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# Efficiency Analysis of Mexican Lazaro Cardenas Port

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**Purpose:** The port administration is an important regulator of international trade operations, as well as a facilitator and accelerator of trade. Hence, it's important to detect the factors that must be improved to achieve greater efficiency. Therefore, the aim of this research is to determine the level of efficiency of the port system of Lazaro Cárdenas in the period 2010-2017.

**Methodology:** This paper develops a simulation model based on operations research, which consists in finding the optimal gantry crane assignment to improve the efficiency of the terminal, through the design of algorithms to the port subsystems services operation and analyses the effect of infrastructure and process improvements on gate congestion.

**Findings:** The results show that the period under analysis was inefficient. These point out the necessity of better operational strategies for the Lazaro Cárdenas port. The results also indicate that the introduction of an appointment system can reduce the average turnaround times.

**Originality:** This paper provide new knowledge that can be used as a new approaches to solve efficiency problems at Lazaro Cardenas port, and also the algorithm created for this analysis could be used in several ports to measure their efficiency as well.

**Keywords:** Logistics, Port, Efficiency, Operational Research

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## 1 Introduction

In order to achieve the kind of competitive international trade that can later on be translated into regional economic development, it is necessary to have the capacity to move products efficiently. For that, ports are fundamental as a tool to increase the competitiveness of external commerce.
In that sense, dry bulk cargo increased by 4.0 per cent, up from 1.7 in 2016, while global containerized trade increased by 6.4 per cent. Which shows the increase in containers' maritime terminals (UNCTAD 2018, p.1). Hence, it is an advantage for seaports the capacity to adapt to current trends and to enlarge their functions inland (Jeevan et al 2015, p. 129). Figure 1 shows worldwide TEUs traffic during the period of 2010 up to 2016. As it can be observed, there is an increase in the number of containers; this implies that there is a new challenge at the containers' terminal in order to manage a larger number of TEUs in a short amount of time and at a competitive price.

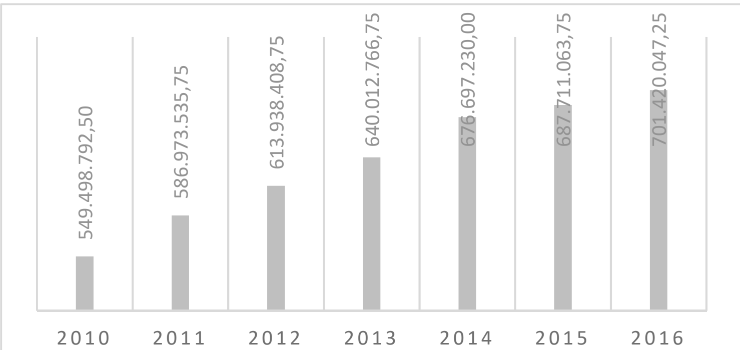


Figure 1: TEUs traffic for the period of 2010 to 2016

The international routes, the presence of hinterland companies and the international agreements are the main factors that push the ports into an international projection. However, the ports have to show the sufficient capacity to manage the international demands and to be evolving according to the interface with the multimodal transport facilitating while also encouraging international trade. That is how ports are a key element in the international trade competitiveness.

Geography of the Mexican ports has been changing since the 90's. The Mexican government's change of vision brought with it a modernization of the ports' logistic system, with development and investment on several maritime terminals improving the cargo and operational capacity while trying to decrease the infrastructure gap.

In 2017, ports in Latin America and the Caribbean rose around 6.1% on the throughput of containerized cargo. The Dominican Republic (24.0%), Colombia (13.3%), Mexico (12.2%), Panama (10.1%) and Brazil (5.0%) were the countries whose container port terminals contributed the most to the change in cargo volume versus the previous year (ECLAC 2018, P.1). With these changes the operative capacity of the Mexican ports increased from 260 million tons in 2012 to 500 million tons in 2017 (Presidencia de la Republica, 2017).

The port of Lazaro Cardenas was choose because it is the most important port in Mexico, and has worldwide infrastructure, a strategic location, connectivity and a large capacity of cargo movement.

Nevertheless, there are several factors to consider in order to improve the logistics at maritime ports, this is due to the operations a container has to face, among which we can find time pressure, minimization of resources, and all the potential problems that need to be faced in order to achieve efficiency. That is why the aim of this research is to determinate the level of efficiency of the port system of Lazaro Cardenas in the period 2010 to 2017.

## 2 Literature Review

The analysis of literature of similar cases were apply in order to find out the port logistic efficiency can be used to identify indicators and Muñuzuri, Escudero, Gutierrez and Guadix (2009), presented a study where they calculated two intermodal centers' efficiencies in order to identify the differences and necessities between the transport systems, such as railway, freight and maritime transport. The main variables considered for that research were: traffic, time, entries and exits.

Radonjić, Pjevčević, Hrle and Čolić (2011), with the goal of evaluating the intermodal container system developed an efficiency analysis of the containers of Serbian ports' lines of operation, used a number or variables such as: time, cost and store capacity. In order to evaluate connectivity of central ports and transport networks, Onyemechi (2010) used the length of the dock and the number of crane as variables.

Ducruet et al. (2014) measured the port efficiency of 1050 ports at 164 countries, using the data of vessels daily movements and the average answer time. They found out the efficiency's geographic pattern by country and continent.

In Robenek et al. (2012), a decision support system was proposed for the management of a terminal, it was based on a linear programming system and simulation to validate the results. Among the problems to be solved were the yard assignment problem (YAP), emphasizing the differences in operations between bulk ports and containers terminals which emphasizes the need to devise specific solutions for bulk ports.

In Cuberos (2015), a problem of crane programming and allocation of resources for different types of transport was solved, it used an adaptation for the problem of simulated annealing heuristics in order to reduce the time that the merchandise must spend in the intermodal terminals, analyzing the loading and unloading operations between the different means of transportation. The variables that were used in his study were: trains, ships, cranes that load and unload containers in the trains, cranes that load and unload containers on the ships, the instant of unloading containers, the instant of loading containers, the instant of train arrival, the instant of departure of train, the instant of ship arrival and the instant of ship departure. The conclusions were that, as the number of cranes capable of unloading and loading containers from ships and trains increases, the solutions reached by the algorithm are better. However, this improvement is not linear, which leads us to think that continuously increasing the number of cranes will not always offer better solutions.

Another work where the parameterization of the algorithm was implemented in order to solve problems of optimization presented on land transport routes of intermodal transportation is Cuberos' (2014) research. The project tries to find the parameters corresponding to the algorithm that provide better results when applied to the problem of land transport.

In Bish (2003), a problem of programming several cranes with restrictions is resolved, dividing it into three subproblems: determining the location of the container once it has been downloaded, defining the allocation of vehicles to the containers that must be transported in the terminal, and scheduling the loading and unloading operations of the cranes. A heuristic algorithm based on the formulation of the problem is developed as a transshipment problem.

Tavakkoli, Moghaddam, Makuj, Salahi and Bazzazi (2009), propose a new mixed-integer programming model for the problem of programming and assigning dock cranes in a container terminal. This work, therefore, proposes an efficient genetic algorithm to solve a programming problem of extended dock cranes (QCP) specified for a container terminal. The results obtained showed a reasonable difference of approximately 1.9% and 3.5% between the optimal solutions found. In addition, the proposed genetic algorithm reaches the almost optimal solution in a reasonable time.

In the study by Correcher, Alvarez, Tamarit and Lescaylle (2015), a mixed linear mathematical programming model is proposed for the problem of assigning berths and cranes to the ships that request the use of the dock in a container terminal. In this study, a continuous dock was considered, dynamic vessel arrival, crane assignment invariable in time and ship processing time depending on the number of cranes assigned to each one. The variables were: the vessel's berthing time, the ship's berth position, the ship's departure delay, the vessel's deviation and the ship's processing. According to the results, the model allowed the research to its optimum point of 40 vessels in a short amount of time.

Another work that proposes an optimization model integrated to a simulation model for the management of springs of continuous localization is that of Arango, Cortes, Onieva and Escudero (2012), where a genetic algorithm is developed to solve the mixed optimization model and a simulation model is proposed with three different scenarios to validate the decisions made by the model, thus the objective of the models is to minimize the operating time of each vessel. The port of Algeciras, which is the busiest container traffic port in Spain, is taken as a case study. In this work, two different traffic growth scenarios are modeled in order to validate the studied model, which was proven to be valid and, at the same time, robust in the face of future growth of the terminal's traffic and, therefore of the input data. The obtained results suppose a reduction of 8.73% in the average time of operations before an increase in traffic of approximately 21%. The use of the genetic algorithm to optimize the assignment of quay, cranes and blocks to ships has been an effective tool, since the algorithm finds a good solution in less than 3 seconds.

In Laureano, Mar and Gracia (2015), the use of the work flow diagram shown helped to determine the factors involved in port efficiency related to container loading and unloading operations. Similarly, the use given to the statistical data can be used as an example of how to apply it in the present study. This work makes an evaluation of the productivity and efficiency of the port terminal of Altamira, of the cranes used in the operations of loading and unloading of containers in ships during the third quarter of 2014. The methodology that was used is based on a statistical analysis of the operation records of the terminal, with the purpose of, when measuring the movements of the cranes, it is possible to know the productivity of the port terminal and, consequently the quality of its services. In general, it is concluded that the productivity of vessel loading and unloading operations significantly influences the production rates of the organization.

## 3 Methodology

The roots of operations research (OR) extend to 1800s; it was when Taylor emphasized the application of scientific analysis to methods of production. Later on in 1917, A.K: Earlang, published his work on a problem of congestion of telephone traffic; also during the 1930s Levinson applied scientific analysis to the problem of merchandising. Nevertheless, it was the First Industrial Revolution, which contributed manly on the development of, OR (Lyeme, 2012).

The council of the United Kingdom Operational Research Society (1962, p.282) defines Operational Research as “the attack of modern science on complex problems, arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defense. It goes on to state the distinctive approach as to develop a scientific model of the system; incorporating measurement of factors such as chance and risk, in order to predict and compare the outcomes of alternative decisions, strategies and controls. The purpose is to help management to determine its policy and action scientifically”.

The main goal of operations research is optimization, i.e., "the act of achieving the best possible result under the given circumstances." (Astolfi, 2006, p.2). Therefore, when operations research is applied according with the general optimization paradigm, the objective function expresses the key decision variables -selected by the researcher- that will influence the quality of decisions by maximizing (profit, product quality, speed of service) or minimizing (cost, loss, risk, time) (Bazaraa et al. 1993, p. 638). Furthermore, besides the objective function, aspects such as physical, technical, economic, environmental, legal, societal, etc. are also considered (Bronson, 1982). So that, in the context of the given model formulation, an optimal solution is selected according to the values -systematically provided- of all decision variables (Horst and Pardalos, 1995) (Marlow, 1993) and (Chong and Zak, 2001).

The operation of services in port is done through complex systems where the definition of infrastructure performance is not easy. Each port is integrated by several interrelated subsystems that provide services to ships and to final users that send or receive cargo through maritime transport. The terminals' planning, for an efficient exploration, is done in context of the medium and long terms, and must be faced as a systematic study.

There cannot be bottlenecks in the operational terminals subsystems. Therefore, it is necessary to know the capacity of each of the terminal subsystem, as well as the performance in each one of them in order to establish which of these subsystems limits its capacity. At the same time, the terminal's capacity is conditioned by the infrastructure, facilities, equipment and human resources involved in each of the phases of the port operation that take place in the terminal (Camarero et al. 2013).

A very important container terminal subsystem is the operation of the gantry cranes, where vessels are loaded and unloaded. The assignment of cranes can be considered a bottleneck if you do not have an optimal planning in place.

Container terminal operations can be grouped into four main classes, which are associated with specific processes and stages in the containe flow. It is mainly focused on the transshipment flow of containers, the associated decision problems that generally originate between the dock and the shipyard, and are:

- Assignment and programming of berth or berth allocation problem (BAP), these decisions are associated with the arrival of the vessel.
- Assignment and programming of gantry cranes (QCAP).
- Transfer operations: Containers are usually transferred inside the terminal by means of internal trucks, straddle carriers and automated guided vehicles.
- Patio operations: These decisions are associated with the storage and stacking of containers. The management of yard operations involves several decision problems.

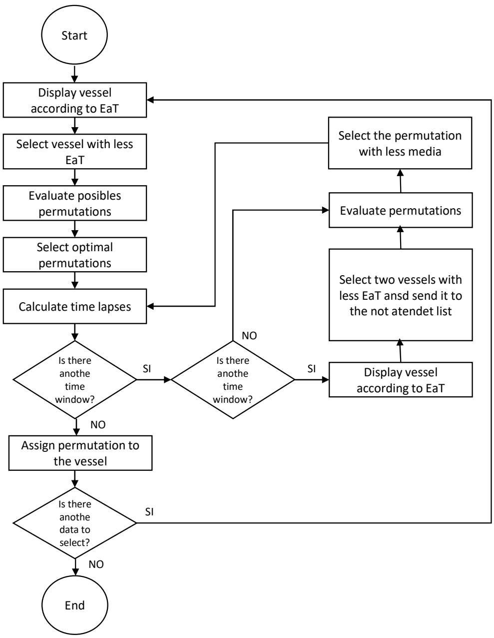


Figure 2: Algorithm of the vessel flow

The Figure 2 shows the graphic representation of the algorithm used for this research. The diagram starts with a database that consists of: set of ships (k), set of containers ($C_k$), the time window of each ship k which is a time lapse with an early arrival time ($EaT_k$) and a late arrival time ($LaT_k$).
The first step the algorithm uses the FIFO method (first in, first out), in which ships were ordered from lowest to highest $EaT_k$, this is done in order to give service to ships respecting the time window. In other words, the first ship that enters is the first ship that leaves. Once the data is sorted, we proceed to apply the basic principle of the simplex method, which is to iterate until finding the best possible solution. Therefore, the ship with the smallest $EaT_k$ is selected for the optimality evaluation considering all the possible permutations. The variable that changes is the number of cranes assigned ( Gk), this assignment will be limited to the number of cranes available in the time span $LaT_k$and $LaT_k$, then the permutation selected is the one that allows to reduce the operation time of ship k.
The calculation of the permutations with the selected vessels is re-done and the best permutation is chosen, in this case, it would be the permutation that obtains the lowest average operating time of the vessels. Once this calculation is made, the cranes are allocated to the ships and the assigned cranes are given the operating time corresponding to the ship so that their status appears busy (0) and cannot be assigned to another ship while they are in operation (1). This sequence is repeated until the ships of the initial list are finished. The data associated with this model is as follows:
$C_k$ = Number of containers to be operated on the ship k
TE = Standard time by TEU.
$G_k$ = Number of cranes operating on the ship k.
TA = Accommodation time per vessel.

n = Number of average ships per year

J = Set of cranes

K = Set of ships

$Tin_k$ = Instant start of operation of the ship k

$Tfn_k$= Instant operation of the ship k

$EaT_k$ = Early arrival time allowed for the ship k

$LaT_k$ = Late arrival time allowed for the ship k

$Tfn_j$ = Start of operation moment of the crane j

$Tin_j$ = Moment of operation of the crane j

$TO_k$ = Operation time of the ship k

$TO_{jk}$ = Operation time of crane j assigned to ship k

$BO_k$ = binary variable. It takes value 1 if the ship k is in operation, 0 otherwise.

$EG_{kj}$ = binary variable. It takes value 1 if the crane is in operation on ship k, 0 otherwise.

The objective of the QCAP is to minimize the operation times of the ships that arrive at the container terminal. The algorithm to find the optimal assignment of cranes is formulated as follows:

$$MIN\ Z = \sum_{k=1}^{n}((C_k * TE)/ G_k) + TA)/n \quad (1)$$

Subject to restrictions

$$Tin_k \geq EaT_k \quad (2)$$

$$Tin_k \leq LaT_k \quad (3)$$

$$TO_k = ((Ck * TE) / G_k ) + TA \quad (4)$$

$$\sum_{k=1}^{n}(BO_k) \leq 3 \quad (5)$$

$G_k \leq 1$ (6)

$TO_k = TO_{jk}$ (7)

and

$TO_k$ , $TO_{jk}$ , Ck, TE, $G_k$, TA, n, $EaT_k, Tin_k, LaT_k, BO_k \geqq 0$ (8)

The objective function (1) is the average operating time. With this objective function, the aim is to minimize the total sum of the average service times in the terminal, that is, the operation time of the vessels. The ships leave the terminal when all the loading and unloading operations on them have finished.

Restrictions (2) and (3) establish when vessels must start their operation in the terminal at a time within their time window. The time window is a time lapse between an allowed early arrival time and a late arrival time and, for the purposes of this work, a time window of 30 minutes was considered. The unloading and loading operation times are considered as dependent on the working capacity of the cranes and the number of cranes assigned to the vessel. Restriction (4) defines that the operation time is considered from the moment the vessel is being docked, including the accommodation variable (TA) which includes the docking and undocking time. In the same way, standard time (TE) is important, which is the average time it takes a crane to move a TEU. Therefore, the ship's time of operation is defined by the number of containers to be operated multiplied by the standard time of the crane. The result is divided by the number of cranes assigned plus the average time it takes the ship to dock and undock in the terminal.

The containers to be operated on each vessel are known in advance, since this information is determined in the stowage plan. The loading and unloading containers are not represented separately but as sets of containers

to be operated on the ship. This simplification is due to the fact that the loading and unloading time of a container is standard for the crane.
For the model, the availability of docking will be determined by the availability of gantry cranes. In addition, the restriction (5) establishes that the terminal has three docking positions, which means that there cannot be more than three ships at the same time in the terminal.
Restriction (6) defines the number of cranes assigned, and must be greater or equal to 1. The restriction (7) ensures that the crane will remain idle until the time it is assigned to a ship. Once assigned the operating time of the crane will be equal to the operating time of the ship that was assigned to it. Finally, restriction (8) refers to non-negativity or negativity conditions.

## 4 Results

Understanding the performance is a concept fundamental to any business including ports efficiency where measuring of achievement against set goals and objectives is complex. After analyzing the structure of the Lazaro Cardenas port, we can point out several results.

Table 1: Average time per year, 2010-2017

| Year | Real operation time | Pessimist operation time | Average operation time | Ideal operation time |
|---|---|---|---|---|
| 2010 | 592.88 | 525.03 | 313.84 | 183.91 |
| 2011 | 593.29 | 517.96 | 316.74 | 205.04 |
| 2012 | 901.83 | 517.96 | 503.31 | 375.44 |
| 2013 | 802.20 | 486.89 | 387.06 | 281.36 |
| 2014 | 677.18 | 492.44 | 288.70 | 192.89 |
| 2015 | 635.23 | 282.89 | 267.03 | 214.33 |
| 2016 | 748.28 | 373.95 | 329.86 | 235.18 |
| 2017 | 619.77 | 277.28 | 267.42 | 208.01 |
| MIN | 592.88 | 277.28 | 267.03 | 183.91 |
| MAX | 901.83 | 525.03 | 503.31 | 375.44 |
| MEDIA | 696.33 | 434.30 | 334.25 | 237.02 |

Table 1 shows the average real operation times and the algorithm operation times for three different scenarios (ideal, pessimist and average). As

we can observe the best operation times were obtained in 2010, but that is also the year where the port had less movement of containers. This contrasts with the results of 2012, year with the worst performance and, also with the biggest number of containers received. This shows a correlation with the number of containers received and the operation time.
In order observed better these relations we calculated how many TEUs were mobilized per minute each year. The Figure 3 presents the results, and as we can see it is on 2014 when the port received more containers or TEUs per minute, and the year with less TEUs was 2010. Once we had the mobilization results, we proceeded to calculate the efficiency considering three scenarios.

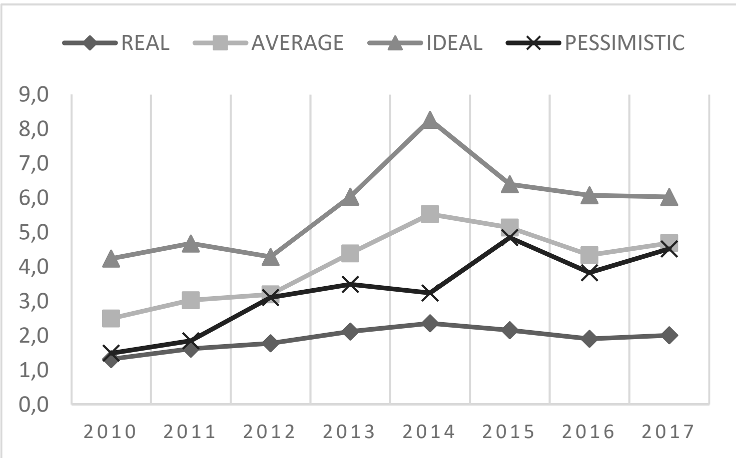


Figure 3: Average TEUs mobilized, 2010 -2017

Table 2 shows the efficiency results per year. The efficiency results can be compared in three different scenarios (ideal, pessimistic, and average). 2012 was the most efficient year if we compare the results with the ideal and average scenarios. However if we considered the pessimistic scenario, 2010 is the most efficient year.

At the same time, Table 2 shows that the worst efficiency result was obtained in 2014 with the ideal scenario, 2015 was obtained with the average scenario and for the pessimist scenario there was a tie between 2015 and 2017. The results point out the importance of an adequate planning in terms of the arrival times of the ships to the terminal. Although these represent a complex task there are different mechanisms that can be improve such as strategic planning considering tracking and tracking through different technologies.

Table 2: Efficiency index per year, 2010- 2017

| Year | Ideal | Average | Pessimist | Average results |
|---|---|---|---|---|
| 2010 | 0.31 | 0.53 | 0.89 | 0.58 |
| 2011 | 0.35 | 0.54 | 0.88 | 0.59 |
| 2012 | 0.42 | 0.56 | 0.57 | 0.52 |
| 2013 | 0.35 | 0.48 | 0.61 | 0.48 |
| 2014 | 0.29 | 0.43 | 0.73 | 0.48 |
| 2015 | 0.34 | 0.42 | 0.45 | 0.40 |
| 2016 | 0.31 | 0.44 | 0.50 | 0.42 |
| 2017 | 0.34 | 0.43 | 0.45 | 0.41 |
| MIN | 0.29 | 0.42 | 0.45 | 0.40 |
| MAX | 0.42 | 0.56 | 0.89 | 0.59 |

As we can observe, the operation time has been inefficient at Lazaro Cardenas terminal port for the period of analysis. However, this is a good time for start planning and for settling down the grounds of the port's organization, so the terminal can satisfy the increasing demand, and face the operational problems before the demand curve increases even more.

Based on the analysis of the obtained results, strategies can be proposed to improve the efficiency of the logistics system of the Port of Lazaro Cardenas, such as the revision of the management and organization model that is being implemented. Due to the model, it will have a direct impact on the structure of the port and its degree of flexibility, the organic vision of efficiency and the amount of work aimed at optimizing the provision of port services.

According to the considerations made, it is also necessary to review the national strategic plan in order to rebuild commercial policy guidelines, as well as the port business plan, which is updated annually. However, the importance of considering it and the importance of lowering it to an operational level is pointed out.

## 5 Conclusions

The present research analyzed the logistics system of Lazaro Cardenas port, in order to determine the level of efficiency of the container movement considering the operation period from 2010 to 2017. The levels of efficiency were calculated through a simulation model based on operations research, which consists in finding the optimal gantry crane assignment to improve the efficiency of the terminal, through the design of algorithms to the port subsystems services operation and analyses the effect of infrastructure and process improvements on gate congestion.

The results help to identify the factors that contribute to strengthen the efficiency levels of the port. These were obtained through the operations research methodology and, show the levels of efficiency considering the variables of execution times of loading and unloading of containers.
The port of Lazaro Cardenas is the most important port in Mexico for cargo handling and has a large presence in Latin America. It has been characterized as an industrial port due to its proximity to the most important steel zone in the country. Lazaro Cardenas port has been considered as a world-class port because it's infrastructure and movement capacity for a great variety of loads. That is why we recommend promoting the competitive advantages of the port as a logistics platform to attract more customers, as well as to take advantage of the capacity and technology offered by the port.
Regarding the aim of this research, which is to determinate the level of efficiency of the port system of Lazaro Cardenas in the period 2010 - 2017, we found out that according to the selected variables, the port wasn't efficient in its cargo movement of TEUs for that period. It is also important to point out that the efficiency levels can depend on many factors, in addition to the number of cranes assigned, the number of containers and the time window. For instance other possible factors that could influence the efficiency of the Port's logistics management are: 1) the distribution of the containers, and 2) the type of traffic to which the operated containers belong. Due to these variables mentioned above, the recommendation is for future research to include these variables too.

These points out the need for better operational strategies for the Lazaro Cárdenas port. The results also indicate that the introduction of an appointment system can reduce average turnaround times. Through the analysis of the results can be point out the necessity of improvement of the operational system, as well as the auto corrective system in order to achieve the efficiency of the port.

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