A Design Tool for a Container and Vehicle Terminal

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Abstract

With the growing demand of the containerized multi-modal transport verified in Brazil, the logistics management processes in associating with the transport and the port operations became a complex activity, involving a great number of variables that interfere in the operation performance. In the current conjuncture, the search for the efficiency in the logistical processes constitutes a primordial factor in this area. The use of the simulation allows to model complex systems, being a very powerful and efficient tool as a decision-making in working out problems.

In this context a simulation model associated with a spreadsheet cost was elaborated to allow the design of the port system in which will operate containers and vehicles, permitting to test a set of resources levels, for example: the number of reach stackers, trucks and ship-to-shore cranes. The model allows to choose the demand of containers (TEU per year) and vehicles (units per year), number of berths, ship-to-shore cranes, reach stackers, also the other parameters like as the operational average times for each equipment. After the simulation of the port system for a defined period of time, we are able to analyse the design of the port equipments and the operational cost and investments. It may realize with a sensibility analyses on the system parameters and verify those influences in the final cost.

The results showed in this paper are related to several tested scenarios. These results evaluate the design of the port resources, the occupation rate of each resource and the ships' queue time at the berth. All those analyses check the effectiveness in using the probabilistic simulation methodology in the logical systems.

Introduction

The present work developed a viability study in implantation the terminal, which is specialized in the movement of containers and vehicles at the port of Paranaguá in the south of Brazil.

Nowadays the most important activity for this port is to export agricultural commodities what characterises it as a bulk cargo port. However the demand for general unitised cargo conditioned in containers such as manufactured products, import raw material and self-driven vehicles has increased in the latest years.

The simulation model is a tool capable of representing the reality with large precision in its results. The quality and the precision of the models' output are guaranteed by the accuracy of the information inputted into the model. Therefore, information like as container movements per hour, shifting rates and time duration of other relevant tasks become important parameters.

It was elaborated a study aiming to analyse the feasible configuration of equipments, port layout, vehicles and containers storage areas, with the goal of optimizing the whole system. This was done focusing on the payback minimization, time of attendance and queue minimization, which would cause the minimization of the global costs of the terminal. To evaluate the proposed configurations it was created a simulation model representing a container/vehicle terminal.

The model generates as an output all the operational data such as queue times and equipment's occupation rates, allowing to identify operational problems, the bottlenecks, resources with low occupation, and other problems.

Description of the Model

The terminal operates both containers and vehicles, which are considered independently.

The activities that take place in the model are related to the import and the export processes. In order to facilitate the modeling process it was created 4 major groups as indicated below:

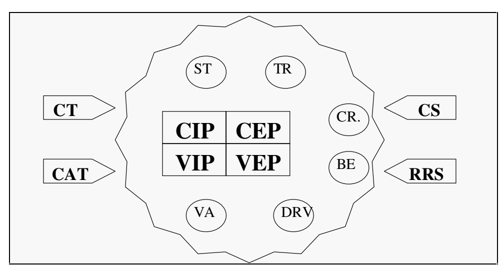
- container's import pile = CIP
- container's export pile = CEP
- vehicle's import parking area = VIP
- vehicle's export parking area = VEP

The containers' pile can be altered by some external entities that will be picking containers up or leaving containers there. The same happens to the vehicles. These external entities, which can also be divided in 4 groups, is indicated below:

- container ships = CS
- roll-on/roll-off ships = RRS
- container trucks = CT
- car transporters = CAT

Still complementing the model, there are internal processes in the terminal that do not modify the number of entities that arrive or leave the system (terminal) but aid the external entities (ships and trucks) to make the existent transition between them and the pile, like moorings, terminal, ship-to-shore cranes, reach stackers, trucks, drivers and vans.

An plan of the system (terminal) is shown Below .



From the system, container or vehicles units enter or leave for just four external entities, as it will be understood later: container ships, ro-ro (vehicles) ships , container trucks and car transporters (vehicles). The resources of the terminal and the internal entities help these external entities to take these units until the piles and vice-versa.

The Logics of the Ships and the Berths

The ships logic consists of its creation and the choice of a berth. The container ships can moor at anyone of the two berths, since these are available for that, but the ro-ro ships can only moor at the second berth due to the smallest number of ships for this type that arrive at the port (it would be waste financial resources for preparing both berths for a mooring ro-ro ships too).

There is a lot of likeness between berth one and berth two, even so the berth two requests an additional logic because of the ro-ro's ships. In the first step we are going to consider the logic of the berth, one or two, when this is busy for a container ship.

After the ship arrives at the terminal, there will be a decision making process consider the number of ship-to-shore cranes that should be allocated to unload and load the ship. The total number of available ship-to-shore cranes is 3. Depending on the utilization of this equipment, more of them can be inputted into the model.

Therefore, the ship will work with one or two ship-to-shore cranes, depending on its readiness at the time of mooring. Once the choice of the number of ship-to-shore cranes to be used is made it will not be possible to change this quantity for the remaining of the time that the ship is at the terminal. After the choosing the ship-to-shore cranes, the unloading process takes place and then the process of loading containers is started.

The Logics of the Unloads and Loads.

The ship arrives in the terminal verifies the readiness of the container's import pile (CIP), limited up to 3500 units (it is the maximum limit of containers that the pile might have, which is a dependent parameter from the available space in the port). After that, the ship-to-shore crane resource and the trucks resources are requested. These can be available or not. If they aren't, an internal queue is formed. Otherwise it is marked to the entity an illustration of an empty truck, whick have to wait the transport requisition to the berth in the garage.

A period of time is given for the ship-to-shore crane to place the container on top of the truck. This process repeats until the end of unload of all containers. After that, the ship begins the loading process.

The loading of the containers to the ship CS begins making a verification of the pile CEP. If it has more than an unit, then the entity goes straight ahead. Otherwise it waits until any truck CT arrives. After that it seeks for the resource trucks. If they are not available, the entity forms an internal queue . The load process finishes when all requests are attended, liberating the ship-to-shore crane and berth resources .

For the operations that use two ship-to-shore cranes, the processes described previously repeat and additional verifications are made to avoid the load process of the second ship-to-shore crane begins before the complete unload by the first ship-to-shore crane and in the loading process, to avoid that the second ship-to-shore crane orders a sign for the ship to go away even before the end of the complete load of the first ship-to-shore crane.

Use of the Berth Two for Ro-Ro Ships

The logic of the berth two involves an additional ramification at the beginning to separate the RRS (ro-ro) for the ships CS (container ships). Then the RRS unload process begins.

The unload process is similar to the containers one; it is made a verification of the import pile VIP, limited in 2400 vehicles in the parking area. If this pile has more than 2400 vehicles, it stops until the car transporters take away some units. After that, for this operation, the ship calls for the drivers resources. If there is at least one available, then the request continues and the drivers unload the vehicles, taking them until the parking area. The return of the drivers to the ship is made through vans, with capacity for eight people.

In the loading process, the existence of vehicles is first verified, in the vehicle's export pile VEP. If this operation does not happen it is stopped until a car transporter take some vehicle. After that the VEP requests the drivers resource. If there is at least one available, then the request continues. The process repeats until loads of all the vehicles. Similarly to the unload process, the return of the drivers to the export parking area is made through the vans.

The Logic of the Parking area

In this part of the logic the trucks and stackers come to do the parking area maneuvers as to load and unload containers of the piles respectively CIP and CEP for the ships moored in the berths.

When a ship unloads a container it uses a truck that goes to the parking area. In the parking area, the ship calls for the stackers resource. If this is available, it leaves the origin station and goes to the container parking area to unload the container of the truck and place it in the import pile (CIP). In that moment, the stacker and truck are liberated and the pile is increased of an unit.

In the request of a pile's container to make the load of the container ship, the stackers readiness and trucks are verified and then they are requested. In case of availability the stacker removes the container of the pile and positions it in the truck, making it liberate soon.

The truck can take the container for the berth one or two, depending on the value attributed to the container. Arriving there, whether berth one or two, which requests the ship-to-shore crane resource that if is available will have a time for the ship-to-shore crane to remove the container of top of the truck. Finished the operation, the ship-to-shore crane and the truck are liberated. The process repeats until all the containers are loaded.

The Logic of the Trucks

The trucks make a similar task than the container ships make: they bring and remove containers of the piles with the help of the internal resources of the terminal. Even so they make it in an inverse way. While the ships increase the import pile, the trucks decrease and vice-versa for the export pile. There are three truck types: one that arrive empty to the terminal, without container, and they leave full, taking a container (type zero); the one that arrive full to the terminal, bringing a container and leave empty, without container (type one) and the one that arrive full to the terminal, bringing a container, and they leave full, taking another container (type two).

The logic of the trucks begins to make the attribution of type and arrival's time. After that the truck goes to the port entrance.

When the truck arrives at the entrance, it is made a choice: if the type zero it verifies space readiness in the terminal, limited in five vacancies. If this is available then the import pile CIP is verified if it is larger than five. If it's true, truck goes to the load area; if it is the type one or two the truck makes two verifications: with the readiness of the unload area, also limited in five vacancies and the number of containers in the export pile CEP, limited up to 3500 units. If it's true, the entity goes to the unload area.

Load of the Trucks

The entity CT goes to the load area (type zero) and verifies readiness of the stacker to make the loads. If there is any available one, the stacker goes to the import pile and it carries the container in the truck. Finished the operation, the decrement of an unit of the pile CIP is marked and the stacker comes back to its garage.

Unload of the Trucks

Similarly, in the arrival of the trucks it is observed the internal vacancy of the port and arriving to the unload area it verifies the readiness of the stackers resource. If this is available, it goes to the unload area. In this place the stacker unloads the container and it already gives the sign of truck's liberation. Meanwhile, the stackers positions the container removed from the export pile CEP. Then one unit is increased to the pile and the stacker is liberated coming back to the garage.

The entity truck that was unload is verified the type (one or two). If it is the type one, it goes away to the highway, passing by the entrance and making the counting. If it is the type two it should go back to the entrance to do the normal process of load (remember that trucks type two arrive full and they leave full). Before that, the entity CT assumes the value of type zero as if it was one truck to be carried.

The logic of the Car Transporters

The logic of the car transporters is very similar to the trucks. It is important to remember that the car transporters take eleven vehicles, and the truck only takes one container.

The car transporters make a similar task to the ro-ro ships: they bring and remove vehicles to\from the parking area using the internal resources of the terminal. While the ships increase the import parking area, the car transporters decreases it. And vice-versa for the export pile. There are three types of car transporters: the ones that arrive empty to the terminal, without vehicles, and they leave full, taking vehicles (type zero), the ones that arrive full to the terminal, bringing vehicles and leave empty without vehicles (type one) and the ones that arrive full to the terminal and they leave full (type two).

The Load of the Car Transporters

When the entity CAT comes for the load area (type zero) it makes a verification in parking area of VIP. If there are more than four vehicles then it requests the drivers to load or unload the vehicles to or off the car transporters. After that, the drivers go to the import parking area to take the vehicles to the car transporter.

The Unload of the Car Transporters

The unload of the car transporters follows a similar logic to the truck's unload. The entity that arrives at the unload area and makes a verification of the pile VEP. If there are less than 2400 vehicles, the entity requests the drivers which unload the cars and place them at the export parking area. Finished the operation, the drivers, the car transporter and the unload area are released.

Operational Analysis

Average Time of Queue and Attendance

The most important parameter for the operational analysis of the terminal are the average waiting time to get a vacancy to moor in the terminal. Also the necessary average time for the ship to complete its operation in the port, because it is na indicator of the performance of the terminal for a given configuration of equipment and it influences directly and decisively in the level of the customers' satisfaction.

Arrangement of the Terminal

To plan the general arrangement of the terminal it should be observed that the main requirements are: storage area in agreement with the exposed in the previous item, movement roads for the ground equipments, area for load and unload of trucks, entrance gates and exit for containers and vehicles. The layout of the terminal should allow the fastest speed of the way operations arriving to the planned rate of load/ unload of the ships.

The storage of the containers was planned like this in piles of 10 length containers (122,0 m), 2 width containers (5,2 m) and 6 height containers (15,54 m). This piling up favors the use of reach stackers in the movement. Besides, it was taken into account a spacing of 46 feet among the piles (aisle), to facilitate the access of the stackers. To the right of those two piles there is left a space of 37 meters for unloaded vehicles of the ships ro-ro can pass over there to make the route between the ship and the storage area.

To turn the embarks the fastest and most organized as possible, it is necessary to have an area for container's pre-stacking . In this area, as big number of piles is not used, and as the operation is fast, the ideal for container's movement is the use of RTGs.

The piles of containers were left closer to the dock, while the area for vehicles was left more distant. So the medium distance traveled by the trucks with the containers is the smallest possible.

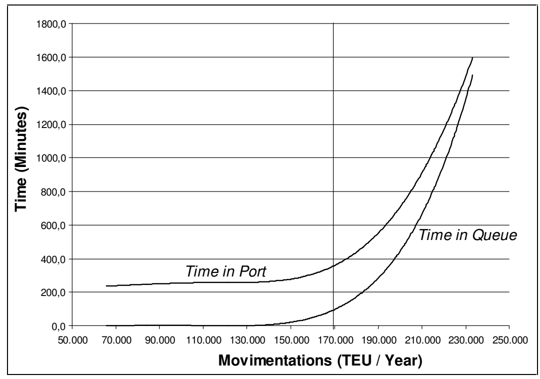
Design of the Equipments

The model created in Arena facilitates to diversify port resources, for example stackers or ship-to-shore cranes, verifying the levels of criteria. The more important levels of criteria for the economical terminal analysis are composed by the annual containers movement rate, the average time of a ship in the port, the average time of a ship in the queue, besides the percentages of use of the resources.

The first goal of the project was to allow a movement of 100000 TEU per year. For that, it was tested 2 cradles, 2 ship-to-shore cranes, 3 stackers and 5 trucks. This arrangement will be called Configuration 1 from now on (briefly "2-2-3-5"). It is important to point out that in those configurations exist also embarks and landing of vehicles at a rate of 12 000 vehicles per year. Below there is a table with several movements of containers year and its levels of criteria.

Configuration 1 2-2-3-5	Total Mov.	Time in Port	Time in Queue	Ocupation Terminal	Ocupation S/S Crane	Ocupation R. Stacker	Ocupation Cart
	TEU / Year	Minuts	Minuts	%	%	%	%
	65 767	237.9	0.0	6.3	7.2	13.4	6.3
	71 681	240.3	1.5	11.6	8.2	14.0	7.3
	86 232	246.2	2.0	8.0	9.4	17.5	8.3
	102 528	257.6	3.3	9.7	11.5	20.3	10.1
	112 387	260.0	4.0	14.9	13.2	23.0	11.8
	139 301	261.5	5.5	13.6	15.7	27.4	14.0
	170 988	277.9	7.8	18.0	19.7	34.2	17.9
	171 696	459.8	204.9	24.8	20.8	38.4	19.1
	201 600	734.3	473.7	28.6	24.0	44.4	22.2
	233 122	1595.2	1491.9	53.4	30.3	55.0	29.3

The table above shows how the time at the port and the queue time changes for the given equipment configuration. for the equipments, when the containers movement increases. It can be noticed that such arrangement should be maintained until an annual movement of 170 000 TEUS. After this level the queue times and the port times are too elevated and the operation becomes unfeasible, as it can be seen at the graph bellow.



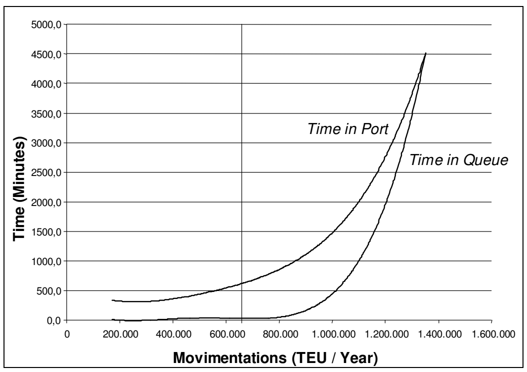
After the 170000 level a new configuration should be used in order to cope with higher demand levels and good levels of criteria. The new configuration simulated was 2 cradles, 4 ship-to-shore cranes, 10 stackers and 15 trucks that it will be denominated Configuration 2 (briefly "2-4-10-15"), very similar to the arrangement of another container terminals existent in Brazil.

It is worth to point out that in Configuration 1 the container ships have an average of 78 containers to unload and 72 to load. These values were extracted from the 1997 Port of Paranaguá database. The increase in the demand for configuration 2 was

60% (124 for unloading and 115 for loading).

Configuration 2 2-4-10-15	Total Mov.	Time in Port	Time in Queue	Ocupation Terminal	Ocupation S/S Crane	Ocupation R. Stacker	Ocupation Carts
	TEU / Year	Minutes	Minutes	%	%	%	%
	170 000	318.0	0.0	12.1	9.3	9.9	8.2
	200 000	318.0	2.0	13.0	10.5	12.6	8.8
	230 000	330.0	2.4	14.3	12.4	16.4	9.6
	260 239	348.5	2.8	15.8	14.8	17.3	10.3
	347 338	351.1	12.9	22.5	20.8	23.3	14.6
	483 658	354.0	13.0	38.0	30.1	34.3	21.2
	652 291	652.4	46.9	46.4	41.8	48.4	29.8
	1 175 350	2547.3	1681.0	95.8	81.7	94.5	61.3
	1 350 676	4512.5	4512.5	97.8	90.0	97.1	72.7

It can be noticed that the maximum demand that this configuration can attend to, without harming the levels of criteria, is near 650 000 TEUS per year, showed in the following graph.



It can be observed in the previous graph that for very high levels of movement, the average time in the port tends to the queue average time due to the great time spent in queue.

A new arrangement called Configuration 3 was then proposed, which was composed of 2 cradles, 6 ship-to-shore cranes, 18 stackers and 25 trucks (briefly " 2-6-18-25 "). Such configuration is based on modern foreign ports. The new operational results can b seen at the following table.

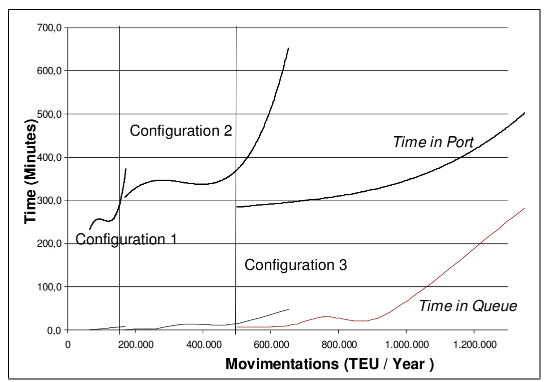
Configuration 3 2-6-18-25	Total Mov.	Time in Port	Time in Queue	Ocupation Terminal	Ocupation S/S Crane	Ocupation R. Stacker	Ocupation Carts
	TEU / Year	Minutos	Minutos	%	%	%	%
	500 000	285.0	6.0	27.0	25.0	21.0	14.0
	650 000	290.0	10.0	37.0	34.0	25.0	17.8
	760 000	310.5	30.9	43.2	35.1	32.7	22.8
	940 000	330.3	35.8	52.1	50.2	41.9	30.1
	1 350 000	502.1	281.5	79.6	65.3	57.0	41.0

This new arrangement can normally operate until a movement of 1000000 TEUS per year. This movement is estimated for the final years in the bidding period (25 years).

In agreement with the above exposed, the configuration changes should happen in the following years:

Change of Configuration	Year
1 -> 2	2003
2 -> 3	2016

The next graph shows the times at the port and at the queue with relation to annual demand, and the configuration changes.



This graph represents the changes of the three feasible configurations along the time. It is noticed that the time of queue is always very small reaching landings of one and a half hour or two hours starting from 1 million of TEU per year.

Economic Analysis

Main Scenario

In this section the economic viability of the project will be analyzed. Initially a scenario will be adopted in which the sequence of works and installation of equipments will be set in the chronogram demanded by the bidding proclamation. And, the growth of the demand will be based on the medium growth observed in the last four years in the port of Paranaguá.

The medium rate of growth in the movement of containers on these last four years was 11,1% per year. We will admit that this rated will maintain for all the 25 years of operation of this project.

It's important to emphasize that the equipments with life duration of 10 and 5 years need to be restored. Thus, we have the following table of purchase of port equipments in the elapse of the years, that represents a part of the annual investments (spot cash):

Equipment's Purchase Forecast				
Investments	**S/S Crane**	**R. Stacker**	**Carts**	**Vans**
Life Duration	25	10	10	5
Year of Purchase				
1997	2	3	5	3
2002	0	0	0	3
2003	2	7	10	0
2007	0	3	5	3
2012	0	0	0	3
2013	0	7	10	0
2016	2	8	10	0
2017	0	3	5	3
Total	6	31	45	15

The depreciation was considered in the following way:

· 20% of the value is lost in the acquisition of new equipments;

· the remaining is depreciated lineally along the equipment's life duration;

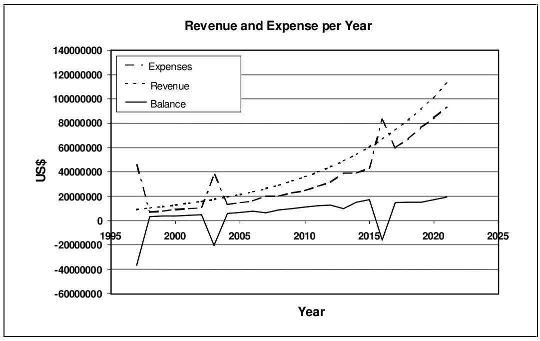
· the residual value is obtained by the product of the rate of lineal depreciation by the remaining of the useful life, given in years.

Cash Flow

According to the scenario described previously, considering that all the investments have been spot cash, we obtain cash flow shown below, with the following results for the tested scenarios:

Year	MOV. TEU/Year	Tot. Expense	Revenue	Balance
1997	88 448	45 835 890.14	9 024 800.00	-36 811 090.14
1998	102 171	7 070 335.46	10 397 100.00	3 326 764.54
1999	113 410	7 915 939.52	11 520 981.00	3 605 041.48
2000	125 885	9 087 453.86	12 768 488.91	3 681 035.05
2001	139 732	9 926 671.75	14 153 222.69	4 226 550.94
2002	155 103	10 778 873.94	15 690 277.19	4 911 403.25
2003	172 164	38 035 172.66	17 396 407.68	-20 638 764.98
2004	191 102	13 524 132.33	19 290 212.52	5 766 080.19
2005	212 123	14 856 459.17	21 392 335.90	6 535 876.72
2006	235 457	16 297 052.01	23 725 692.85	7 428 640.84
2007	261 357	20 247 810.89	26 315 719.06	6 067 908.17
2008	290 106	20 396 410.84	29 190 648.16	8 794 237.32
2009	322 018	22 743 146.86	32 381 819.45	9 638 672.59
2010	357 440	24 811 834.96	35 924 019.59	11 112 184.64
2011	396 759	28 022 801.44	39 855 861.75	11 833 060.31
2012	440 402	31 555 664.44	44 220 206.54	12 664 542.11
2013	488 846	39 188 338.29	49 064 629.26	9 876 290.97
2014	542 619	39 073 447.82	54 441 938.48	15 368 490.66
2015	602 308	43 227 815.13	60 410 751.71	17 182 936.58
2016	668 561	83 265 953.49	67 036 134.40	-16 229 819.08
2017	742 103	60 165 956.98	74 390 309.19	14 224 352.21
2018	823 734	67 362 487.68	82 553 443.20	15 190 955.52
2019	914 345	76 777 914.65	91 614 521.95	14 836 607.30
2020	1 014 923	84 613 748.64	101 672 319.36	17 058 570.72
2021	1 126 565	93 738 793.02	112 836 474.49	33 413 548.11
			IRR =	**12%**

Graph of the Revenue and Expense per year of Operation



It can be noticed that the port operation generates a profit to the operator in every year of operation, expect in the years that happens great investments, as expansions and equipment's purchase. On those years we noticed sharp points of expenses, that coincide with sharp points of accumulated damages in the tenth year. The revenue grows in the same proportion that the movement, being always superior to the expenses, being obtained an internal rate of return of 12%.

Conclusions

The simulation model for a port system presented in this document was accomplished with the purpose of aiding the process of taking of decision in the administration and port planning.

A typical problem of taking of decision in this context is the fact of the port having to adapt with the growing demand of terminals and specific areas for container's operations for the adaptation of the current terminals. It's necessary great investments to drift when and how accomplish, that is an extremely complex task, which can be aided with a simulation model, which evaluates several arrangements and number of equipments, being created a tool that will give support to the process of decision.

This work emphasizes the project that support tool to the decision, as well as all the considerations that were done for its development and validation.

To reinforce the potential of the information obtained in the simulation as tool of taking of decision, it were already simulate arrangements existent in Brazilian ports and also arrangements that in future will be implanted due to the growth of that segment of the load's transport. The model showed to be efficient and reliable because its results (times of queue, efficiencies, productivity and movements of containers) are very close to the operational results obtained from the port authorities of the simulate ports, allowing its use as planning tool and analysis of options with objective of minimizing the operational costs.

The use of the simulation technique in this case was shown extremely appropriate, with very reliable results. That reliability depends on the sophistication of the model and the quality of the data of inputted into the model (operational times, frequencies of arrival of trucks and ships as well as the percentages of fail of the equipment).

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