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A MODEL FOR PREDICTIVE CAPACITY OF A CONTAINER TERMINAL STATE: A SYSTEM DYNAMICS APPROACH

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A MODEL FOR PREDICTIVE CAPACITY OF A CONTAINER TERMINAL STATE: A SYSTEM DYNAMICS APPROACH

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ABSTRACT

Low performance of operational practices and wrong perceptions on demand forecast cause improper investments on new facilities for containers terminals, without taking into account the best use of their available resources. Accordingly, it would be desirable to model dynamic behaviour among demand, capacity and productivity of container terminal services, like reception, storage and distribution, to forecast their performances faced to demand evolution with time. This paper presents a system dynamic model to evaluate impacts from demand variations on 18 container terminals associated to ABRATEC – Brazilian Association of Public Containers Terminals – and their response capability to compensate demand growth with increasing productivity. The behaviour of the developed dynamic models was demonstrated by means of simulations carried out with the Vensim Standard 5.6d system dynamics software.

Keywords: capacity, productivity, system dynamics, container terminal.

1. INTRODUCTION

The operational dynamics of a containers terminal is governed by market perceptions and from decisions that arise from those perceptions. Under that perspective, according to Sterman (2000), the interpretation of the real world not only drives our decisions but also alter our mental model about the reality creating different decisions rules and new strategies. Thus, our decisions alter our environment, leading to new decisions that trigger side effects, consequently delay reactions, changes goals and bring the intervention of others in the system. For example, the problem of berth scheduling for optimizing vessels arrival time in the containers terminals with the terminal yard organization is highly complex, not only operationally but administratively in order to cope with all commercial and logistics demands. However, the complexity lies in finding the best solution out of an astronomical number of possibilities.

According to Sterman (2000), the dynamics complexity, in contrast, can arise even in simple systems with low combinatorial complexity due to the complexity arises from the interactions of the agents over time.
Even Kim K. and Kim H. (1999) highlighted the difficulty in developing simulations to port operations due the dynamicity of the system, there are some simulation methods able to describe operational features, along with different levels of complexity, and reasonably explain that industry, despite its dynamic complexity. Among those methods, the system dynamics is known as a flexible modelling one and is able to effectively to simulate different scenarios and describe their results related to the perception and decision-making processes undertake by the decision-makers of the industry in short, medium and long term.
Thus, in this paper, to assess the impact of the demand variation on the container terminal state capacity and productivity, the methodology based in system dynamics was chosen.

2. THE DATA COLLECTION

According to Evangelista (2005), the liner shipping industry is notorious for poor communication among its players and mediocre information management connected with a wide range of logistical deficiencies. Information is the main factor that affects the dynamics features of a logistics system and, according to Davis (1993), the uncertainty is the key-element that impact the effectiveness of a supply chain.
Historically, within the scope of logistics chain, the seaports industry is unique. Comparing with others industries, the seaports industry is the late to adopt technological innovation to its operational control and commercial transaction. This is associated with the traditional resistance to release data and information. Due to such constraint, many times, to investigate the impact of demand fluctuation over a container terminal state based in public data could, not be viable or even reliable.
However, such research is possible when the data collected is less sensitive to unreliability such as container traffic, which could be validated throughout the seaports stakeholders, the technical capacity of a terminal, its project productivity and the perception of the decision-makers over operational, logistics, commercial and bureaucratic issues.
In this research the method adopted involved a number of data capturing techniques, including interviews and observations.
The operational and statistical data was collected throughout the container terminal state, also attaining the executive's perception before the exogenous parameters like time to project demand and time to adjust capacity to cope with demand. Reference points for decision-making as planning horizon and operational non-linear relationships as the effect of density on productivity were also considered to modelling the behaviour pattern of the container terminal state studied.
In possession of those data and added by field observations, it was possible to develop a model which dynamically represents the system operational behaviour over time and how is the system response to market pressure.

3. SYSTEM DYNAMICS METHODOLOGY

Given the methodological difficulties of research on productivity analysis of a container terminal state, this study adopts a computer simulation methodology to analyze the growth of the terminals capacity and finally their productivity. Since a computer simulation model could help users of the model easily implement the potential scenarios in a computer, make themselves familiar with the dynamics situations of interest, and test different strategies to

cope with demand variation. In other words, the computer simulation model for the productivity analysis can be useful as a learning tool.
Among the several computer simulation methodologies, the system dynamics modelling is chosen for this research. System dynamics is a methodology to the construction of simulation models to complex systems. It was formulated by Jay Forrester in the early 1960s at MIT Sloan School of Management and enhances the understanding of complex system to assist businesses and government organizations in strategy development, analysis of policy options and analysis of dynamic processes in which capturing information flow and feedback are important considerations. A system dynamics model captures the factors that affect the behaviour of the system in causal-loop diagrams represented by stocks and flows structure of information and materials. These representation help to describe how the multiple interdependent components of a system interacts among themselves in multiples feedback loops that are highly dynamic, involving multiple feedback processes, nonlinear relationships, operational data and managerial perceptions that drives to decisions that will alter the system environment. Hence, system dynamics can be properly applied in systems whenever their components can be expressed as variable behaviours through time as we can see in industrial systems, engineering process systems, dynamic urban development systems, corporate strategy development system, biology systems, medicine and so.
The dynamic of containers seaport is highly complex. All management decisions and strategies are involved in processes related to the use of its assets, reflecting the effect of these decisions on the financial performance of the business. Thus, the system dynamics are very helpful in explaining the relationship between the internal and external variables to a containers terminal system.

The following structure shows a simple diagram of the process flow of containers in a seaport container terminal.

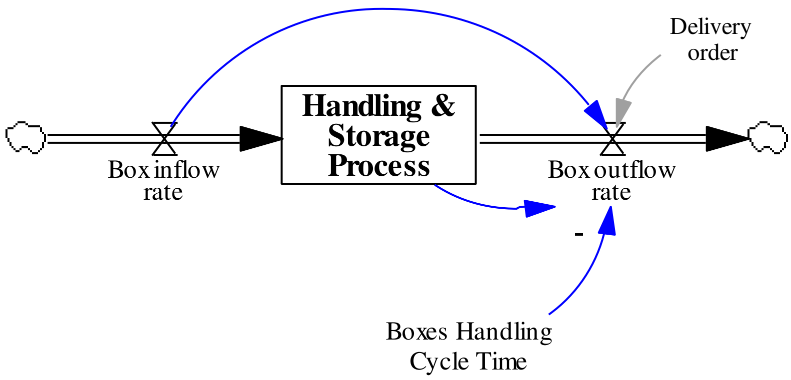


Figure 1: Basic stock and flow model in a container terminal. Source: Authors.

4. MODEL VALIDATION METHODOLOGY

It is important that a model based on system dynamics can not only represent virtually the real world, but also reproduce and predict its behaviour, which is to explain how that behaviour is generated and suggest how to change the existing behaviour.
System dynamics models are by nature descriptive, which illustrates how the real system actually operates in some aspects. To generate accurate output behaviour is not sufficient for model validity. What is crucial is the validity of the internal structure of the model that must be able not only to reproduce and predict its behaviour, but also explain how the behaviour is generated, and possibly suggest ways of changing the existing behaviour. However, to validate the external and the internal structures of the model cannot be entirely objective,

formal and quantitative rather than it can be subjective, informal and qualitative. Therefore, it is hard formally validate a system dynamics model, Barlas (1989, 1996).
According to Barlas (1996) and Forrester (1961), given the difficulty of model validation in system dynamics, it is widely accepted that model validation is a process of confidence in the utility of the model gradually, by constantly confronting the model with data and experts opinion. According to Oliva (1996), validity of a system dynamics model cannot be discussed without reference to a specific purpose, hence, model validation is a gradual process of confidence building with respect to purpose of model, rather than a binary accept/reject divisions.
To summarize the model validation in system dynamics, Barlas (1996) proposed two steps regarding to the model validation process for a system dynamic model, as below:

1. Structure validity and,

2. Behaviour validity.

Table 1: Validation process for models in system dynamics. Source: Sterman (2000).

Building the dynamic model
Objective: Development of dynamic model, based on mental model through which the developer believes that the model reproduces the structure and behaviour of the real world.
Structure validity
Objective: In the structure validity the model should explain the real system with causal links embedded in the model. The validity of the model structure is assessed by direct comparison with the knowledge about the real system structure. Causal loop diagrams are often useful ways of testing the structure validity.
Behaviour validity
Objective: The validity of the behavioural model is measured by how far the model faithfully reproduces the behaviour of the system as in the real world. According to Barlas (1996), it is crucial to understand that the emphasis is on the pattern of behaviour such as periods, frequencies, trends, etc., and not on specific events. Once the model has confirmed the default behaviour of the system as it is in the real world, it can be considered as passing the behaviour validity test.

For an industry state modelled by systems dynamic methodology, beyond the logical structure validation it must also be validated behaviourally through observations and market data collection that will generate a process of empirical calibration, which will be validated via sensitivity tests.
In order to calibrate the model, input data should be collected first. There are five types of data to be collected: endogenous input variables, exogenous input variables, reference points for decision-making, information delay time and nonlinear relationships. Those data are collected from various industry source and interviews with the industry decisions-makers.
After collected the real data, the model structures and key parameters were consulted with industry seniors' executives to ensure the structure validity of the model and start the empirical calibration process.
For nonlinear variables, when their values are out of the knowledge of industry seniors executives, acceptable values of estimated parameters must be applied in order to keep showing the model behaviour in accordance with the real world. Thus, for the validity of the model must be used real data and market parameters reasonably estimated.

5. EMPIRICAL CALIBRATION AND BEHAVIOUR REPRODUCTION TEST

After collecting the data for exogenous parameters, the model can now be calibrated to the real industry data in order to ensure the behaviour validity. In order words, for the behaviour validity, simulation results from the model should successfully regenerate the behaviour of the historical industry data series.
Many tools are available to assess a model capability to reproduce the behaviour of the system in the real world. In this research was used the coefficient of determination (R2) as measure of fit in order to show the degree of success of the model that simulates the historical behaviour of the industry variables.
The coefficient of determination, by itself, does not validate the model, which depends on error testing that indentify how reliable is the model and its suitability to the real world throughout the sample period.
According to Sterman (2000), large errors may be due to a poor model or a large amount of random noise in the data, reflecting the random or cyclical shocks in one of the data series and not present in the others captured in the real world. Hence, to the assessment behavioural of a model it is important not just to know the sources of error but the total size of the error, because even a total error may be large if a mode of behaviour in the real system is deliberately excluded as irrelevant to the model purpose.
Several statistical methods help to decompose the errors. In this research is used the Theil inequality statistics that provide the interpretation of the errors break-down into systematic and unsystematic components, dividing the Mean Square Error (MSE) into three components: Bias, unequal variation and unequal co-variation.
In this research all discrepancies believed significant leaded to model revision and it was not introduced neither fudge factors nor exogenous variables whose sole function would be to improve the historical fit of the model.

6. THE VENSIM 5.6.D AS SIMULATION TOOL

Simulation software for system dynamics environment as Vensim Software (Ventana® Systems, Inc.) are used to model complex systems and to test decision-making policy based on the model. The Vensim Software is used as simulation tool in several industry, as energy, manufacturing, aerospace, financial, information and communications technology, pharmaceuticals, petrochemical, retail, agriculture, fishing, automotive, government and military. In this research was used the Vensim Standard for Windows®, version 5.6d.
The Vensim® has functions to set the dynamic equilibrium of the models. Through those functions are constructed the equations that govern the dynamic relationship between variables that represent stocks and flows of materials or information. In this research were used the following predefined functions:

1. IF THEN ELSE (cond, X, Y) - Returns X if condition is non-zero, otherwise Y.: Returns first value (X) if condition (cond) is true; second value (Y) if condition is false. cond must be a Boolean expression or an expression or variable that can be interpreted as Boolean. Only the value returned is evaluated, so the other value could be an expression that would lead to an error;

2. SMOOTH(X, T) - Returns a first order exponential smooth of X over time T. The SMOOTH function is commonly used to take time averages and represent expectations. It is different from IF THEN ELSE in that it has time behavior built into it;

3. INTEG(R, N) - Performs numerical integration of R starting at N (defines a level). Returns the integral of the rate. The rate is numerically integrated. The initial value is the value of the variable on the left-hand side of the equation at the start of the simulation;

4. FORECAST (I, A, H) - Forecast for I over the time horizon H using an averaging time A;

5. LOOKUP AREA (lookup, start, end) - Returns the area under a Lookup Table between start and end in a nonlinear relation. This function is useful for normalizing lookups in problems such as determining the intensity of effort in a project given the fraction of work that has been completed.

7. THE DYNAMIC MODEL OF CAPACITY

The dynamic model of container terminals capacity simulates the terminal response to demand over time through the expansion of its super and infrastructure.
The model developed took as baseline the inventory management model, "stock-management system" Sterman (2000), which is widely accepted. However, due to the peculiar characteristics of the port industry, the Sterman base model was set for this industry. In this model, the decision-makers are assumed to calculate the investment for adjust capacity mainly on the bases of projected demand and the desired capacity.
The inputs to this model are real demand, planning horizon, desired capacity and annual capacity growth rate.
The structure below represents the dynamic model for the container terminals capacity:

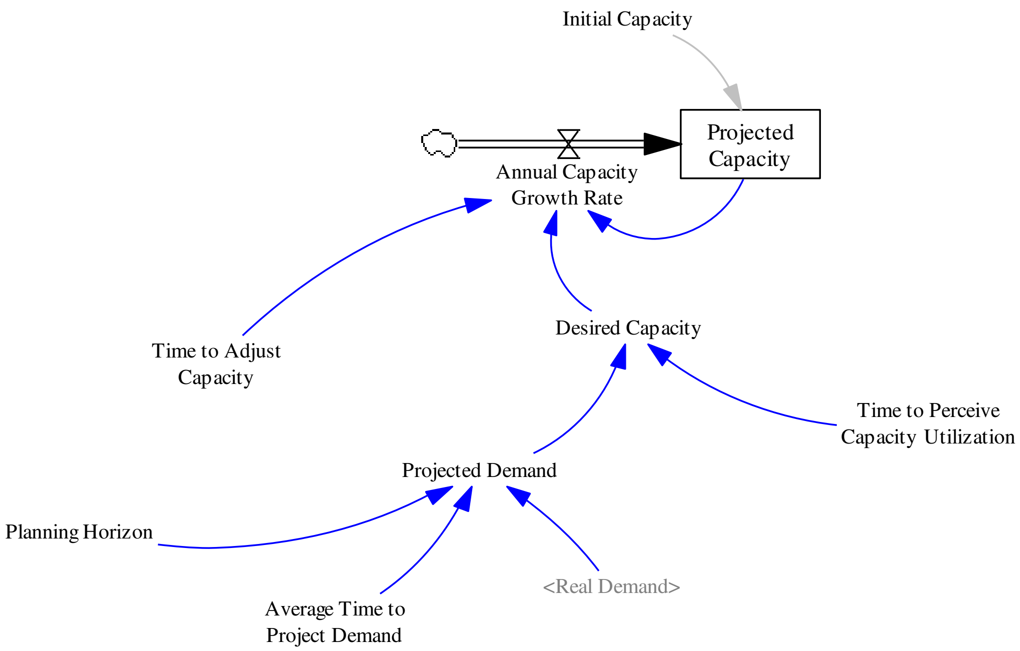


Figure 2: Structure of Capacity Model. Source: Authors.

Detailed equations of this model are provided below:

1. Desired Capacity = SMOOTH (Projected Demand, Time to Perceive Capacity Utilization);

2. Projected Capacity = INTEG (Annual Capacity Growth Rate, Initial Capacity);

3. Projected Demand = FORECAST (Real Demand, Average Time to Project Demand, Planning Horizon);

4. Annual Capacity Growth Rate = IF THEN ELSE (Desired Capacity <= Projected Capacity, 0, (Desired Capacity – Projected Capacity)/ Time to Adjust Capacity)

Detailed causes tree of this model is provided below:

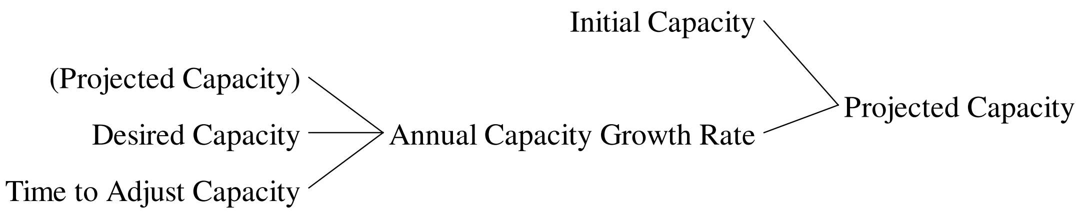


Figure 3: Causes tree of Capacity Model. Source: Authors.

According to the knowledge about the real system and the specific purpose of the model, the model structure and their algorithms seek to demonstrate the validity of its dynamic structure.

7.1. The real dynamic capacity of the containers terminal state assessed

The real dynamic capacity of a container terminal is defined by its infrastructure aspects, handling system and the time spent in logistics operations. Assessing those aspects it was possible to disclose the annual dynamic capacity of 18 container terminals associated to ABRATEC – Brazilian Association of Public Containers Terminals.
The following table shows the findings in TEU (Twenty foot equivalent unit) and boxes handled:

Table 2: The table shows the container terminals capacity over time. Source: ABRATEC

Year	2000	2001	2002	2003	2004	2005	2006	2007
Total Capacity (TEU/year)	2.365.200	2.619.240	3.622.260	4.409.565	5.017.603	5.380.048	5.934.118	6.355.283
Total Capacity (Box/year)	1.576.800	1.746.160	2.414.840	2.939.710	3.345.069	3.586.699	3.956.079	4.236.856

7.2. The behaviour accuracy of the model

After passing the structure validity test, a model should be tested for behaviour validity. The behaviour is to measure how accurately the model can reproduce the major behaviour patterns exhibited in the real system. According to Barlas (1996), it is crucial to note that the

emphasis is on the pattern prediction (periods, frequency, trends and so), rather than points (events) prediction. As long as a system dynamics model can reproduce the patterns of the real system, it is considered as passing the behaviour validity test.
In the container terminals capacity model the mainly endogenous parameters are real demand, desired capacity, projected demand and the annual capacity growth rate, while the mainly exogenous parameters to be considered in the model in order to assess the terminals state adjustment capacity are initial capacity, the time for decision-makers to adjust the terminals capacity based on their perception of the terminal capacity utilization, planning horizon and the average time to project demand.
The data collected show the endogenous and exogenous parameters, within which are defined the variables of decision points and time perception of decision-makers, as provided below:

1. Decisions points:
   a. Planning Horizon.
2. Time perception:
   a. Time to Adjust Capacity; Average Time to Project Demand; and Time to Perceive the Capacity Utilization.

The numerical result for the behaviour validity test is show through the table:

Table 3: The table shows the actual terminal capacity, according to ABRATEC, versus projected capacity.

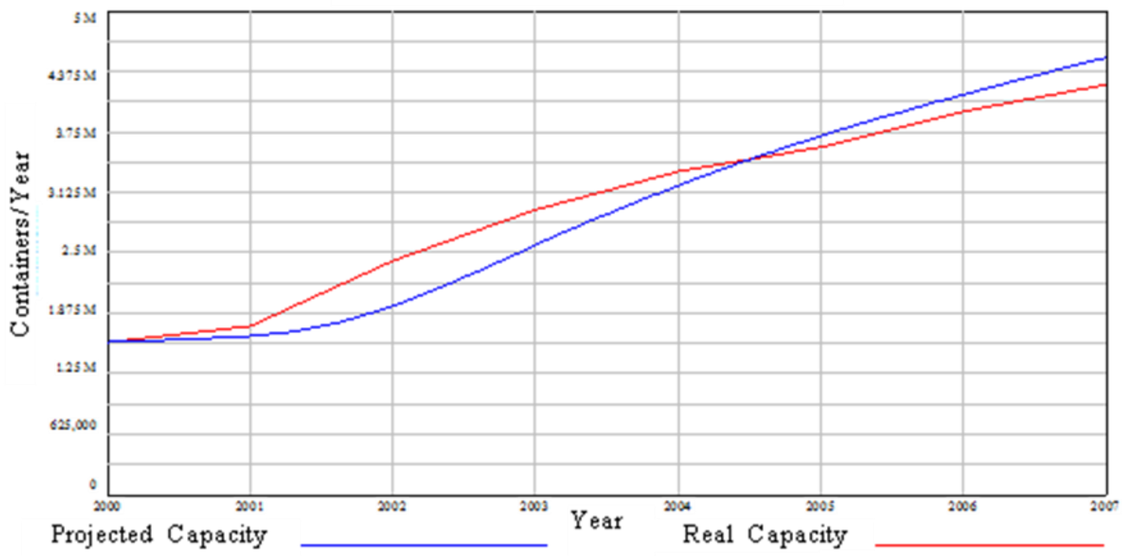
Year	2000	2001	2002	2003	2004	2005	2006	2007
Projected Capacity (Box/Year)	1.576.000	1.638.000	1.951.000	2.575.000	3.194.000	3.705.000	4.133.000	4.516.000
Real Capacity (Box/Year)	1.576.800	1.746.160	2.414.840	2.939.710	3.345.069	3.586.699	3.956.079	4.236.856

The exogenous input variables considered for the model are presented in the table below:

Table 4: The table shows the exogenous input variables. Source: Authors

Variables	Value	Unit	Description and Source
Initial Capacity	1.576.800	Box/year	Initial dynamics capacity of the terminal state according to ABRATEC.
Time to Adjust Capacity	1,55	Year	Time over which the decision-makers consider between the time of decision to expand the capacity and the availability of this capability: +/- 18 months.
Time to Perceive the Capacity Utilization	0,25	Year	Time for decision-makers to confirm the current capacity utilization trend: it is estimated to be around 3 months from the calibration process.
Planning Horizon	3	Year	The number of years that decision-makers consider when they estimate desired terminal capacity in the future based in a projected demand. Value derived from empirical calibration and confirmed with industry executives.
Average Time to Project Demand	1	Year	Averaging time for past demand used in the projected demand. It is assumed to be 1 year according to the industry executives.

The following graphic shows the real capacity of the terminals over time compared with the projected capacity over time obtained by the model simulation:



Graphic 1: The graphic shows the projected capacity versus real capacity. Source: Authors.

7.3. Behaviour validity test of the container terminal state capacity model

The graph above shows the simulation model tracking the historical data of the system in the assessed period. The results of the behavioural test are shown in the following table:

Table 5: The table shows the historical fit of the model. Source: Authors

R^2	MAPE	Theil inequality statistics		
		Bias	Unequal Variation	Unequal Covariance
0,981	7,09%	0,065	0,348	0,587

The simulation results show that the model tracks the historical system data quite well. Thus, the correlation of the real capacity to projected capacity is 0.981, in other words the correlation clearly indicates the symmetry behaviour of the values obtained in the simulation model with the values collected in the real world. The Mean Absolute Percent Error (MAPE) between the simulated and actual data are less than 8%, indicating a close fit of the model to the actual behaviour of the containers terminal state. In addition, the low bias and variation components of the Theil's inequality statistics indicate that errors are unsystematic.

Is it possible to observe in the graphic 1, that the data variation shown in the real world data and are not reproduced in the simulation result, indicates the presence of "noise" caused by "random shocks" or cyclic behaviour.

Many industries and systems, including the maritime industry with its international and logistics transport systems, quite often tend to amplify "random shocks" as response to increase of demand (*Bullwip effect*).

8. THE DYNAMIC MODEL OF PRODUCTIVITE

The dynamic model of container terminals productivity simulates the operational terminals capacity to respond to the market pressure through containers delivery capacity while the terminals infrastructure goes through the expansion capacity over time.

The inputs to this model are real demand and projected capacity. However, the terminals face a productivity constraint due to the density of containers stacked in the terminal and the average time those containers kept stored in the yard. Such productivity restrain can be due to legal aspects, terminal layout and commercial advantages offered, or even by the interests of the shippers. Thus, the productivity of the terminal depends on the use of its assets, which, in turn, is governed by the density of stored containers that affects the productivity in a non-linear way.

The following structure represents the dynamic model for the container terminals productivity:

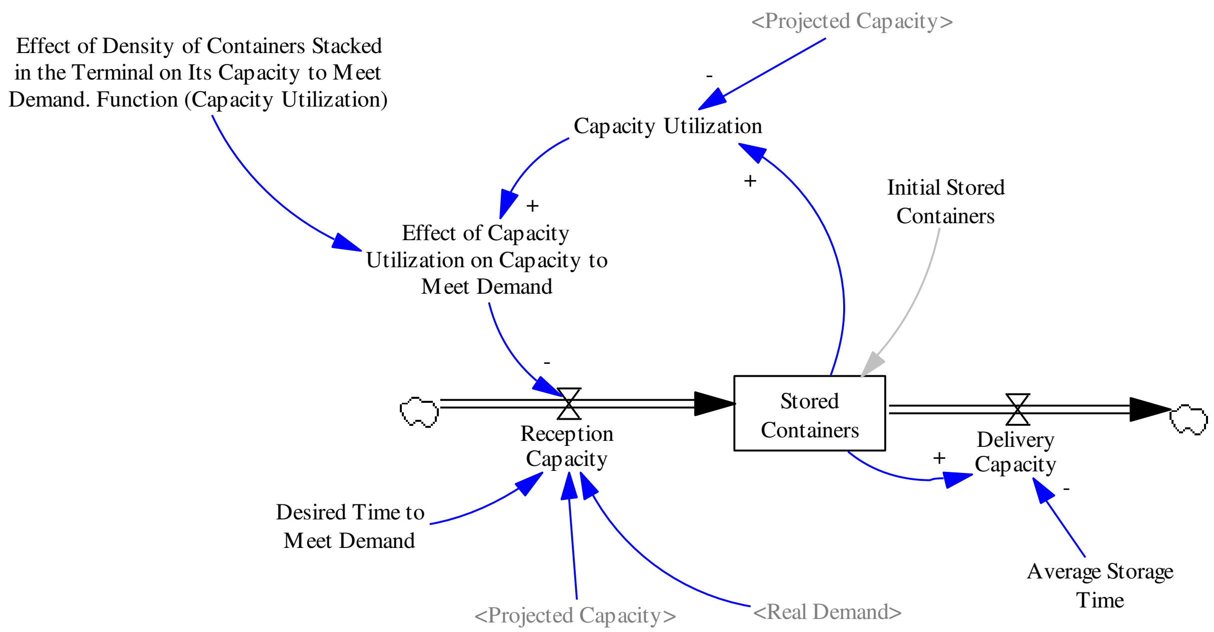


Figure 4: Structure of Productivity Model. Source: Authors.

Detailed equations of this model are provided next:

1. Delivery Capacity = Stored Containers / Average Storage Time;

2. Reception Capacity = IF THEN ELSE (Projected Capacity > Real Demand, (Real Demand / Desired Time to Meet Demand) / Effect of Capacity Utilization on Capacity to Meet Demand, (Projected Capacity / Desired Time to Meet Demand) / Effect of Capacity Utilization on Capacity to Meet Demand);

3. Stored Containers = INTEG (Reception Capacity – Delivery Capacity, Initial Stored Containers);

4. Effect of Capacity Utilization on Capacity to Meet Demand = "Effect of Density of Containers Stacked in the Terminal on Its Capacity to Meet Demand. Function (Capacity Utilization)" Capacity Utilization

Detailed structure of this model is provided below:

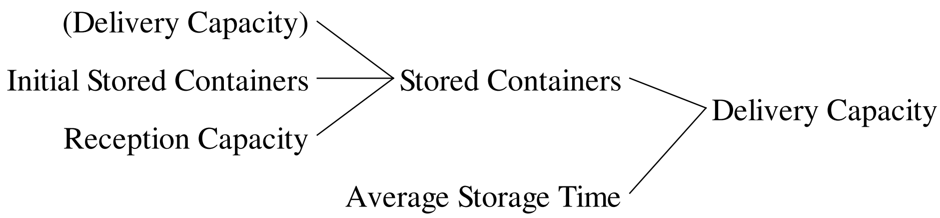


Figure 5: Causes tree of Productivity Model. Source: Authors.

According to the knowledge about the real system and the specific purpose of the model, the model structure and their algorithms seek to demonstrate the validity of its dynamic structure.

8.1. The behaviour accuracy of the model

In the container terminals productivity model the mainly endogenous parameters are real demand, projected capacity, capacity utilization and the effect of capacity utilization on capacity to meet demand, while the mainly exogenous parameters to be considered in the model in order to assess the terminals state productivity over time are desired time to meet demand, initial stored containers and average storage time.

The data collected show the endogenous and exogenous parameters, within which are defined the variables of time perception of decision-makers and the nonlinear relationship with no variables considered as decision points, as provided below:

1. Time perception:
    a. Average storage time;
    b. Desired time to meet demand.
2. Nonlinear relationships:
    a. Effect of capacity utilization on capacity to meet demand.

In reality, data for exact impact of capacity utilization on capacity to meet demand are not readily available because it depends heavily on the handling systems used by the terminals, Thomas (1996). In this model, therefore, the effect of capacity utilization on capacity to meet demand is exogenously input by calibrating the model in order to simulate the effect of density of containers stored in the yard on the terminal productivity. In this calibration process is estimated, on bases of observation of the real world, the relation between the average numbers of moves necessary to perform storage or removing a container in a stock pile up to 5 boxes of height.

The following graphic shows the effect of container stack density on productivity with the numbers of moves estimated by field observation:

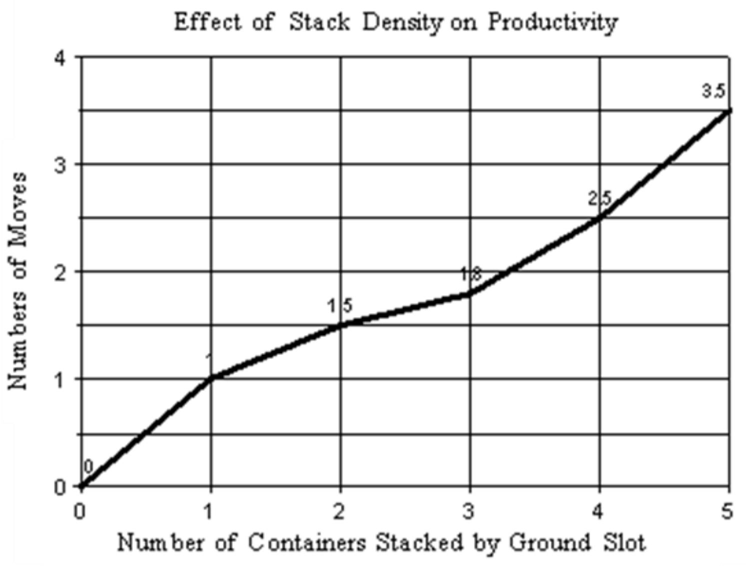


Figure 6: Effect of stack density on productivity. Source: Authors

For modelling calibration propose, supported by the system observation, the capacity of a container terminal to handle containers in a year Y, is given by its full capacity to handle container at the end of year Y-1, because a container terminal just can account initially with new facilities when those are fully ready to use, hence new facilities in process of availability in a year Y just will be fully ready to be used at the beginning of the year Y+1.

The numerical result for the behaviour validity test is show through the table below:

Table 6: The table shows the actual terminal productivity, according to the terminals layout, operational practices and handling system, versus projected productivity. Source: Authors.

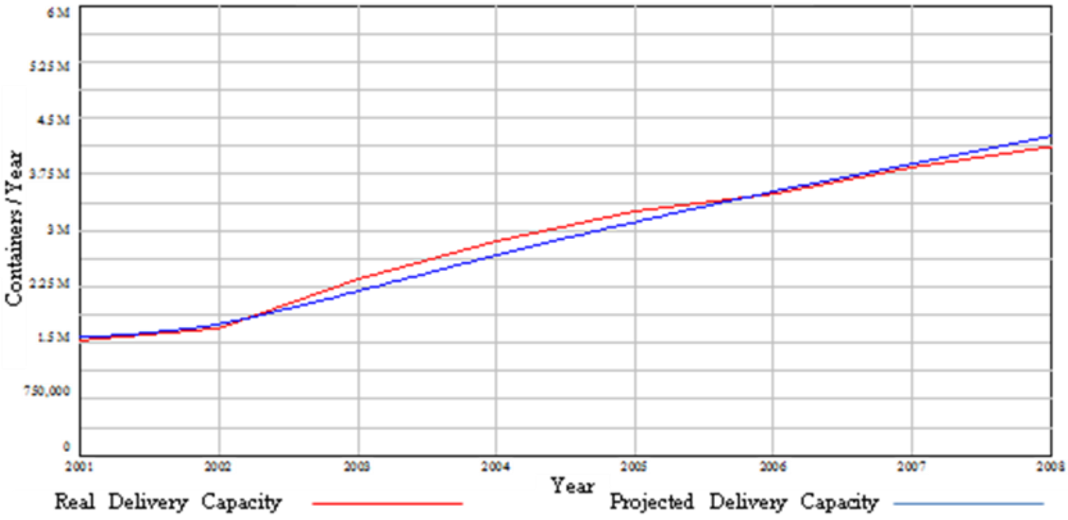
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Projected Delivery Capacity **(Box/Year)**	1.583.000	1.754.000	2.190.000	2.669.000	3.114.000	3.517.000	3.893.000	4.255.000
Real Delivery Capacity **(Box/Year)**	1.533.852	1.698.599	2.349.066	2.859.640	3.253.958	3.489.006	3.848.325	4.121.455

The exogenous input variables considered for the model are presented in the table:

Table 7: The table shows the exogenous input variables. Source: Authors

Variables	**Value**	**Unit**	**Description and Source**
Average Storage Time	1,028	Year	The average time to a container to keep stored in the system studied is considered 10 days. The annual traffic of containers should flow freely through the terminals at the exact period of one year; however, taking an average period of storage of 10 days, the container flow is estimated to be around 1.028 years from calibration process.
Desired Time to Meet Demand	1	Year	The desired time to meet demand is assumed to be 1 year. It is estimated by from the calibration process and confirm with industry executives.

The next graphic shows the real delivery capacity of the terminals over time compared with the projected delivery capacity over time obtained by the model simulation:



Graphic 2: The graphic shows the projected delivery capacity versus real delivery capacity. Source: Authors

8.2. Behaviour validity test of the container terminal state productivity model

The previous graph shows the simulation model tracking the historical data of the system in the assessed period. The results of the behavioural test are shown in the following table:

Table 8: The table shows the historical fit of the model. Source: Authors.

R^2	MAPE	Theil inequality statistics		
		Bias	Unequal Variation	Unequal Covariance
0,993	3,68%	0,037	0,048	0,915

The simulation results also show that the model tracks the historical system data quite well. Thus, the correlation of the real delivery capacity to projected delivery capacity is 0.993, in other words the correlation clearly indicates the symmetry behaviour of the values obtained in the simulation model with the values collected in the real world. The Mean Absolute Percent Error (MAPE) between the simulated and actual data are less than 4%, indicating a very close fit of the model to the actual behaviour of the containers terminal state. In addition, the low bias and variation components of the Theil's inequality statistics indicate that errors are unsystematic indicating the model validity concerning the behaviour test.

9. CONCLUSION

This paper presented a system dynamic model to represent the dynamics of productivity and capacity in a group of 18 container terminals associated to Brazilian Association of Public Containers Terminals – ABRATEC. Overall, the model was able to explain the causal linkages driving the dynamic behaviours of the system variables and track the dynamic behaviours of the terminals state in real world from 2000 to 2008, thus increasing the confidence of the model. During the interviewing process, it could be observable that there were not considerable differences of perception regarding to the exogenous variables among the containers terminals' executives throughout the country. Exogenous variables, such as

"Time to Perceive the Capacity Utilization", "Average Storage Time" and "Desired Time to Meet Demand", whose perceptions seemed to be not much consistent among them, were resolutely estimated by the calibration process and confirmed with industry executives. The model output could help to predict future development of a container terminal state, since the model approach is able to project the necessary terminals capacity over time in order to cope with a forecasted demand. Consequently, the executives are able to project the assets needs to cope with the market behaviour. The model simulation also gives the opportunity to the terminals decisions maker to tune its mental model regarding to the exogenous variables or even redesign its handling system toward a better productivity and costly effective way, concerning their container terminals within a container terminals state. In other words, the model helps the planners, via simulation, to choose the operational and logistics strategies that best fit to their terminals in a medium or long term period. Given the confidence demonstrated by the model, it can be used as a reference system to test the influence of demand variation over time on a container terminal state capacity needs, according with its overall productivity.

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