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Assessment of a container terminal expansion using simulation

Aurelio López-González, Silvia V. Medina-León, Alvaro González-Angeles, Ismael Mendoza-Muñoz & Margarita Gil-Samaniego-Ramos

Facultad de Ingeniería, Universidad Autónoma de Baja California, Mexicali, México, lopez.aurelio@uabc.edu.mx, svmedina88@gmail.com, gangelesa@gmail.com, ismael.mendoza@uabc.edu.mx, margarita.gil.samaniego.ramos@uabc.edu.mx

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Abstract
The paper presents a methodology to construct a Discrete Event Simulation model to assess the expansion of a container terminal. The methodology was applied to the Ensenada International Terminal located in Mexico. The simulation integrates all the operations of the container terminal including the arrival of vessels, trucks, and storage of containers. The expansion plan included the addition of anew berth, and additional storage yard space. The expansion model was evaluated under different demand increments. Recommendations were provided on the level of demand that the expansion may be able to serve. As a result, the additional berth will increase the capacity, but the projected storage space will support up to a 140% increase in demand with a 20% in reserve. The terminal must consider additional storage space either in the terminal or at an external facility for additional demand greater than 140%, or for having a larger storage reserve.

Keywords: seaport; container terminal; capacity; resources; discrete event simulation.

Evaluación de expansión de una terminal de contenedores usando simulación

Resumen
El artículo presenta una metodología para construir un modelo de simulación de eventos discretos para evaluar la expansión de una terminal de contenedores. La metodología fue aplicada a la Terminal Internacional de Contenedores de Ensenada ubicada en México. La simulación integra todas las operaciones de la terminal de contenedores, incluida la llegada de embarcaciones, camiones y almacenamiento de contenedores. El plan de expansión incluyó la incorporación de un muelle adicional y espacio adicional de almacenamiento en el patio. El modelo de expansión se evaluó bajo diferentes incrementos en la demanda. Se proporcionaron recomendaciones sobre el nivel de demanda capaz de servir. Como resultado, el muelle adicional aumentará la capacidad, pero el espacio de almacenamiento proyectado soportará hasta un 140% de aumento en la demanda con un 20% de reserva. La terminal debe considerar espacio de almacenamiento adicional, ya sea en la terminal o en una instalación externa para una demanda adicional mayor al 140% o para tener una mayor reserva de almacenamiento.

Palabras clave: puerto; terminal de contenedores; capacidad, recursos; simulación de eventos discretos.

1. Introduction

The Ensenada International Terminal (EIT) started operations in 1997, and it is located in Ensenada, Baja California, Mexico, 68 miles south of the US border. The terminal is dedicated to the movement of containers and general cargo handling. The container traffic of EIT in 2018 was of 194,431 TEUs (Twenty-Foot Equivalent Unit is a standard unit for counting containers of various capacities) and was the fifth port in Mexico with the highest container traffic [1].

In general, Mexico keeps growing its port operations with public and private investments [2]. The position of EIT is strategic due to the proximity to the ports of Los Angeles and Long Beach. The EIT has the potential to serve as an alternative port. Indeed, when there is port congestion in Los

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Angeles or Long Beach, some vessels may change their schedule and arrive at EIT. The terminal can receive vessels of up to 11,000 TEUs.

EIT currently has two berths. One of the berths is for bulk cargoes such as wheat or minerals, and the other is for containerized cargo. EIT was interested on knowing the impact on adding a new berth for the service of containerized vessels, and the planned expansion of the storage yard. Simultaneously, the terminal was interested on knowing how the system would respond to demand increments. Due to the focus on analyzing containerized cargoes, this study excludes data for the berth devoted to serve bulk cargoes.

The analysis tool chosen to assess the planned expansion of the terminal was aDiscrete Event Simulation (DES). A simulation shows the impact of any changes to the system before doing any actual change in the real system, and before making a big investment. Particularly, a Discrete Event Simulation provides a detailed analysis of the system, and it is popular for analyzing complex systems. A seaport terminal is a complex system due to the large number of operations, resources and variables involved [3]. Therefore, when analyzing systems like a seaport terminal, one of the recommended options is the use of asimulation [4]. Unlike mathematical models, a simulation allows to incorporate several variables that affect the system's behavior.

Simulation is a technique used frequently to analyze and solve problems in port and container terminals. In fact, over the past 50 years the use of simulation on container terminals has increased considerably, especially since 2000 [3]. The two pioneers using simulation in ports were Steer and Page in 1961 [5] and Beatti in 1971 [6]. They both used Montecarlo simulation. Then, studies emerged using general purposes languages to develop port simulations starting with the use of FORTRAN by Lawrence in 1973 [7] and Borovis and Eindor in 1975 [8], and then Pascal, for example in the work of El Sheikh et al. in 1987 [9], and Wadhwa in 1992 [10]; then, most recently C++ and Java; for example Petering in 2011 [11], and Guo and Huang in 2012 [12] used C++; Veenstra et al. in 2012 [l3], Zhang et al. in 2014 [14] used Java. Also, simulation-oriented languages emerged; for example, SLAM used by Park and Noh in 1987 [15], and Legato and Maza in 2001 [16], SIMSCRIPT used by Darzentas and Spyrou in 1996 [17], and GPSS/H used by Dragovic in 2006 [18]. However, with the advances in computing, later high-level simulator products emerged. These products were very easy to use. They typically operated by graphical user interfaces, menus, and dialogs [19]. These high-level simulators have become the most popular tools for the creation of Simulation Models (SM) in ports. For example, software Arena used by Merkuryev et al. in 1998 [20], and by Kulak et al. in 2013 [21]; software Flexsim used by Huynh in 2009 [22], and Kabakeb et al. in 2015 [23], and software Anylogic used by Kondratyev in 2015 [24]. Now, considering all the options available to create the simulation models, according to the extensive literature review done by Dragovic et al., Arena resulted the most popular simulation tool used to create simulation models in ports published on scientific journals from 1961 to 2015, where 21.4% of the studies chose Arena as their simulation tool [3].

The use of simulations models (SM) in container terminals are diverse. According to Dragovic et al. [3] the applications of simulation models in container terminals from 1961 to 2015 were about performance evaluations [8,25], analysis of transfer and storage equipment [26,27], analysis of automated operations [28,29], logistic planning [30,31], determining storage policies [32,33], and determining operational policies [34,35].

The specific application of this project was evaluating the impact on service levels with the expansion of the terminal. In literature, we can find container terminals who have constructed SM to evaluate expansions [36-39]. For example: Tang et al. [36] presented the expansion project of Lushun Ro-Pax terminal; Wu et al., [37] used DES to evaluate the necessity of a tenth terminal in Hong Kong port, and if the existing facilities could handle more demand without getting inadequate service levels (vessel waiting times); Sheikholeslami et al., [38] applied DES to simulate a container terminal in Iran. They used the model to evaluate the effect of increasing the access channel depth and quay length to reduce container ships waiting times; Veloqui et al., [39] developed a discrete simulation model for the Consorzio Napoletano Container Terminal to evaluate the effect at incrementing the number of servers in the access gate and the yard. All these expansion projects [36-39] presented their studies tailored to the container terminal outlining the main points of the project. This paper has the purpose of presenting a methodology for constructing and using a simulation model for assessing the expansion plans of a container terminal. This methodology was applied to the case of EIT.

2. Methodology

The methodology used to assess the expansion plans of the EIT is described in the following points.

2.1. Description of the processes in the EIT

First, the authors created the conceptual model. According to their flow, containers were identified as import, export or transshipment containers. Import containers are the ones unloaded from the vessels, stored in the terminal, and then picked up by external trucks, and transported inland. Export containers are the ones received from inland by trucks, stored in the terminal, and then loaded to the vessels. Transshipment containers are containers unloaded from vessels and kept in the storage yard until another vessel picks them up and transport them to a different port. Fig. 1 describes graphically the different flow of containers.

The operations of the EIT start with the arrival of the vessels from different shipping lines to the terminal based on determined schedules. If the berth is busy, the vessel waits in the anchorage area, otherwise it goes directly to the berth. The first process with the vessel is unloading import and transshipment containers. Quay cranes move the containers from the vessel to yard trucks. The yard trucks transport the

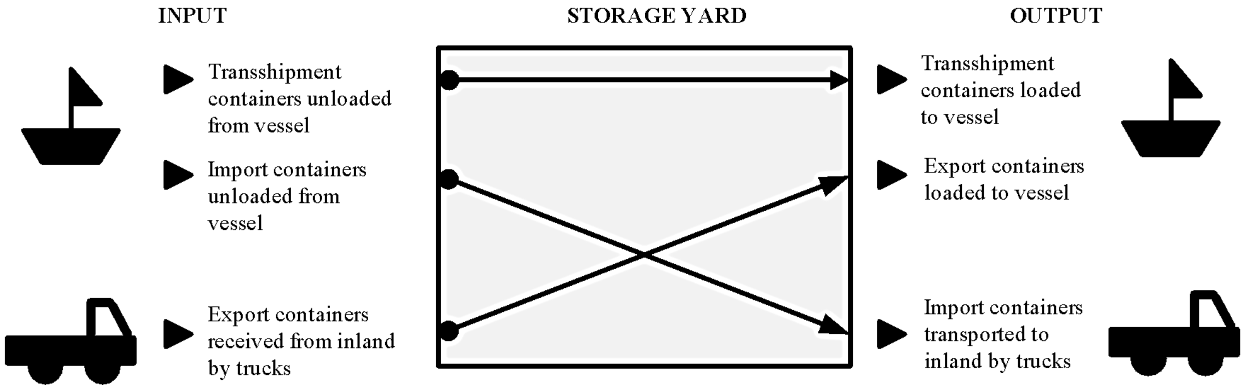

Figure 1. Flow of containers.
Source: The Authors.

containers from the berth to the storage yard where in turn, yard cranes move the containers from the yard truck to the storage position in the yard.

After unloading all containers, the loading process starts. Now reversing the process, yard cranes move import or transshipment containers from their storage position to the yard trucks, and then the yard trucks move the containers to the berth where a quay crane moves the container to the vessel. After the required containers are loaded, the vessel leaves the berth, and continues to the next port. As well as there are sea operations, there are land operations, so import containers in the storage yard are picked up by external trucks to transport them to inland destinations. In addition, the terminal receives export containers from inland, transported by trucks, to be loaded to vessels later. The period of time in which a container stays in the storage yard is known as dwell time.

The storage yard allocation is organized in blocks. The depth of each block is mostly of 6 rows of containers, and the length of each sub-block varies from 12 to 25 slots (each slot can accommodate one 20ft container lengthwise). The stacking height is 5 containers high. There are lanes between the blocks for passing trucks and loading and unloading operations. The storage yard is segmented by type of container, which can be transshipment, import and export. Furthermore, import and export containers can be full or empty. Therefore, there is a section allocated at the storage yard for import full containers, import empty containers, export full containers, export empty containers, and transshipment containers. In addition, some containers can be classified as refrigerated requiring electrical power; however, this characteristic was excluded from the model for simplification purposes. The storage capacity of the terminal was of 7500 TEU. A TEU or Twenty-Foot Equivalent Unit is a standard unit for counting containers of various capacities. Containers come in various standard sizes for example 20-foot, 40-foot, 45-foot, 48-foot and 53-foot. However, TEU is the standard unit to measure capacities of container ships or terminals. As an example, a 40-foot container is equivalent to 2 TEUs.

2.2. Data collection and preparation

The simulation model used data based on records provided by Ensenada International Terminal that included arrivals of vessels and trucks, loading, and unloading containers. Operation and transportation times that were not available in records were sampled directly. In these cases, the authors took an initial sample of size 30, and then calculated the margin of error of the sample using Eq. 1 [19].

$$E = t_{\alpha/2,n-1,}\frac{s}{\sqrt{n}} \tag{1}$$

Where E: Margin of error of the sample mean
t: t student value
s: standard deviation
n: Sample size (30 initially)
α: level of significance of 5%

Then, the percentage of margin of error of the sample mean was calculated.

$$\%E = \frac{E}{\underline{x}}\, x\, 100 \tag{2}$$

Where %E: Percentage of margin of error of the sample mean
E: Margin of error of the sample mean
$\underline{x}$: Sample mean of the representative variable

If the percentage of margin of error of the sample mean (%E) exceeded 10%, then the study would require a bigger sample size, and Eq. 3 determined the sample size required to meet the acceptable error (E_a) of no more than 10% of the sample mean [19].

$$n = z_{1-\alpha/2}\frac{s}{E_a} \tag{3}$$

Where z: z value of the normal distribution.
E_a: Acceptable margin of error of the mean calculated by

$$E_a = \frac{\%E_a\underline{x}}{100}$$

$\%E_a$: Percentage of acceptable margin of error. In this project an error of 10% was considered acceptable.

Eq. 3 is equal to Eq. 1 with only a couple of considerations. Instead of using a t-value from a t-student distribution, the authors used a z-value from a normal distribution because the sample size is greater than 30. Also, since the population standard deviation is unknown, the sample standard deviation (s) is used assuming that it will be the same.

In addition, the authors adjusted process times to probability distributions using the tool “Input Analyzer” of the Arena software. The software finds the probability distribution that fits best for the data. The authors used the Chi-Square test or Kolmogorov tests to validate an acceptable fit with a 95% confidence level. Fig. 2 shows as an example the report of probability distribution with best fit for the process storage time for unloaded containers.

2.3. Assumptions and simplifications of the simulation model

The simulation model considered the following assumptions and simplifications:

- Although the equipment deployed at the yard blocks to handle containers in the current system was formed by 3 Rubber Tyred Gantry Cranes or RTGs Cranes, and 2 Reach Stackers, both cranes were programmed as a single type of resources called yard cranes. Yard cranes carry out the storage, pickup and reshuffling operations of containers in the storage yard.
- For programming purposes, the space at the yard storage was considered unlimited. However, the analysis considered the limitations of 7500 TEUs for the current model and 8520 TEUs for the expansion model.
- The model did not consider the characteristic of refrigerated containers.
- The model did not include the berth devoted to serve bulk cargoes.

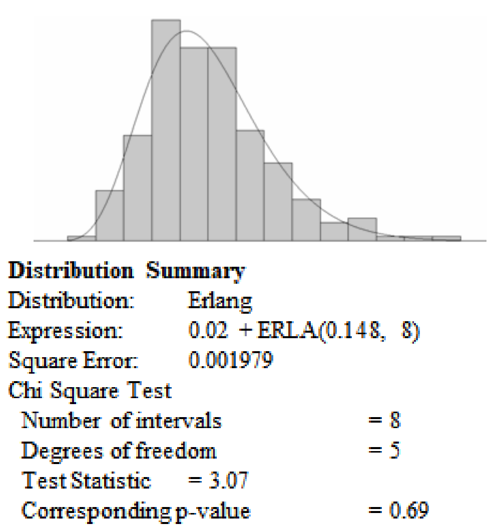

Figure 2. Example of probability distribution with best fit to the data.
Source: The Authors.

2.4. Programming the simulation model

The authors developed the discrete event simulation model using Arena software from Rockwell version 9 [19, 40, 41] because of its simplicity at programming, and its features at analyzing outputs such as process analyzer and optimization tools [19]. The simulation model developed for EIT includes arrival of vessels, unloading and loading of export containers, movements of containers within the terminal and the storage yard, reception of export containers transported by trucks, and delivery of import containers transported inland by trucks. The authors divided the programming of the model in 5 sections to facilitate its description presented as follows.

Section 1 Vessels. Programming the vessel entity. The inter-arrival times for vessels followed a Weibull distribution. The program duplicates the vessel entity two times, where the original entity keeps being the vessel. The first time, the program duplicates the vessel entity to generate the number of containers to be unloaded from the vessel, which then continue in section 2. The second time, the program duplicates the vessel entity to generate the number of containers to be loaded into the vessel which then continue in section 3. The number of duplicates was determined by statistical distributions fitted to the data. In addition, the program keeps the vessel on hold for two times. The first time, the vessel waits for the signal that the unloading process has concluded, and the second time that the loading process has concluded. Variables keep records of the number of containers loaded and unloaded, and when they meet the goal, the program sends a signal and the vessel is free to leave the port.

Section 2 Unloading containers from ship. Now the duplicated entities received from section 1 are containers in the ship to be unloaded. The program assigns a type to each container, which can be: 1) full container, 2) transshipment container, and 3) empty container. Depending on its type, the container is sent to a certain section of the storage yard, and then to a specific block. The import containers (full and empty) have a delay represented by a statistical distribution, and then continue in section 4 where they are going to be picked up by an external truck. On the other hand, the transshipment containers are kept in storage until they continue in section 3 where another vessel will request them.

Section 3 Loading containers to ship. Now, the duplicated entities received from section 1 are tickets to pull export containers from the storage yard, and then load them to the vessel. First, the program decides the type of container to be loaded which can be 1) full container, 2) transshipment container, or 3) empty container. The containers previously arrived from inland, and in the case of transshipment containers, they came from other vessels. The program removes the containers from programmed queues where each container has been assigned an approximate departure time based on a statistical distribution. The program first loads the containersthat have the longest surpassed time or that are closest to the departure time.

Section 4 Import containers picked up by trucks. Import containers unloaded in section 2, and kept in the storage yard, are picked up by external trucks, and then transported to different destinations of the region.

Section 5 Reception of Export containers transported by trucks. Export containers arrive at the terminal by trucks from inland. Inter-arrival times for export containers follow a non-stationary Poisson process, and the Arena´s module "Schedule" was used to program this type of arrival. Each container is assigned a type of container which can be: 1) full container or 3) empty container. Then, the containers are sent to a section at the storage yard, and then to a specific block according to their type. The program assigns the containers an approximate departure time, and then they will be pulled as explained on section 3.

2.5. Defining running parameters of the model

The model required a warmup time to execute because the terminal is a steady state system. A steady state system is a system where operations keep running through all the days with no specific starting and ending times. As a result, the real system has already entities around, whereas a simulation model starts out with no entities. Therefore, the computer needed to run the model for a while (warm up time) in order to have a similar level of entities in the model as the real system before starting to collect statistics. The authors used the Welch Graph method to determine the warmup time [19]. This method consists on selecting a variable that describes the system as steady state, running the model, and plotting the behavior of the variable over time. The warmup time is the point in the graph where the variable starts showing a steady behavior instead of growing as a positive slope. For this study, the authors selected the variable "number of containers at the storage yard" to determine the warmup time. The model run 30 replications, each of 365 days duration. Fig. 3 shows the number of containers at the storage yard through time for each replication. Each replication is shown with a different gray tone. Fig. 3 shows that the warmup time was reached in 500 hours (20.83 days), which was rounded up to 21 days. Thus, the authors calculated the replication length adding 21 days of warm up time to 365 days. As result, the replication length was of 386 days.

In order to determine the proper number of replications, the authors run 30 replicates of the model, each of 386 days duration. Then, the authors used Eq. 1 [19] to determine the Error (E) of the sample mean of a representative variable. In this case n is the number of replications of the simulation model. For this study, the authors selected "Number of containers at the storage yard" as the representative variable where n=30, $\underline{x}$=2404, s=610.05, $t_{0.025,29}$= 2.045. Using Eq. 1, the margin of Error of the sample was E= 227.80. Consequently, using Eq. 2 the percentage of margin of error (% E) was of 9.47%. Because this value is less than 10%, the percentage requested by the customer, 30 replications were enough. As a result, the model run 30 replications, each one with a duration of 386 days and a confidence level of 95%.

2.6. Validation of the model

The authors validated the model by comparing values between the model and the real system, and by face validation. For face validation, key personnel of the terminal with high knowledge about the terminal operations participated in a meeting with some of the authors. After the personnel reviewed the outputs of the model, they made some clarifications, and then the authors adjusted the model to meet their observations.

For the comparison, the authors selected a set of representative parameters to compare the real value against the value obtained from the simulation model. Table 1 presents the parameters used.

The table includes parameters about the vessel, movement of containers, and the storage yard. For each parameter, the authors calculated the percentage of Error (% Error) using Eq. 4:

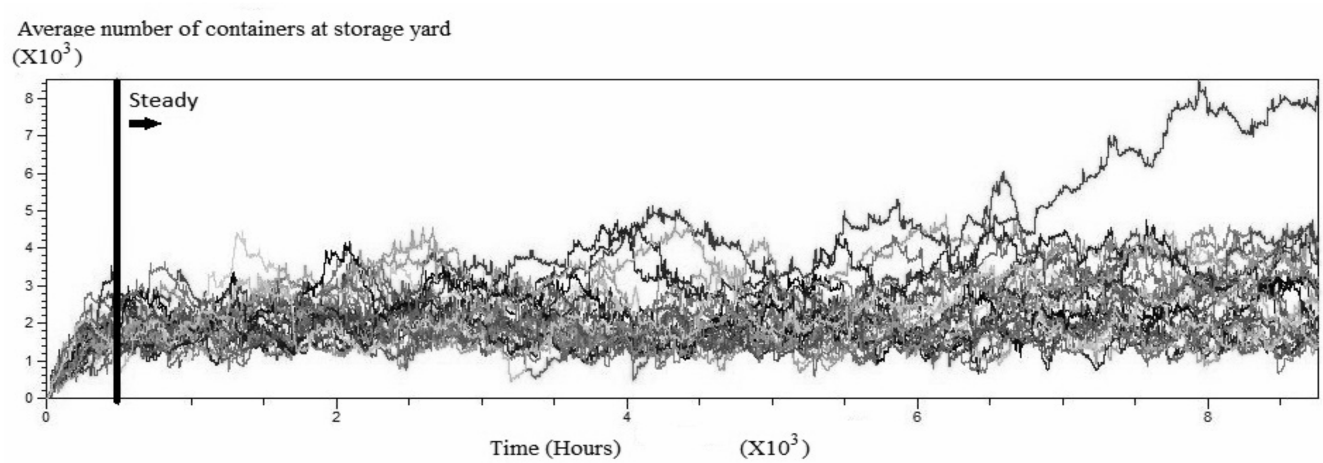

Figure 3. Warm up analysis.
Source: The Authors

$$\% \, Error = \left| \frac{Real\ Value\ Average - Current\ Model\ value\ Average}{Real\ value\ Average} \right| * 100 \quad (4)$$

In all cases, the percentage of error (% Error) was less or equal to 8%, and the personnel of the terminal accepted the model as valid. Thus, the model was valid to be used for experimentation.

2.7. Experimenting with the model

The authors performed the experimentation of the model in two phases. The first phase compares the current model against the expansion model. The expansion model incorporated a second berth for serving containerized vessels, and additional storage space. It also includes an increase in supporting resources such as cranes and trucks; however, the demand was constant. In the second experimentation phaseusing the expansion model, the authors increased the demand at different percentages, and compared the results of the performance indicators to the current model.

3. Results

3.1. Phase 1 Experimentation: Comparing the current model versus the expansion model while keeping a constant demand

In this phase, the authors ran the expansion model (scenario 1) using 30 replications, and then compared the results to the current model. The expansion model included adding a berth to serve containerized vessels, as well as increasing the storage yard area from 7500 TEU capacity to 8520 TEUs. This number is based on the expansion plans of the terminal. Adding a berth may involve an increase in supportive resources such as cranes and trucks. For the scope of this study, the authors duplicated the number of cranes and trucks; however, future analysis can be carried out to assess the effect of changing the number of cranes and trucks and make specific recommendations. In this experimentation phase, the demand was kept constant. The purpose of this experimentation phase was to know the impact on the performance indicators with the expansion plans of the terminal. Table 2 shows the effect on the performance indicators when expanding the terminal. The column “Difference” was obtained by subtracting the “Current model” value to the “Expansion model” value. The column “% of change” was obtained by dividing the “Difference” value over the “Current model” value and multiplying by 100. In average,the number of vessels waiting for berth was insignificant for the current model (0.043) and even more for the expansion model (0.006). In addition, there was an 85% reduction on the average vessel waiting time for berth from 1.38 hours to 0.21 hours or 12.6 minutes. Likewise, there was

Table 1
Model validation.

Description of parameter	Real	Current model	Diffe-rence	% error
Average vessel waiting time for berth (Hours)	1.45	1.38	-0.07	5%
Average vessel length of stay (Hours)	9.69	9.62	-0.07	1%
Container dwell time mean (Days)	9.63	10.20	0.57	6%
Number of vessels served	265	267	2.37	1%
Average number of total TEUs usedat storage yard	3,600	3,847	247	7%
Storage yard utilization (7500 TEUs)	48%	51%	3%	6%
Number of full containers loaded to vessel	30,655	33,049	2394	8%
Number of transshipment containers loaded to vessel	3,664	3,526	-138	4%
Number of empty containers loaded to vessel	6,146	6,621	475	8%
Number of full containers unloaded from vessel	16,464	17,488	1,024	6%
Number of transshipment containers unloaded from vessel	3,518	3,559	41	1%
Number of empty containers unloaded from vessel	22,699	23,711	1,012	4%
Number of full containers to export arrived by land	34,149	33,797	-352	1%
Number of empty containers to export arrived by land	6,734	6,780	46	1%
Number of full containers imported by truck	16,464	17,407	943	6%
Number of empty containers imported by truck	22,699	23,598	899	4%
Total containers loaded to vessel	40,465	43,196	2,731	7%
Total containers unloaded from vessel	42,681	44,758	2,077	5%
Total containers arrived by land to export	40,883	40,577	-306	1%
Total containers imported by truck	39,163	41,005	1,842	5%

Source: The Authors.

Table 2.
Effects on performance indicators at expanding the terminal.

Performance indicator	Current model	Expansion model (scenario 1)	Difference	% of change
Average number of vessels waiting for berth (unit)	0.043	0.006	-0.04	-87%
Average vessel waiting time for berth (Hours)	1.38	0.21	-1.17	-85%
Average vessel length of stay (Hours)	9.62	8.22	-1.40	-15%
Storage yard utilization (%)	51%	43%	-8%	-
Berth utilization (%)	23.86%	19.45%	-4.41%	-

Source: The Authors.

a 15% reduction on the average vessel length of stay. This reduction was due to the additional supportive resources. When only one berth is occupied, yard cranes and storage yards can be used to serve only one vessel, accelerating the service time. In addition, there was an 8% reduction on the storage yard utilization.

3.2. Phase 2 Experimentation: Comparing current modelversus expansion model and considering demand increments

This experimentation phase considered the same expansion model of phase 1; however, it considered increasing the demand at increments from 20% up to 180%. The authors named each scenario based on the percentage of increased demand. For example, “20%” refers to the evaluation of the expansion project considering an increase of 20% on the arrival of vessels and trucks. This analysis allows determining when the resources reach current, and saturation levels. A saturation level occurs when the utilization of the resource is more than 80% of the time. In these experiments, the authors used 15 replications in each scenario.

Fig. 4 presents the average vessel waiting time for berth at increasing the demand. It shows that this indicator kept below the current model time, which is 1.38 hours, up to the point where the demand increases 160% more. Therefore, adding a second berth for containerized vessels will help reduce vessels waiting time for up to 140% increase in demand.

Fig. 5 shows the average vessel length of stay. Similarly, the average vessel length of stay kept below the current model time for up to 140% demand. At 160% more demand, the average vessel waiting time exceeded the current model time. Therefore, the expansion will help reduce vessels length of stay for up to 140% increase on demand. This reduction was mainly due to the additional cranes and trucks considered on the expansion.

Table 3 shows the utilization of key resources when the demand is increased. First, for the storage yard, the current level is quickly surpassed at 60% increase on demand. Therefore, storage space is a critical resource in the terminal for increasing demand. Depending on the planned reserve area, the terminal can support a greater demand. For example, a 140% increase on demand has 80% storage yard utilization and a 20 % reserve. If the terminal feels comfortable with 80 % storage yard utilization on average, then it can support up to 140% increase on demand. Secondly0,0 Table 4 shows that less than current berth utilization is kept up to 60% percent increase on demand, and there is still enough capacity available. Finally, quay cranes and yard cranes are resources with very low utilization even when the demand is increased.

Table 4 presents a summary on which performance indicators in the expansion model kept below or equal to current model levels up to a certain increment on demand. It shows that the bottleneck was the storage yard space because the current level of 51% is kept up to a 40% increase on demand.

Nevertheless, there is still storage capacity available for additional increments of demand. According to Table 3, if a limit was set to 80% of storage yard utilization, then an additional demand of up to 140% could be supported. If the container terminal is looking for a bigger increase on demand than that of 140%, or more reserve, then it needs to consider adding more storage space than the 1020 TEUs planned or consider an external storage facility.

After analyzing the effect of the demand, and considering up to an 80% use of resources, the expansion plan could support up to 140% increase on demand. In summary, Table 5 presents the performance indicators values of the current model and the expansion model with 140% more demand. The average vessel waiting time for berth and the vessel length of stay show a reduction even with the increment on demand. On the other hand, the utilization of all the resources is increased, but still the level is 80% or less. The critical resource is the storage yard space.

The authors presented the results to the directives of the terminal, and they considered them of great value for their long-term planning.

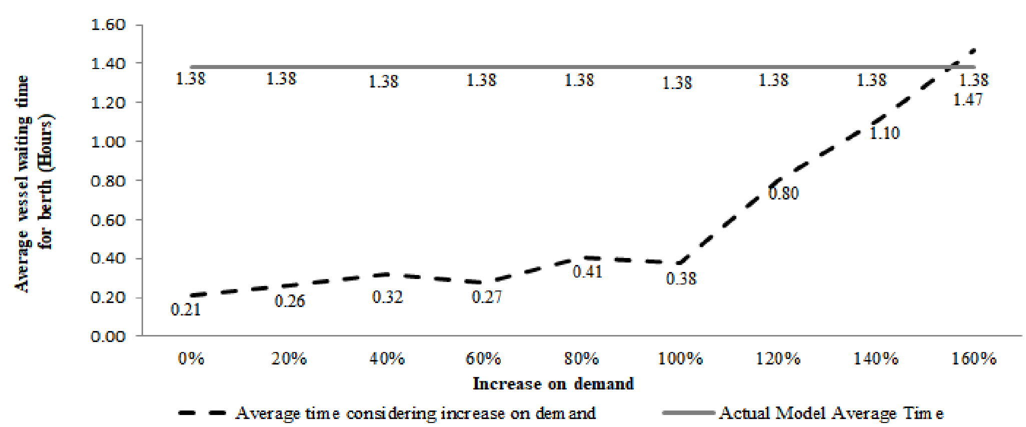

Figure 4. Average vessel waiting time for berth.
Source: The Authors.

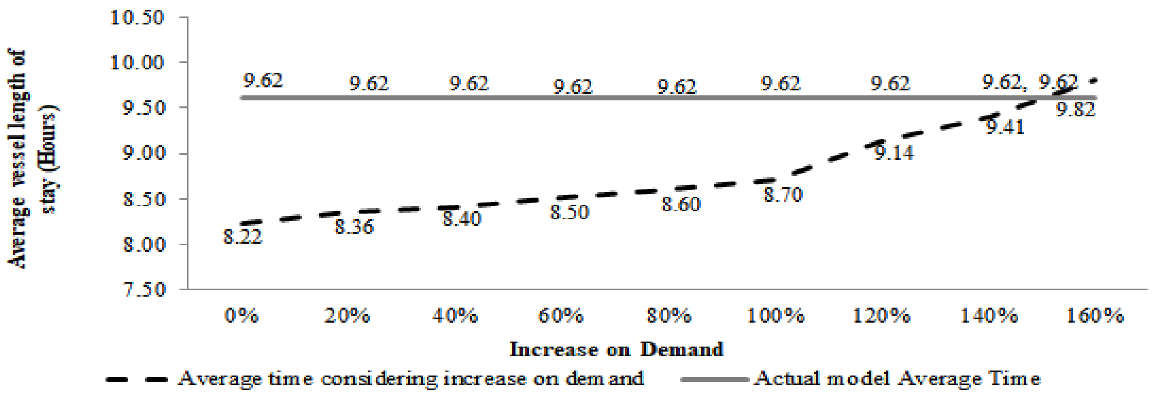

Figure 5. Average vessel length of stay.
Source: The Authors.

Table 3.
Utilization of resources when demand is increased.

Resource	Utilization									
	Current model	Considering an increase on demand of: 0%	20%	40%	60%	80%	100%	120%	140%	160%
Storage yard	51%	43%	49%	48%	55%	60%	69%	70%	80%	88%
Berth	24%	19%	20%	23%	23%	25%	25%	30%	36%	38%
Quay crane	17%	8%	10%	12%	14%	16%	17%	19%	20%	22%
Yard crane	8%	4%	5%	6%	7%	8%	8%	9%	10%	11%

Source: The Authors.

4. Discussion

Since every container terminal is different in size, technology used, policies, and services provided, plus considering that the problem faced by every terminal is different, container terminal models are difficult to translate to other terminals. Simulation models are tailored to the container terminal and the specific problem. However, all projects assessing expansion of a terminal included in their methodologies fundamental steps on any simulation study, these were: problem formulation, model verification and validation, and experimentation. Unlike other expansion assessments [36-39], the methodology used in EIT, presented more detailed steps to follow for the construction and use of the SM for assessing expansion plans of a container terminal using DES. These included: data collection and preparation, assumptions and simplifications, and defining running parameter of the model.

5. Conclusions and recommendations

The expansion plan will increase the capacity of the Ensenada International Terminal serving up to 140% increase on demand with 20% reserve in storage space. If the terminal expects a demand greater than the additional 140%, then it should consider increasing the planned storage, or consider an external storage facility. On the other hand, the utilization of truck and crane resources was very low considering the assumed quantities. Thus, the authors recommend to expand the study to detail the requirements of truck and yard crane resources. This requires that the terminal provides data about the destination of transshipment and export containers in order to consider storage positions, and specific movement of containers. In addition, this new data will allow the assessment of policies for the allocation of containers in the storage yard.

Table 4.
Summary of performance indicators and demand levels where the values are kept less than or equal to current levels.

Performance indicator	Increase on demand
Average vessel waiting time for berth	140%
Average vessel length of stay	140%
Storage yard utilization	**40%**
Berth utilization	60%
Quay crane utilization	100%
Yard crane utilization	100%

Source: The Authors.

Table 5.
Comparing current versus expansion values with 140% increase on demand.

Performance indicator	Current model	Expansion model + 140% demand
Average vessel waiting time for berth	1.38 Hrs.	1.10 Hrs.
Average vessel length of stay	9.62 Hrs.	9.41 Hrs.
Storage yard utilization	51%	80%
Berth utilization	24%	36%
Quay crane utilization	17%	20%
Yard crane utilization	8%	10%

Source: The Authors.

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A. López-González, holds a BSc. Eng. in Industrial Engineering and a MSc. in Science and Engineering, both from the Universidad Autónoma de Baja California (UABC), Mexico. He worked and researched on ports processes from 2008 to 2016 in Ensenada, Mexico. He completed a Research Internship at Universidad Politecnica de Cataluña (UPC) in Barcelona, Spain in 2013. ORCID: 0000-0002-8854-199X

S. Medina-Leon, received her BSc. Eng. of Industrial Engineering from the Instituto Tecnológico de Mexicali, Mexico, the MSc. of Engineering from University of Toronto, Canada, the MSc. in Mathematical Sciences from University of West Florida, USA, and the Dr. in Sciences from Universidad Autónoma de Baja California, Mexico. Her research interests include simulation and operations research.
ORCID: 0000-0001-7259-5603

A. González-Angeles, received the BSc. Eng. of Industrial Mechanical Engineering, and the MSc. in Heat treatments and metalography from Instituto Tecnológico de Morelia, México and Dr. in Sciences in Metallurgical and Ceramic Engineering at the Advanced Studies and Research center of the IPN, CINVESTAV- Campus Saltillo, México. He is currently a professor at Universidad Autónoma de Baja California.
ORCID: 0000-0002-9475-5759

I. Mendoza-Muñoz, received his BSc. Eng. of Mechanical Engineering, MSc. and Dr. in Sciences from the Facultad de Ingeniería at the Universidad Autónoma de Baja California, Mexico,. Currently, he is professor at the Facultad de Ingeniería UABC. He has published in international journal, memories in extensive and participated in international congresses.
ORCID: 0000-0002-0810-2090

M. Gil-Samaniego-Ramos, is PhD in Engineering from the University of Baja California (UABC), Mexico. She is a full-time research professor at Industrial Engineering Department at UABC. Her research interests include design of experiments and simulation for industrial process optimization. She is the author of several research articles and conference papers. She is a member of the National System of Researchers in Mexico.
ORCID: 0000-0001-8061-8019.