



## A SIMULATION FRAMEWORK FOR OPTIMIZING TRUCK CONGESTIONS IN MARINE TERMINALS

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### ABSTRACT

One of the prominent issues that marine terminal operators are seeking to address is to how effectively reduce the truck turn-around times. The time a truck spends at a terminal for loading and/or unloading cargo is a real cost scenario which will affect the overall cost of the container trade.

This research uses the Taylor II simulation software to develop a queuing based simulation methodology that may assist the terminal operators in minimizing truck congestions and smoothing the gate operation to reduce truck turn-around times at marine terminals. The main goal of this paper is to help to reduce the average number of trucks in queues and average trucks' waiting times in both entrance and exit gates of the ports.

**Key words:** Simulation Framework, Truck Congestions, Optimization, Marine terminals, Truck turn-around times

### INTRODUCTION

In general, container terminals can be described as open systems of material flow with two external interfaces. These interfaces are the quayside designed for loading and unloading of ships, and the landside where containers are loaded and unloaded on/off the trucks (Steenken *et al.*, 2004). Most terminals are taking measures to increase their throughput and capacity by (Huynh and Walton, 2005):

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- Introducing new technology
- Optimizing equipment dwell-times
- Increasing storage density
- Optimizing ship turn-around times
- Optimizing truck turn-around times

A great variety of container terminals exists mainly depending on which type of handling equipment are combined to form a terminal system. Koshnevis and Asef-Vaziri (2000) define three performance analysis variables including throughput, space utilization and equipment utilization. Kozan (2000) discusses the major factors influencing the transfer efficiency of seaport container terminals by developing a network model. Similar studies in this field are carried out by Nam and Ha (2001), Lie *et al.* (2002), Vis and de Koster (2003), and Murty *et al.* (2003). Nishimura *et al.* (2009) implement Lagrange method for optimizing the container yard operation.

Berth planning problems may be formulated as different combination of optimization problems depending on the specific objectives and restrictions that have to be observed. Kim and Kim (2002) have discussed a method of routing yard-side equipment during loading operations in container terminals by an encoding method. Park and Kim (2003) have used a mixed-integer-programming model which simultaneously scheduled berth and container cranes. Legato and Mazzo (2001), Nishimura *et al.* (2001), Imai *et al.* (2001 and 2005), Moorthy and Teo (2006) have all carried out numerous studies on berth planning problems. Lee and Chen (2009) optimize the berth operation by evaluating different arrival patterns.

Nowadays, the logistics activities, especially at large container terminals, have reached a degree of complexity that further improvements are required the interaction of scientific solutions. Simulation models have become the viable tools for decision-making in port activities. Kia *et al.* (2002) have investigated the role of computer simulation in evaluating the performance of a container terminal in relation to its handling techniques and the impact it makes on the capacity of terminal. Parola and Sciomachen (2005) have presented a discrete event simulation modelling approach related to the logistic chains of an intermodal network. Bielli *et al.* (2006) have provided a help-tool in a port decision support system implementing simulation *via* Java environment. Froyland *et al.* (2008) have presented an algorithm to manage the container exchange facility, including the allocation of delivery locations for trucks and other container carriers. Zeng and Yang (2009) have developed a simulation optimization method for scheduling the loading operations in container terminals.

The time a truck spends at a terminal for loading and/or unloading of the cargo is a real cost scenario which affects the overall cost of the container trade. Han *et al.* (2008) have studied a storage yard management problem in a transshipment hub where the loading and unloading activities are both heavy and concentrated with the aim of reducing traffic. Historically, truck turn-around times have received a very lit-



tle attention from terminal operators because landside congestions have never been a barrier to their smooth operations. Truck turn-around times are the times that a truck takes to complete an activity such as picking up an import container. As shown in the studies conducted by Palmer (1996), Kim and Kim (1998), Kim *et al.* (2000), Regan and Golob (2000), Klodzinski and Al-Deek (2002), Mongelluzzo (2003), and Huynh and Walton (2005), by optimising the truck turn-around times and thereby the landside shipping cost, the terminals would gain a competitive advantage in the industry. In the research carried out by Jula *et al.* (2005), the container movement by trucks with time constraints at both origins and destinations was modeled as an asymmetric multi-Travelling Salesmen Problem with time windows which often referred to as the full-truck-load problem. Murty *et al.* (2005) have described a variety of inter-related decisions made during daily operations at a container terminal. Their goal was to minimize the waiting time of customer trucks. Jinxin *et al.* (2008) have proposed an integer programming model for containers handling, truck scheduling and storage allocation as a whole. Trucks are spending more and more idling time at ports because of congestions. There are two common measures that terminal operators are looking at to overcome this problem. First, adding more yard cranes; and second, employing the aid of computer technologies such as the truck appointment systems (Huynh and Walton, 2005). The main focus of this research is on the second alternative in which the idea is to flatten the gate activity to an efficient level so as to reduce the trucks' queuing time.

Consequently, the objective of this research is to minimize the trucks' congestions at the main gates of the Shahid Rajaei Port Complex, the major Iranian seaport, and hence to reduce the truck turn-around times. Even though the case study is unique and distinctive of its kind, the general processes and characteristics are similar to a typical container terminal as shown in Figure 1.

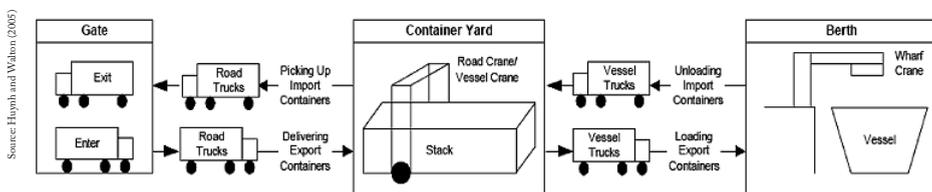


Figure 1. Process of loading/discharging operation in marine terminals.

Achieving this objective and finding the bottlenecks, the following three main patterns will be examined:

1. Arrival patterns of trucks at entrance,
2. Departure patterns of trucks at exit, and
3. Service patterns of weighbridges.



Accordingly, the study will provide a new methodology using the Taylor II simulation software which will attempt to integrate all functions needed for a simulation study by combining all determining parameters in a simple manner and a high flexibility with ease-of-use without making concessions to the functionality of the tasks.

After perusing the queue and waiting time histograms for mentioned patterns, for both entrance and exit, three different solutions would be proposed and modelled. The challenging issues inherent truck congestion in marine terminals, coupled with the limitation of existing research, motivate this study.

**PROBLEM STATEMENT**

The Shahid Rajae Port having 26 specialized berths can serve 22 merchant vessels and 2 tanker ships, simultaneously. The port is equipped with 6 main automatic weighbridges in following patterns:

- 2 are located near the main entrance of the gate complex,
- 2 are located near the exit gate, and,
- 2 are located at the transit yard where only one of them is operational.

Based on the number of Bills of Ladings (B/Ls) analysed, Table 1 represents the traffic of trucks in the port of Shahid Rajae during the period of study (Mar.-Jun. 2009).

Table 1. Traffic of trucks in the Port of Shahid Rajae

Item	Trucks	Chassis
From Shahid Rajae	204,579	77,833
To Shahid Rajae	153,184	64,374

To help identifying the bottlenecks in the process of loading and/or unloading operation of trucks, this section will also study the main patterns of trucks' turn-around times, including:

- Arrival pattern of trucks at the main entrance of the gate complex,
- Service pattern of weighbridges located at the both entrance and transit gates,
- Departure patterns of trucks at main gate exit, and
- Service patterns of weighbridges located at the main exit of the gate complex.

**Arrival Patterns of Trucks at the Main Gate Entrance**

Trucks arriving at the main gate entrance are generally categorized in four groups, including; 1) empty trucks calling at the loading points, 2) trucks carrying export cargoes, 3) trucks carrying the transit cargoes and 4) urban trucks entering the terminal.

Based on the data collected from more than 1500 trucks in one of the busiest working days, the arrival pattern of trucks is confirmed to the Lognormal distribu-



tion with an average of 17.56 sec. per truck. From all arrivals, 65% were weighed at the gate entrance. Amongst remaining trucks, 45.3% were weighed inside the port area and others were the urban trucks which were not weighed. Also, amongst all arrivals, 49.6% were the empty chassis which were not weighed.

### **Service Pattern of Weighbridges**

Data analysis showed that service patterns of weighbridges located at the entrance, transit and gate exits are compatible with Beta distribution with an average of 68.66 sec. per truck. After the process of weighting, all trucks are controlled by custom authorities inside the port.

### **Departure Patterns of Trucks at the Main Exit of the Gate Complex**

Departure trucks are categorized in four groups including 1) those carrying the imported cargoes, 2) container carriers, 3) trucks carrying the transit cargoes, and 4) the empty trucks discharging their cargo in the port. The departure patterns of trucks are considered to confirm to a negative exponential distribution with an average of 24.27 sec per truck.

## **SIMULATION MODEL DEVELOPMENT**

The Taylor II program designed by F&H Simulation Inc. is employed in this study. The Taylor II program is a menu-driven simulation package mainly used in manufacturing, warehousing, and material handling industries. The program is specially developed for the analysis and evaluation of quantitative problems with a dynamic character (Nordgren, 1998). The program enables simulation of discrete event systems with discrete entities.

A proper simulation demands three groups of parameters:

- Element parameters describing the behaviour of elements, including capacity and properties of customers (arrivals and departures),
- Job parameters including properties of servers such as processing, transporting and storing, and
- Stage parameters including supplementary information about customers.

The following assumptions are considered during this study:

- Traffic is uniformly distributed over the entire yard for import and export cargoes,
- The port is considered to be operational for 365 days/year and 24 hours/days,
- All containers have the same length,
- No collision among trucks and between trucks and cranes,
- No double moves, and
- The characteristics of the facilities (weighbridges) are the theoretical figures given by manufacturers and do not change during the study.

This section of study follows with modelling of the case study based on the required parameters. After perusing the queue and waiting time histograms (Predefined graphs) for patterns mentioned earlier and finding out the bottlenecks involved in the processes of entrance and gate exits and weighbridges, it tries to eliminate the probable defects in the system.

Achieving this purpose, three different solutions would be proposed and modelled for both the entrance and the gate exits, respectively.

### Simulating the Model of the Main Entrance of the Gate Complex and Transit Weighbridge

At the first step, the properties of queue at the gate entrance and transit weighbridge should be identified. Figures 2 and 3 represent the queue and waiting histograms for main gate entrance and transit weighbridge, respectively.

Figure 2. Congestions at the main gate entrance in the busy working times.

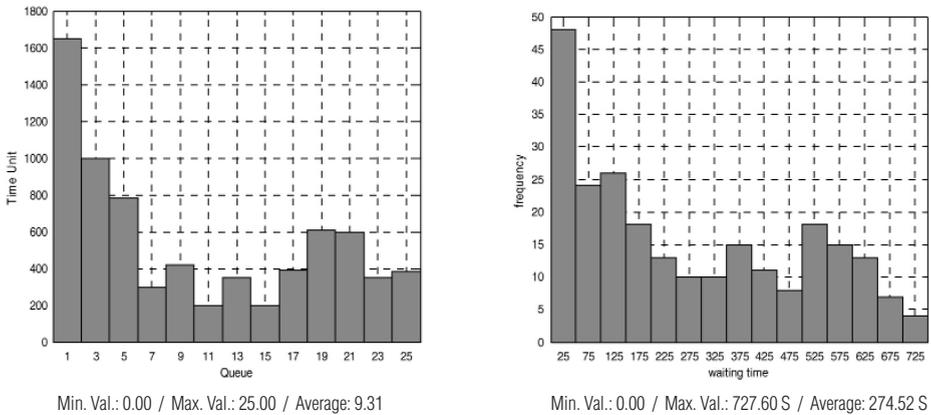
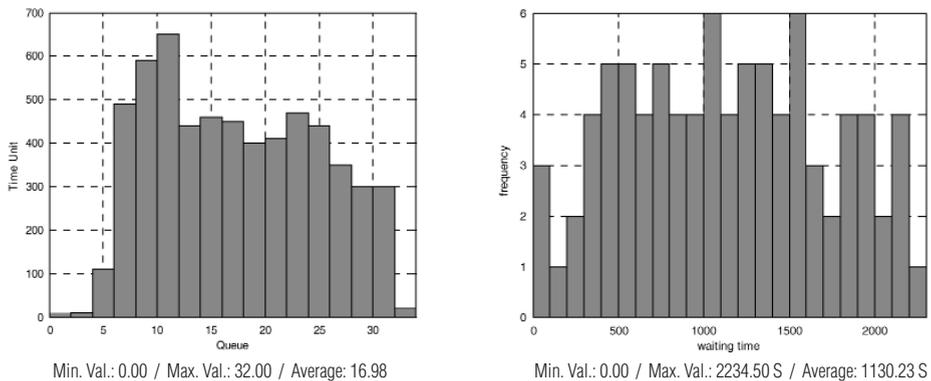


Figure 3. Congestions at transit weighbridge in the busy working times.





Simulation results showed that the two weighbridges of gate entrance are 84% and 54% busy, respectively. Transit weighbridge is also 82% busy at the peak hours of working days.

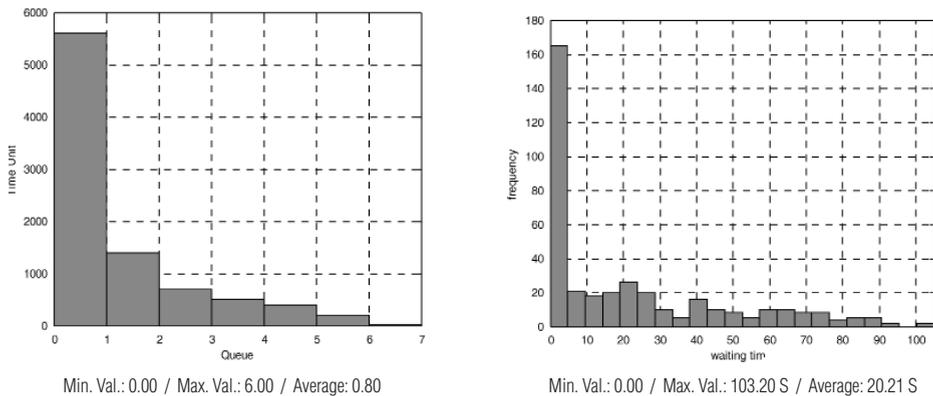
To reduce truck congestions at the gate entrance, three models have been designed and simulated. They include:

- Weighting trucks where drivers do not get off their vehicles,
- Installing an extra weighbridge at the gate entrance, and
- Weighing empty chassis with two transit weighbridges.

### Trucks are weighed where drivers do not get off their vehicles

Generally, drivers get off their trucks for Custom and port formalities. This model proposes a system in which drivers remain in vehicles during the weighing process. This is possible with a little change in control room of weighbridges. In this case, service patterns of weighbridges of gate entrance will be compatible with Logistic Distribution requirements with an average of 36.80 sec. per truck. Figure 4 represents the queue and waiting histograms for these weighbridges.

Figure 4. Congestion in weighbridges of entrance gate in busy working times (First model).



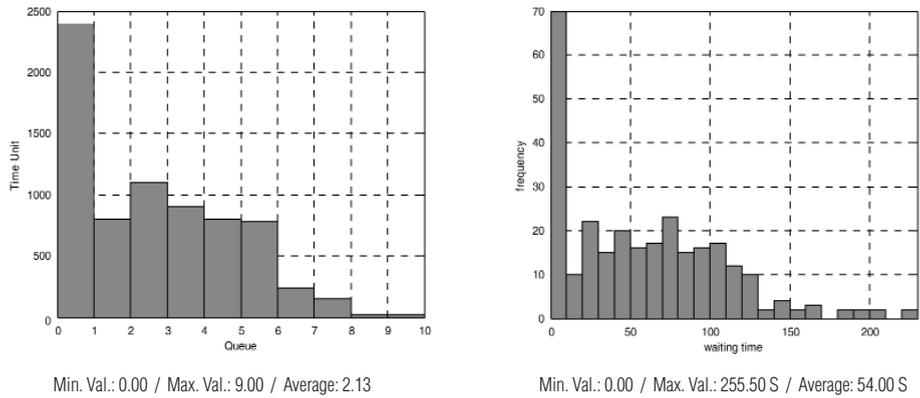
In this new pattern, the two weighbridges of the gate entrance will be 77% and 68% busy.

### Installing an Extra Weighbridge near the Gate Entrance

This model proposes that an additional weighbridge embeds near the two weighbridges at the gate entrance, thus all arrival trucks would be weighed in by three weighbridges. The queue and waiting histograms of these weighbridges are shown in Figure 5.



Figure 5. Congestions in weighbridges of gate entrance in busy working times (Second model).

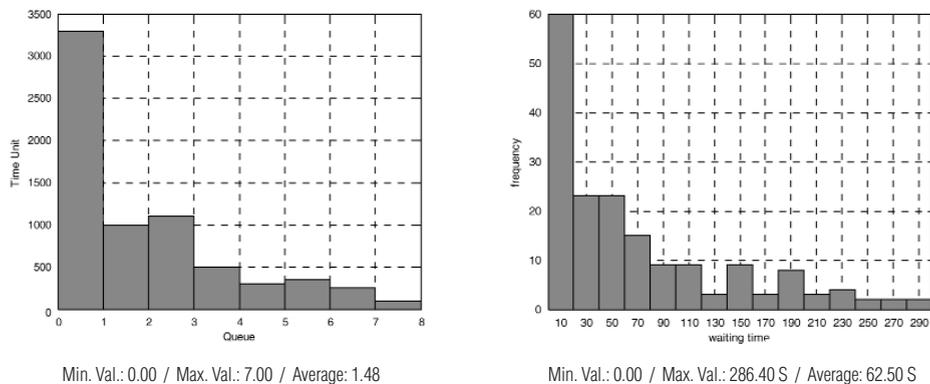


Simulation results show that these weighbridges will be 88%, 85% and 92% busy.

### Weighing Empty Chassis with Two Transit Weighbridges

The third model proposes that both of the transit weighbridges become active and all empty chassis are directed to these weighbridges for weighing. Implementing this model will decrease truck congestions in both the entrance and transit weighbridges. Figure 6 shows the effect of this model on congestions in weighbridges of gate entrance.

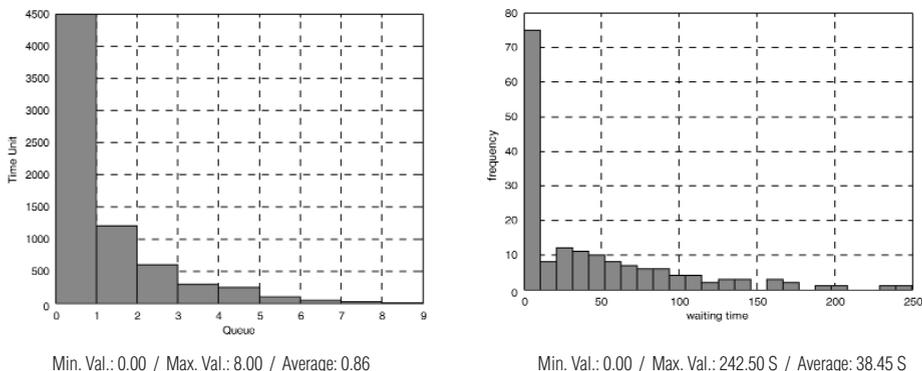
Figure 6. Congestions of weighbridges at the gate entrance in the busy working times (Third model).



The two weighbridges at the gate entrance are found to be 84% and 79% busy. The effect of this model on congestions in transit weighbridges is shown in Figure 7.



Figure 7. Congestions at the transit weighbridges in the busy working times (Third model).

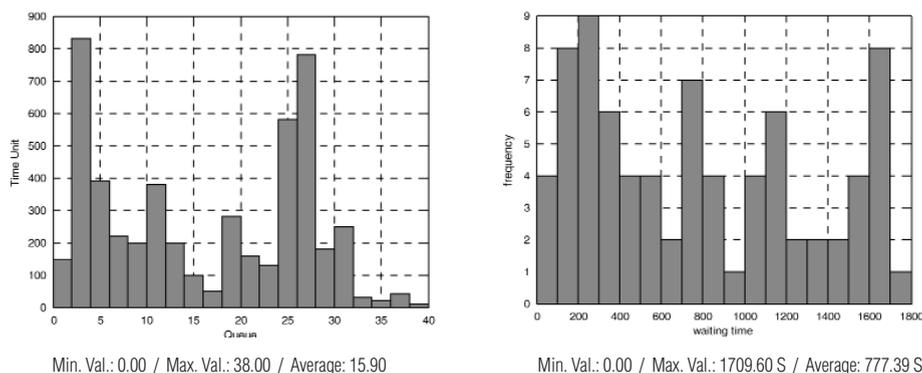


In the third model, transit weighbridges found to be 69% and 79% busy.

### Simulating the Main Gate Exit

As mentioned earlier, there are two active weighbridges at the main gate exit. The bottlenecks at the gate exit, the queue and waiting histograms of trucks in these weighbridges are identified and shown in Figure 8.

Figure 8. Congestions at the weighbridges of gate exit in busy working times



Simulation results showed that the two weighbridges at the gate exit are busy 99% and 98%, respectively in the peak hours of working days.

For modelling the gate entrance and transit weighbridges, three simulation models have been proposed for reducing truck congestions. These include:

- Weighting trucks where drivers do not get off their vehicles,

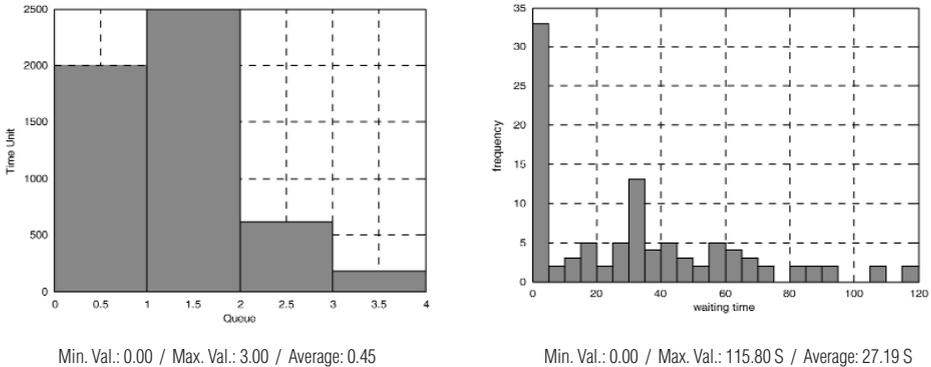
- Installing an extra weighbridge at the gate exit, and
- Weighing vehicles carrying container with transit weighbridge

This section follows with evaluating the effects of proposed models on reducing truck congestions in gate exit.

### Trucks are Weighed where drivers do not get off their vehicles (Gate Exit)

This model proposes a system in which drivers remain in vehicles during the weighing process. It will be simply possible with a little change in control room of weighbridges. Same as the proposed model for gate entrance, service pattern of weighbridges of the gate exit will also be compatible with Logistic Distribution requirements with an average of 36.80 sec. per truck. Figure 9 represents the queue and waiting histograms for these weighbridges.

Figure 9. Congestions of weighbridges at the gate exit in busy working times (First model).



Weighed trucks should refer directly to the parking area for Customs’ controls. The first and second weighbridges at the gate exit are found to be 58% and 90% busy.

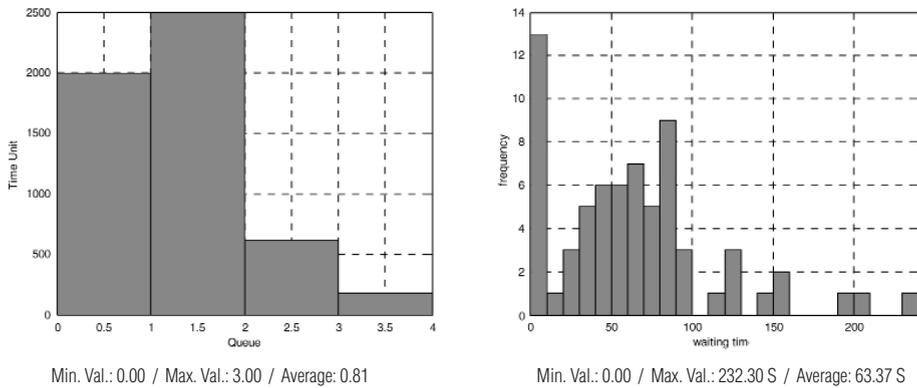
### Installing an Extra Weighbridge Near the Gate Exit

In this case, an extra weighbridge should be installed in gate exit near the previous two weighbridges and all departure trucks should weigh by these weighbridges. Figure 10 shows the queue and waiting histograms for these weighbridges.

The first and second weighbridges are found to be 99% and 91% busy in the new model. The extra weighbridge which is considered only for using at peak hours of traffic is 64% busy.



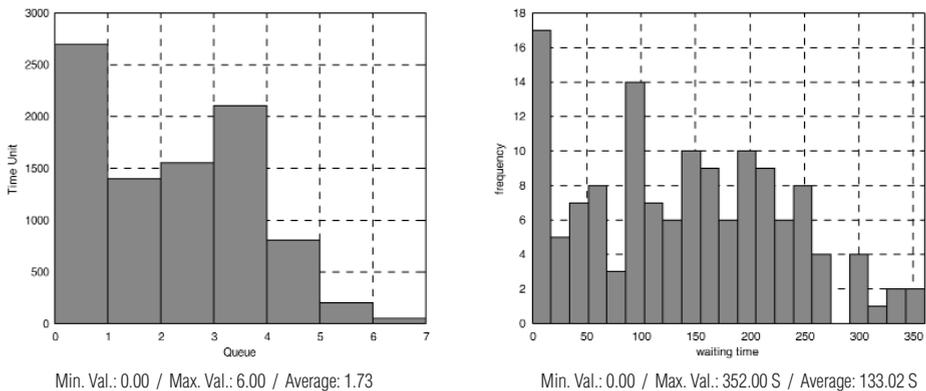
Figure 10. Congestions in weighbridges of gate exit in busy working times (Second model).



### Weighing Vehicles Carrying Container with Transit Weighbridge

The third model proposes that the transit weighbridge only to serve the trucks that carry containers. Other trucks should be weighed by weighbridges at the gate exit. Queue and waiting histograms for transit weighbridge are shown in Figure 11.

Figure 11. Congestions in transit weighbridge in busy working times (Third model).



In this pattern, the first and second weighbridges at the gate exit found to be 99% and 97% busy. Also, the transit weighbridge is found to be 84% busy.

### DATA ANALYSIS

Number of queuing lines and average waiting time of customers are regarded as the main parameters of a queuing system. Following table represents the results of

implementing the proposed models and their effects on reducing the truck congestions in the port area and provides a comparison among these models.

Table 2. Simulation results for proposed models

Item			Present model	Proposed model			Congestions Reduction (%)		
				First	Second	Third	First	Second	Third
Weighbridges of gate entrance	Queuing number	Max. (Que.)	25	6	9	7	76	64	72
		Ave. (Que.)	9.31	0.8	2.13	1.48	91	77	84
	Waiting time	Max. (Sec.)	727.6	103.2	225.5	286.4	86	69	61
		Ave. (Sec.)	274.52	20.21	54	62.5	93	80	77
Transit weighbridge	Queuing number	Max. (Que.)	32	—	—	8	100	100	75
		Ave. (Que.)	16.98	—	—	0.86	100	100	95
	Waiting time	Max. (Sec.)	2234.5	—	—	242.5	100	100	89
		Ave. (Sec.)	1130.23	—	—	38.45	100	100	97
Weighbridges of gate exit	Queuing number	Max. (Que.)	34	3.5	3.33	6.33	89	90	81
		Ave. (Que.)	15.56	0.6	0.77	2.77	96	94	82
	Waiting time	Max. (Sec.)	1667.9	123.2	234.4	411.46	93	86	83
		Ave. (Sec.)	770.07	29.01	61.01	174.37	97	92	75

As illustrated in Table 2, the first model resulted the most reductions in the truck congestions at the entrance and gate exits and also at the transit weighbridge. Same as the first model, using the second proposed model, the truck congestions in the transit area is totally eliminated, even though it is considered as the second priority among all models. In comparison with the first and second models, there is less reduction in truck congestions in the third model which assigns the transit weighbridge to empty chassis and container carriers.

### CONCLUSIONS

Trucks are spending more and more idle times at ports because of congestions that impose additional costs on port authorities, carriers and the supply chain as a whole. The main idea behind this research was to flattening the gate activities to an efficient level to reduce the trucks' queuing time.



The objective of this research was to minimize truck congestions at the main gates of Shahid Rajaei Port and reducing the truck turn-around times in a prevailing queuing system. Achieving this purpose and finding the bottlenecks, three main patterns including 1) arrival patterns of trucks in entrance, 2) departure patterns of trucks in exit and 3) service patterns of weighbridges have been specified and modelled using the Taylor II simulation software.

After perusing the queue and waiting time histograms for the above patterns and for both the entrance and exit gates, three different solutions were proposed and modelled.

Among all models, implementing the first model which simply weighs the trucks where drivers do not get off their vehicles during weighing process has resulted the highest reductions in the trucks' congestion times as successfully been tested in many modern ports such as Southampton, Felixtow, Thames Port, Liverpool, Kobe and Singapore. Installing two extra weighbridges at both of the entrance and gate exits, which is more investable in comparison with the first model, has shown to be the second priority and hence ranked the second between the three models. Finally, the less priority has been given to the third model that assigns the transit weighbridge for specific vehicles such as empty chassis and container carriers.

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