time stepped simulation facilitates the analysis of movements of truck inside the port and allows for detailed infrastructure analysis. The field data such as number of trucks entering/exiting, service times, labor breaks and time taken for loading and unloading process inside the terminal were incorporated as inputs in the port network to replicate the field scenario as realistically as possible. The calibration of simulation parameters helped to replicate the current traffic pattern and to identify factors contributing to congested situation. Observation of the realistic animated representation of the traffic flow in VISSIM during the simulation process gives us an understanding of the traffic flow pattern over time and also the probable causes of congestion. Since the road layout created in VISSIM replicates the present road network, the congestion caused by sudden lane width change or geometric design issues can also be observed during the simulation process.

7.2 Road network and Input parameters

The road network was created to reflect the geometry of the roads inside the port. The road specification such as road width, turning radius, median and the routing condition such as one way or two way roads were implemented in creating the road network. It is essential to develop the road network along with input parameters such as traffic volume, average speed, and rate of acceleration similar to that observed inside the port. The following are the input parameters that were modified to perform the simulation.

- Geometry: The geometry of the network was coded based on a AutoCAD map file provided by Chennai Port.
- Vehicle Counts: 36 hours vehicle counts from the port gate registers were used to specify the hourly vehicle counts from each entry gate.
- Routing Decisions: These were updated as per the decisions observed in the field.
- Driver Characteristic: Has been assumed to follow default behavior in software.
- Desired Speed: The mean desired speed with which the truck travels inside the port was obtained from existing literature since the GPS studies done were unable to reflect free-flow conditions as there was congestion throughout the period of study. Speed of 15 to 25 km/h was assumed for the simulation based on the vehicle type. For example, a single unit truck – empty would travel at a higher speed than a loaded double trailer.
- Rate of acceleration: This was obtained from the literature. Again this data could not be obtained from the GPS surveys since truck traffic was heavily congested and free movement was severely hampered.
- Stop time: Stops were provided at the entry and exits of gates and terminals to match the checking booths (both security and customs). The summation of processing time and service times were also furnished for each stop. Lunch break and dinner break times were also incorporated.

Few additional assumptions in the model include:

- The vehicle composition includes single unit truck loaded, double trailers loaded, single unit truck empty, double trailers empty, car carriers 60-80 foot long, and oil tankers. The vehicle composition was further divided to specify the percentage of each vehicle type to create the vehicle mix observed in the port.
- In reality trucks were parked wherever there was space – both on and off road. In simulation the random parking of trucks were not considered.
- Vehicles entering the terminals were made to park in the parking spaces provided in the terminal for the duration equal to the loading/unloading process inside the terminal.
- Finally, since most of the traffic was towards the two container terminals, the remaining traffic to the Yards, Ambedkar Dock, and Jawahar Dock were combined and simulated as a single destination.
- The simulation time was increased from 36 hours to 48 hours since there were few vehicles yet to exit in the system at the end of 36 hours of simulation.

7.3 Simulation using field condition

Travel time and average speed was used as the output parameters to compare the congestion level in the simulation with the observed field conditions. The simulated travel times excluding the processing time and time taken for loading and unloading the trucks are shown in table 5.

Simulation shows that the trucks are queued at checking booths and queue length increases during the labor breaks at noon, 5.00 pm and 8.00 pm. The travel time obtained from the simulation using the field service time as input was much lower than the travel time observed in the field (Table 5). There could be several reasons for this, including the roads inside the port are more congested and the simulator is unable to capture all the details or the trucks parked randomly on the roads that could not be simulated or for some other reason the trucks are traveling at lower speeds in reality. We believe the most likely cause is the surveyed service times were significantly lower than usual service times. The officials at the gate worked more efficiently since they were being observed during the survey.

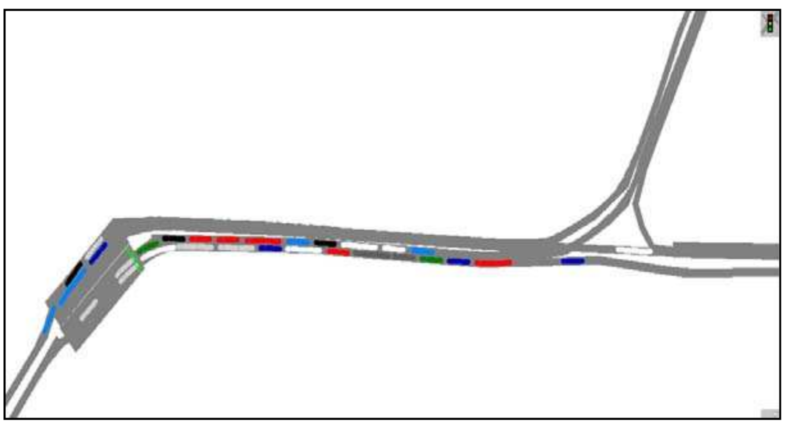

Figure 2: Truck queue at Gate 0 exit.

Table 5: Simulated Travel Time using surveyed service time.

Section Name	Terminal B	Terminal A
Gate 0 to Terminals	41m	27m
Terminal to Gate 0	1h 15m	1h 05m
Terminals to Gate 10	32m	45m
Gate 10 to Terminals	1h 01m	NA

7.4 Base case scenario

The aim of the base case scenario is to obtain the travel time from simulation similar to the field condition by varying the values of input parameters. The service time at the entry and exit gates of the terminals and port was varied to obtain delays comparable with field condition. As mentioned earlier, we believe the measured service times were the minimum values one could obtain and not a reflection of average service times. Further the high delay values in the field clearly indicate the measured service times are not realistic. The service time at the port entry gate is not changed since the hourly vehicle volume from the port register takes care of the service time at entry point. The inbound and outbound service times was calibrated until the travel time of the sections was similar to the actual travel times. The calibrated service times were found to be 2.5 times the actual service times as shown in table 6. O' Brien, T. et al. (2014) states in his paper that the service time in Los Angeles port varies between 5 minutes to 8 minutes. The calibrated service times are comparable with service time in other ports. Even with the increase in service times the travel time for each section is lower than the field condition (table 6).

Table 6: Travel time of Base Case Scenario.

Section Name	Terminal A	Terminal B
Gate 0 to Terminals	2h 02m	2h 39m
Terminal to Gate 0	1h 45m	1h 56m
Terminals to Gate 10	4h 15m	1h 49m
Gate 10 to Terminals	NA	4h 13m

7.5 Alternatives

During our visits to the port for data collection we observed that the road adjacent to Terminal A entry gate was very congested due to the trucks queuing to enter terminal A. All trucks entering through gate 0 had to use this road to get to terminal A or terminal B. Any problem in the operation of terminal A causes road block affecting the truck movement destined to terminal B too. In order to find solution for the congestion problem inside the port, few routing alternatives have been considered and simulated. The following are the alternatives considered:

1. Terminal A entry through an alternate road.
2. Providing a slip road for terminal A exit.
3. Staggered check points at gate 0 exit.

7.5.1 Alternative 1: Terminal A entry through an alternate road

The idea of this alternative is to provide separate routes for inbound trucks destined to terminal A and terminal B to alleviate the congestion caused by the queuing of the trucks waiting to enter terminal A. A three lane road of 0.8 km connecting the existing port road from gate 0 to terminal A can be constructed. In this scenario the terminal A entrance was assumed to get access through an alternate road passing through a defunct iron ore yard and the present terminal A entry would be converted as exit (figure 3). The simulation was performed using the calibrated service time with the altered routes. The improvised routing (figure 3) and the resulting travel times are as shown in table 7.

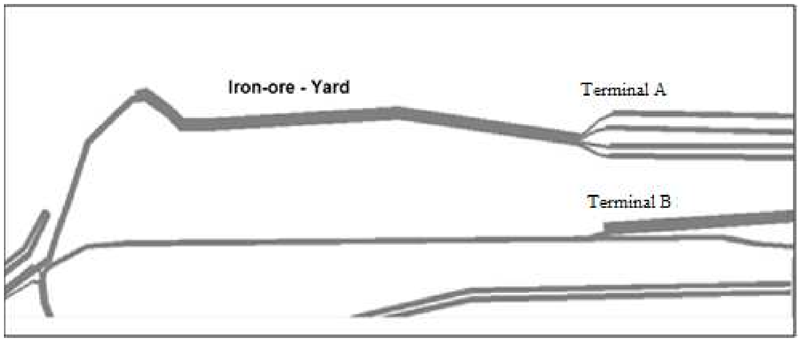

Figure 3: Terminal A entrance through an alternate road.

Provision of separate entry and exit routes did not improve the congestion situation from the base case. This shows that the actual delay was due to queues at the gates that extend beyond the exit/entry gate blocking the access road. The increase in travel times from gate 0 to the terminal A may be partly due the increase in the terminal A approach road length through the iron ore yard. The travel time of the trucks from terminal A to gate 0 has not improved (table 7) due to the merging of the terminal A outbound trucks with the trucks coming in the peripheral road, and trucks entering from gate 2.

7.5.2 Alternative 2: Providing a slip road for terminal A exit

Two lane slip roads (small section of road that allows access to highways) connecting the terminal A exit and peripheral road is assumed to be provided to alleviate congestion at a major intersection. In this scenario the outbound terminal A trucks would take the slip road to exit through gate 0, gate 10 or gate 2 (figure 4). The simulation was performed without changing any other input data, or other routing decisions. The travel time of the trucks from terminal A and terminal B exiting through gate 0, gate 10 or gate 2 has decreased (table 7) considerably as expected from the slip road option. The simulation showed the queue length of terminal A trucks has also decreased due to the decrease in wait time for merging. It is important to note that this alternative is a purely geometric modification to the road network and could be evaluated using traffic simulation techniques only. Typical analysis using queuing models may not be capable of addressing such alternatives.

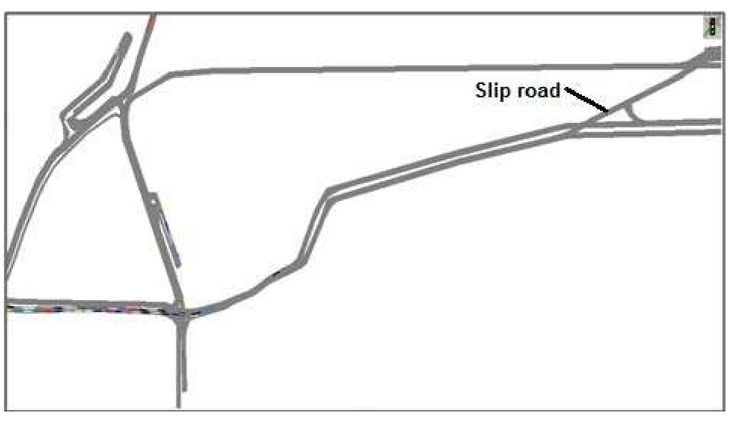

Figure 4: Slip road for terminal A exit.

Table 7: Comparison of travel time for alternative Scenarios.

Section Name	Terminal A entry through alternate road	Slip road	Staggered check

	Terminal B	Terminal A	Terminal B	Terminal A	Terminal B	Terminal A
Gate 0 to Terminals	3h 19m	3h 39m	2h 20m	2h 16m	2h 20m	2h 16m
Terminal to Gate 0	3h 34m	2h 36m	1h 37m	1h 19m	1h 25m	52 m
Terminals to Gate 10	1h 49 m	4h 39m	1h 43m	3h 43m	1h 43m	3h 43m
Gate 10 to Terminals	4h 19m	NA	4h 19m	NA	4h 19m	NA

7.5.3 Alternative 3: Staggered checking points at gate 0 exit

The trucks entering and exiting the port undergo multiple checks at the gate as well as the terminal. This alternative scenario considers combining the customs and security checks together at gate 0 exit and providing 3 extra check points arranged in a staggered fashion. The primary motive here is to increase the number of serving booths without requiring additional space at the exit gate of the port. The staggered alternative requires at least three lanes and hence an additional lane of 200 m length before the gate 0 has been provided. A total of 5 check booths are provided including three check booths spaced out longitudinally in the second lane, one check booth in the first lane and one in the third lane aligned with the last one in the second lane as shown in figure 5. As expected, the travel time reduced due to the staggered check booths (table 7).

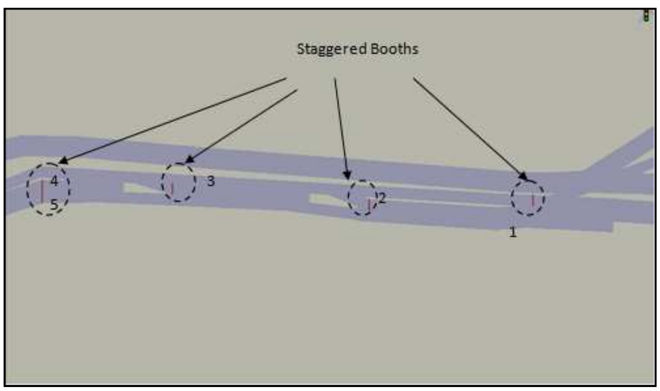

Figure 5: Staggered Check point at gate 0 exit

The vehicle counts segregated by exit gate and important parameters such as travel time and speed for the considered alternatives are provided in tables 8 and 9. The comparison of average speed between two scenarios namely base case and slip road shows that the provision of slip roads has improved vehicle speed marginally while for the alternative with terminal A entry through iron ore yard the average speed had decreased. The vehicle count in table 8 shows that more than 73% of the trucks exit by gate 0 and 24% trucks exit by gate 10 which is similar to the data from the exit gate registers.

Table 8: Comparison of vehicle counts.

Vehicle Counts	Actual	Base Case	Slip Roads	Staggered
Gate 2 Exit	52	11	30	44
Gate 0 Exit	1720	1600	1696	1735
Gate 10 Exit	573	422	520	549
Total	2345	2033	2246	2328

Table 9: Comparison of parameters.

Parameter	Base case	Terminal A	Slip road	Staggered

		alternate road		
Average Speed (km/h)	0.951	0.712	0.972	0.986
Travel time (s)	6h 12m	8h 19m	5h 50m	5h 25m

8 CONCLUSION

The travel time results shows that the congestion or queuing of trucks is due to the longer document processing and security check times that has a negative impact on the number of trucks serviced per hour. The checking process can be expedited by making use of existing technology such as computerizing the checking process or providing RFID tags to trucks. Enabling such technologies will improve monitoring and performance appraisal of security and customs checking as well as reduce congestion and improve through put at the port. Chennai port has only one gate that is operational 24 hours a day and has one entry and exit path/route. The unavailability of the container status in the terminal container yard forces the truck drivers to join the queue at the earliest possible time in order to pickup/drop the containers. In addition to delays due to security verification process this early queuing complicates the situation at the port gate and inside the port. The roads are often congested/blocked by these trucks waiting for container along the road. This can be alleviated by constructing slip roads as a means to provide more flexibility in route option (i.e the slip road acts as a connector to switch from one road to another) for the trucks entering or exiting the port. Simulation shows reduction in overall congestion and delay due to the provision of slip roads. Hence provision of more slip roads wherever possible and operating multiple gates at different times of the day can be considered. This solution is based on the data used for micro-simulation of Chennai port and is project-specific based on the purpose and need of the project. Few short term measures recommended includes maintenance of road infrastructure such as maintenance of roads, provision of medians or separators for traffic flow regulation and emphasis of rules and regulation for unnecessary parked trucks. The study demonstrates the utility of using traffic micro-simulation to study congestion inside the port. However the micro-simulation can be performed with required calibration and validation for each specific site and analyzed before implementation.

ACKNOWLEDGMENTS

We would like express our sincere gratitude to Chennai Port Trust Authorities for their initiative in starting this study and for their continued support. We are grateful to the Centre of Excellence in Urban Transport, Department of Civil Engineering, IIT Madras for supporting us in this project. We would like to thank all the enumerators, the staff of ITS Lab and students of Transportation Engineering Department, IIT Madras who helped in data collection, transferring data and supported us during the project.

REFERENCES

Banister, D., and J. Berechman. 1999. "Transport Investment and Economic Development." London: Taylor & Francis.

Chang, H. H. Jula, A. Chassiakos, and P. Ioannou. 2006. "Empty Container Reuse In The Los Angeles/Long Beach Port Area." Presentation made at the *National Urban Freight Conference*, Long Beach CA, Feb. 1-3, 2006.

Christopher, K. 2011. "Port Of Miami Cargo Gate: Using Technology To Improve Throughput And Enhance Security: Part 1." *Port Technology International*. E Paper. http://www.porttechnology.org/images/uploads/technical_papers/PT43-18.pdf.

Davies, P. 2006. "Off-Dock Storage of Empty Containers in the Lower Mainland of British Columbia: Industry Impacts and Institutional Issues." Presentation made at the *National Urban Freight Conference*, Long Beach CA, Feb. 1-3, 2006.

Giuliano, G., and T. O'Brien. 2007. "Reducing Port-Related Truck Emissions: The Terminal Gate Appointment System At The Ports Of Los Angeles And Long Beach." *Transportation Research Part D* 12(7), pp. 460–473.

Huynh, N., and C. M. Walton. 2008. "Robust Scheduling Of Truck Arrivals At Marine Container Terminals." *Journal of Transportation Engineering* 134(8), pp. 347–353.

Huynh, N., F. Harder, D. Smith, S. Omar, and P. Quyen. 2011. "An Assessment of Truck Delays at Seaports Using Terminal Webcams." *TRB paper* 2222. pg 54 -62.

Lee, S. W., D. W. Song, and C. Ducret. 2008. "A Tale of Asia's World Ports: The Spatial Evolution in Global Hub Port Cities." *Geoforum*, Elsevier, 2008, 39 (1), Pp.372-385.

Legato, P., and R. M. Mazza. 2001. "Berth Planning and Resources Optimization at a Container Terminal via Discrete Event Simulation." *European Journal of Operational Research*, 133(3), 537-547.

Le-Griffin, D. H., and J. Moore. 2006. "Potential Impact of Short Sea Shipping in the Southern California Region." METRANS Research Report 04-04.

Motono. I., M. Furuichi, H. Kimoto, and S. Suzuki. 2011. "New Concept of Off-dock Container Traffic Control for Heavily Congested Ports." Researchgate –E paper.

O'Brien, T., and D. H. Le Griffin. 2014. "Impact of Streamlined Chassis Movements on Marine Terminal Capacity and Emissions Reductions." TRA Conference Poster id 28225.

Owen, J., and B. Wargo. 2011. "A Study by Pier-pass And Ability/Tri-Modal of Gate Turn Times in Los Angeles-Long Beach." *The journal of Commerce*, (Issue April 2011).

Roso, V. 2007. "Evaluation of the Dry Port Concept from an Environmental Perspective: A Note." *Transportation Research Part D: Transport and Environment*, 12(7), 523-527.

Rowell, M., and E. McCormack. 2011. "Port Of Seattle Keystone Project." A technical report, Civil and Environmental Engineering, University of Washington.

Sathaya, N., R. Harley, and S. Madanet. 2009. "Unintended Environmental Impacts Of Nighttime Freight Logistics Activities." Working Paper VWP -2009-2011, UC Berkeley Centre for Future Urban Transport.

Sharif, O., N. Huynh, and J. M. Vidal. 2011. "Application of El Farol Model for Managing Marine Terminal Gate Congestion." *Research in Transportation Economics*, 32(1), 81-89

Vacca, I., M. Bierlaire, and M. Salani. 2007. "Optimization at Container Terminals: Status, Trends and Perspectives." In *the 7th Swiss Transport Research Conference*.

Yahalom, S. 2001. "Intermodal Productivity and Goods Movement Phase 2: Land Access to Port and Terminal Gate Operations." University Transportation Research Center, Region II.

Zhang, X., Q. Zeng, and W. Chen. 2014. "Optimization Model for Truck Appointment in Container Terminals." An unpublished thesis. Department of Civil and Environmental Engineering University of Utah, Salt Lake City, UT.

AUTHOR BIOGRAPHIES

GITAKRISHNAN RAMADURAI is an Assistant Professor, Transportation engineering division in Department of Civil Engineering at Indian Institute of Technology (IIT) Madras. He completed his PhD in Civil Engineering from Rensselaer Polytechnic Institute, Troy, New York, USA in 2009. His research interests include transport network modeling and simulation, urban freight, safety analysis, and Intelligent Transportation Systems. His email address is gitakrishnan@iitm.ac.in.

GAYATHRI RAJAMANICKAM is a senior project officer in Transportation engineering division in Department of Civil Engineering at IIT Madras. She holds M.E in traffic and transportation engineering from University of Louisville, Louisville, Kentucky, USA. Her research interest includes traffic analysis, traffic modeling and simulation, and transportation planning. Her email address is gaya1377@gmail.com.